Facilitating Pareto-Optimal Coordination by Subsidies in Deterministic and Stochastic Payoff Settings

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Abstract

Can subsidies promote Pareto-optimum coordination? We found that partially subsidizing 2 out of 6 players in a laboratory coordination game usually produced better coordination and higher total payoffs both with deterministic and stochastic payoffs. After removing the subsidy, high coordination continued in most groups with stochastic payoffs, but declined for groups with deterministic ones. A post-game survey indicated that decision justifications differ between deterministic and stochastic payoff settings. Temporary subsidies seem to promote lasting coordination in risk reduction, whereas in a deterministic setting, subsidy may be counterproductive, because it crowds out other rationales for coordination.

1. **Introduction**

In many situations, individual agents in an interactive game or a social network reinforce each others' decisions. Examples include Schelling's (1978) tipping points on racial composition in a neighborhood, and Leibenstein's (1950) "bandwagon effects" in which one agent's demand for a good increases with others' demand level.

The existence of such mutual reinforcement has been captured by coordination games with multiple Pareto-ranked Nash Equilibria (NE). Interdependency among airlines with respect to luggage security (Kunreuther and Heal 2003) is an example of such coordination. Airline companies face the decision whether to invest in luggage security screening equipment. The new equipment will greatly reduce its risk of terrorist bombs, but the company still faces indirect risk of unsafe luggage transferred from other airlines who decide not to invest in the screening equipment. The Pareto preferable equilibrium is that all airlines invest and eliminate the risk. A second equilibrium is that no airline invests because of the high indirect risk from non-investing airlines. Other examples of interdependent security (IDS) include wildfire protection decisions (Shafran and Flores, 2008), computer network security update (Kearns 2004), and failure of divisions in organizations to invest in risk reducing measures (Kunreuther and Heal 2005; Kunreuther 2009)

Comment [K1]: There can be more than 2 equilibria if bags are transferred between more than 2 airlines. HK

Another real-world coordination problem is the garbage disposal decision households face daily in some communities in China. Often 20-30 households share a garbage bin outside of their apartment building. For unknown reasons, some residents tend to leave their garbage outside of the bin. This behavior may affect others' in at least two ways. First, once the garbage left outside accumulates, others need to step on those outside garbage in order to dump their own garbage into the bin, which imposes an extra cost. Second, it sends a signal that littering is acceptable in this community, thus reducing the psychological cost of breaking a social norm to keep the public area clean. A Nash equilibrium is reached when everyone starts to leave the garbage outside. The inferior Nash equilibrium of littering outside the bin is so common that during the 2008 Beijing Olympic season, one of the slogans was actually "Learn to be Civilized and Dump your Garbage in the Bin". Obviously, the more preferable Nash equilibrium of disposing of garbage in bins provides everyone with a cleaner environment at virtually no additional cost.

Note the difference between the garbage disposal game and the airline security example. The airline security example is a coordination game in a stochastic setting, with an outcome that depends not only on the degree of cooperation (how many airlines invest in protection) and nature's move (whether or not there is a terrorist attack). The garbage disposal coordination game involves deterministic outcomes and with the outcome depending only on the degree of coordination i.e. the number of individuals who leave garbage outside of 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.

Comment [K2]: It would be good to provide more details on the nature of the IDS aspects of these examples. HK

The above examples illustrate social reinforcement in which positive decisions by a few individuals are likely to lead others to follow suit. Recently, Heal and Kunreuther (2009) modeled this behavior in a game theoretical framework by showing that changes in the decisions by a subset of players can theoretically shift the 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. One obvious external intervention is to subsidize a subset of players.[1]

2. Role of Incentives in Coordination Games

This paper investigates how people respond to positive incentives in an interdependent coordination game. Rational choice theory predicts that subsidies promote the Pareto optimum, if non-subsidized players believe that this optimum is easier to be attained, given that subsidized players are more likely to choose the Pareto preferable option. REF. On the other hand, human motivation typically is more complex than suggested by rational choice theory and not necessarily purely consequentialist. For example, the research on the overjustification effect in psychology reported that expecting rewards reduced intrinsic motivations for previously enjoyable activities (Lepper et al. ,1973; Greene et al., 1976).

Comment [K3]: Indicate what you mean by consequentialist in this setting---looking at outcomes but not process?

Comment [K4]: Indicate what you mean by consequentialist in the above problem and the overjustification example. More specifically add a sentence on how the overjustification research relates to our problem.

More recently, behavioral economists began to test the relationship between a

[1] Zhuang et al. (2007) present a dynamic theoretical model of interdependent security where the probability of losses evolves over time and the agents have heterogeneous discounting rates. Zhuang et al. conclude that subsidy is more efficient if allocated to those agents least likely to improve security on their own.

specific kind of reward, financial reward, and motivation. Motivation crowding theory (Frey and Jegen, 2001) suggests that external monetary intervention, such as a subsidy or a financial punishment, may undermine intrinsic motivations, by changing either the decision maker's preference, or changing her perception of the task.

In a field study, Meier (2007) found that using subsidies to encourage the provision of one type of public good, charitable giving, promoted the willingness to contribute in the short run, but had a negative net long run effect by reducing aggregate contributions. Meier proposed several possible underlying reasons for this crowding-out effect include such as incentives undermining pro-social motivations, such as a sense of responsibility, trust between donors and the magnitude of contributions being reduced by the subsidy. Conditional cooperation can be compromised if incentives lead individuals to conclude that nobody will contribute in the absence of the incentive.

Comment [K5]: Is that what the study showed?

More generally, in coordination games the players' strategies depend not only on their own preferences and motivations, but also on their perception of those of the others. Subsidies could potentially "crowd out" other reasons for a given choice of strategy, which may cause players to be even less willing to choose the Pareto preferable option.

Coordination in stochastic settings may differ from coordination with deterministic payoffs with similar payoff structure as illustrated above in comparing investment in airline security and disposing of garbage. Berger and Hershey (1994) found subjects less likely to contribute to a public good when returns were stochastic rather than deterministic. Gong et al. (2009) report that individuals are less cooperative than groups in deterministic prisoner's dilemma games but more cooperative than groups when the outcomes are stochastic.

We now briefly review previous experimental work on coordination games in both deterministic and stochastic settings. Experimental studies on coordination games in deterministic settings have attracted much attention over the past two decades. The existence of multiple equilibria in coordination games makes it difficult to predict which equilibrium a system will reach. The problem is thus an empirical one. Following Van Hayck et. al (1990, 1991), we hereafter refer to failing to reach the Pareto optimum equilibrium in a coordination game as coordination failure. Previous experimental research has found that coordination failure is common in the lab, but that coordination can be improved by a variety of methods (for a review, see Camerer, 2003).

Camerer (2003) divides coordination games into three categories: matching games, e.g. beauty contest game; games with asymmetric payoffs, e.g. battle of sex; and games with asymmetric equilibria, e.g. stag hunt game. The game type most related to our work is the order-statistic game with multiple Pareto-ranked Nash equilibria (Van Hayck et. al, 1990,1991) of which the stag-hunt game is a special case. In a typical order-statistic game, N players each choose among a fixed set of actions, (X1, X2, ..., Xn). A player's payoff is increasing in the order-statistic of all players, usually the median or minimum of the chosen actions, and decreasing in the deviation of the player's choice from the order-statistics. This game mimics a real-world decision faced by team members: the production level depends on the median person's effort or the minimum effort, and people prefer not to work too hard or too little. Multiple Pareto-ranked Nash equilibria exist in an order statistic game: all players choosing X1, or X2, …. , or Xn. Depending on the nature of the order statistic, usually there is a payoff-dominant or efficient equilibrium in which all players choose the highest action to maximize the payoffs, and a secure equilibrium in which all players choose the action that maximize the lowest possible payoff.

Previous research finds that people often fail to reach the payoff dominant equilibrium and fall into the security equilibrium that yields lower payoffs. Different studies have tested different ways to encourage coordination, such as lowering the attractiveness of the secure action (Brandts and Cooper, 2004), reducing deviation cost from the order statistic (Goeree and Holt, 2005), smaller group size (Van Huyck et al., 2007), and communication and information sharing (Van Huyck et al., 1993; Chaudhuri et al., 2005).

One method that is particularly relevant to our research on subsidy is charging an entry fee to encourage coordination. Subjects in Cachon and Camerer (1996) coordinate to an equilibrium with higher payoffs when they have to pay an entry fee than when there is no fee, because players use "avoid losses" as a selection principle which leads to an expectation that others will try to avoid losses as well, and choose an equilibrium with a positive payoff after the entry fee is subtracted. In a sense, the entry fee functions as a negative subsidy that changes both the players' preferences and their expectation of other players' preferences. A more complete review on the order statistic game, including the stag-hunt game, has been provided by Devetag and Ortmann (2007).

The games characterizing the experiments in this paper also belong to the category of critical mass games. In a critical mass game, players usually make binary decisions (X or Y), and once a threshold of players choose X (Y), all other players can be expected to follow X(Y). Urban segregation and weekly seminars participation are typical examples of a critical mass game (see in Schelling (1978) for more details) as are the threshold public good games in which a public good is provided once the total contribution meets or exceeds a threshold value (Van de Kragt et al., 1983; Isaac et al., 1989). In a critical mass game, information about other player's historical decisions and increasing returns above the critical mass are encourage players to reach the efficient equilibrium (Devetag 2003).

An additional complication arises in situations characterized by the presence of uncertainty, such as the IDS game. In a stochastic coordination game, the decisions of the agents depend on both their expectation of others' actions and their own risk preferences. For example, Hess et al. (2007) find that coordination failure is common in an IDS game in which players simultaneously make decisions to coordinate investment to reduce the probability of losses, but coordination is improved when the degree of interdependency is small relative to the overall risk, or when decisions are made sequentially. probably because making decisions in sequence increases the leader's expectation on others following her strategy.

To determine potential reasons for previously observed differences between

Comment [K6]: What real world game are you referring to? Describe the production game in more detail.

Comment [K7]: Defiine what is meant by "security equilibrium" and why it is called that.

Comment [K8]: Why is a *charging an entry fee* related to *subsidy?*
Do you mean that those not charged an entry fee or subsidized?

Comment [K9]: Clarify what you mean by "avoid losses".What do players do differently when they pay an entry fee than if they don't. Show how this relates to the experiment we are undertaking with subsidies and how the negative subsidy (entry fee) changes preferences in a positive way.

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Comment [K11]: Is there empirical to support this point. If yes, insert Ref. If no, I would delete this point.

successful and unsuccessful coordination in stochastic and deterministic settings, we studied subsidy effects in both types of coordination game. In light of the disparity between the positive short-term effect and negative long-term impact of subsidies reported by Meier (2007), we also tested whether provision of a subsidy carried over to subsequent non-subsidized periods. Our results show that that partially subsidizing 2 out of 6 players in a laboratory coordination game usually produced greater coordination and higher total payoffs, especially in a stochastic setting where subsidy had a significant effect in tipping some groups into the Pareto-optimum equilibrium. After removal of the subsidy, high coordination continued in most groups with stochastic payoffs, but declined with deterministic ones. A post-game survey indicated that decision motivations may differ between deterministic and stochastic settings. Temporary subsidies may promote lasting coordination whereas subsidy may be counterproductive in a deterministic setting because it crowds out other bases for coordination.

Section 3 describes the study design, Section 4 describes our results. Implications are discussed in Section 5.

3. Experimental Design

3.1 General Setup

We conducted two games: a stochastic coordination game and a deterministic one. The stochastic game is based on the IDS game by Kunreuther and Heal (2003), in which n players each need to make a discrete decision, strategy A or B. All players face the possibility of a local security breach with probability p of losing L. Strategy A can eliminate the local breach risk at a cost of C. Besides the local breach, a player also faces possible interdependent security breaches, i.e., 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, either from the local breach or the cross breach. Each player's initial wealth is Y.

Let π *(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 are given respectively by

Comment [K12]: I suggest we use italics for all notationl. HK

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

and

$$\pi(B,0) = Y - \{p + (1-p) q \prod_{t=0}^{n-2} (1-q)^t\} L \qquad (2).$$

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

$$\pi(A, n-1) = Y - C \qquad (3)$$

and

$$\pi(B, n-1) = Y - pL \qquad (4)$$

In a coordination game, π(A,0) < π(B,0), and π(A,n-1) > π(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 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 $\pi(A,s-1) < \pi(B,s-1)$.

Howard and Geoff, can you double check to make sure that the above are correct?

Comment [K13]: Geoff: This seems right to me. Please confirm. HK

2.2 The Coordination Games

There were 6 players in a game. The parameters were chosen so that the tipping point was 4. That is, if 4 or more players chose A, a player had a higher expected payoff by also choosing A 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=0.4, q=0.2, 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.

Table 1: Probabilities of Losing 100 Talers in the Stochastic Game

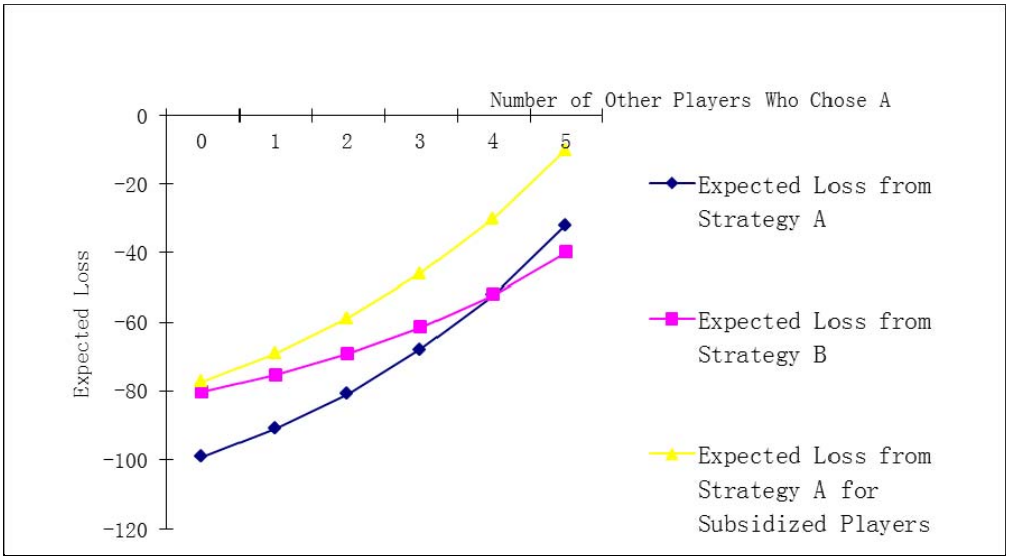
		Number of Other Players Who Choose Option A					
		0	1	2	3	4	5
Your Choice	**Option A** (cost= 32)	67%	59%	49%	36%	20%	0%
	Option B (cost= 0)	80%	75%	69%	61%	52%	40%

As shown in Figure 1, the expected loss of strategy B is less than the expected loss (including the cost of choosing A) of strategy A until at least 4 players choose A. Theoretically if less than 4 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.

Note that in Figure 1, there is a third line that represents the expected loss from Strategy A for subsidized players. The subsidy is set to be 22 Talers. That is, those who are subsidized pay 10 Talers a the cost of Strategy A instead of 32 Talers. For a risk neutral subsidized player, the expected loss of strategy A is always less than that of strategy B.

Comment [K14]: Using an exponential utility function, can you indicate how risk averse a person would have to be so that she would want to choose B as a function of how many other players chose B? My guess is that the person would have a high risk aversion coefficient c in making that choice but it would be good to know this. HK

Figure 1: Expected Loss in the Coordination Game



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.

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

2.3 Four Conditions

A 2X2 between-subject design: (Subsidy vs. Baseline) X (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 subsidy provision and the stochastic/deterministic setting.

As in most coordination studies, we ran repeated games to allow for learning and convergence to the equilibria. The same 6 players play 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 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. Participants were told that there was a 20% chance that their final payoff would depend on their number of Talers at the end of the game. Before making their decision between option A and B in each period, players also indicated how many other players they expected to choose A. After each period *t*, players were given information on their loss, accumulated losses, wealth level, and number of players choosing A in all past periods, including period *t*.

Comment [K15]: We need to say whether a game consisted solely of Session 1 or both Session 1 and 2?

We tested whether there was a carry-over effect of subsidy by running a second session in each condition. At the beginning of Session 2, players' wealth level was restored to 2000 Talers. The same 6 players 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. Players were not aware of the existence of Session 2 until they finished Session 1.

Comment [K16]: I thought that noone in Session 2 got a subsidy in Session 2. Is that correct? HK>

2.4 Participants and Procedure

288 people (48 6-person groups) participated in the study. 82% of participants were between 18 and 25 years old, and 62% were females. All were paid a $10 show-up fee. 20% were randomly chosen to be paid the dollar values of Talers they earned in the game.

Comment [K17]: See Comment K15.

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 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 insure 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 instruction and before playing the game, all participants were required to complete a quiz that contained questions regarding the game, the procedure, decision method, payment information etc., At the end of the experiment, participants answered a survey that provided information about their risk preferences (Holt & Laury (2002?), their reasons for choosing A or B, and demographics.

Comment [K18]: Indicate whether the survey was the same one as used by Holt and Laury?

4. Hypotheses and Results

4.1 Hypotheses

We tested the following hypotheses:

The General Subsidy Effect Hypothesis.

H1: Players are more likely to choose Strategy A with subsidy than without subsidy in both the stochastic and deterministic game. H1 was tested using the between-subject data from 48 groups in Session 1 only.

The Subsidy Carry-over Effect Hypothesis.

H2: The higher cooperation rate in Session 1 due to a subsidy is sustained after the subsidy is removed. H2 was tested using data from Sessions 1 and 2.

4.2 Results for Session 1

Average cooperation rates (percentage choosing A) across periods in the 4 conditions are reported in Table 3. We first focus on the data from Session 1. Random effect logit regressions confirmed H1, i.e., players were more likely to choose Strategy A with a subsidy than without a subsidy ($p<0.01$) after controlling for period and individual subject differences. The complete regression results are reported in Table 4. Note that the rate of coordination dropped over time, consistent with previous studies and learning from feedback over time. 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. Note that the coefficient for Period is negative ($p<0.05$), indicating that the coordination level decreased over time. This is consistent with previous findings in coordination games (reference to be added).

Comment [K19]: Which studies? HK

Comment [K20]: Why did cooperation drop as one learned over time? HK

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	0.64	Deterministic –Subsidy	0. 74	Stochastic-Baseline	0. 71	Stochastic-Subsidy	0. 79
Session 2	Deterministic-Subsidy	0. 79	Deterministic-Baseline-	0. 68	Stochastic-Subsidy	0. 76	Stochastic-Baseline	0. 79

Table 4. Random Individual Logit Model for Choosing Strategy A in Session 1

Variable	Coefficient	Standard Error	z value	Pr(>|z|)
Dependent Variable				
Choosing A				
Independent Variables				
Constant	1.23	0.26	4.68	0.00
Stochastic Game	0.57	0.31	1.86	0.06
Subsidy	0.98	0.31	3.19	0.001
Fixed Effects				
Period	-0.01	0.006	-2.06	0.04
Rho	5.76	2.40		
Log likelihood		-2422		
Sample size		5760		

Figure 2 provides more details on 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 0.17 if only 1 out of 6 players in that group chose A. At the first sight, it appears that the subsidy effect in encouraging players to choose A are similar in the stochastic and deterministic game, except that players were somewhat more likely to choose A in the stochastic game than in the deterministic game ($p<0.10$). The average cooperation rates, however, mask important group differences and decision dynamics in different periods, as shown in Table 5 and Figure 3.

Figure 2: Cooperation Rates in Session 1

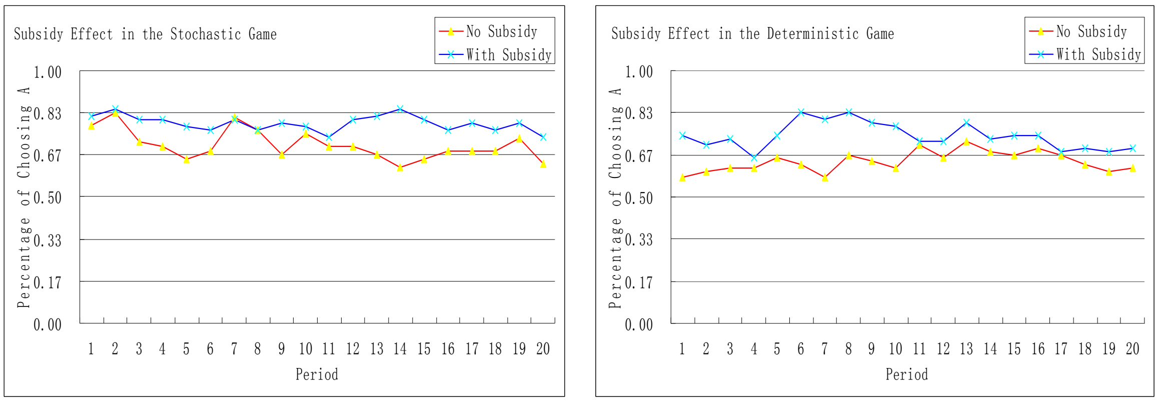


Table 5 reports all 48 groups' cooperation rates in the 20 periods of Session 1, grouped into Period 1-5, 6-15, and 16-20. Again, group averages in each period category confirm H1, namely that subsidy encouraged players to choose Option A. The subsidy-induced coordination improvement occurred at the beginning periods (Period 1-5) and was sustained through the game. This suggests that the subsidy changed participants' expectations of the number of other players who might choose Option A and the options chosen by others over time confirmed these expectations.

Comment [K21]: Can you provide data to confirm this pont given that you asked players to indicate what they expected oterhs to do? HK

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
Period 1-5	1.00	0.47	0.73	0.57	0.67	0.80	0.93	0.83	0.43	0.93	0.74
Period 6-15	1.00	0.62	0.43	0.33	0.77	0.80	0.90	0.80	0.57	0.80	0.70
Period 16-20	1.00	0.67	0.27	0.67	0.77	0.67	0.83	0.80	0.40	0.77	0.68
All Periods	1.00	0.59	0.47	0.48	0.74	0.77	0.89	0.81	0.49	0.83	0.70

	Stochastic - Subsidy												
	Group Number												
	5	11	12	13	18	19	20	21	35	37	38	39	Average
Period 1-5	0.77	0.80	0.80	0.63	0.80	0.80	1.00	1.00	0.83	0.93	0.53	0.83	0.81
Period 6-15	0.77	0.80	0.58	0.83	0.73	0.80	0.98	0.98	0.87	0.98	0.50	0.67	0.79
Period 16-20	0.87	0.83	0.57	0.90	0.73	0.70	0.87	1.00	0.77	1.00	0.37	0.63	0.77
All Periods	0.79	0.81	0.63	0.80	0.75	0.78	0.96	0.99	0.83	0.98	0.48	0.70	0.79

	Deterministic - Baseline													
	Group Number													
	1	2	15	24	28	29	34	36	45	46	47	48	49	Average
Period 1-5	0.57	0.90	0.77	0.80	0.20	0.27	0.50	0.53	0.60	0.53	1.00	0.63	0.67	0.61
Period 6-15	0.37	1.00	0.98	0.90	0.70	0.07	0.35	1.00	0.28	0.43	1.00	0.52	0.92	0.66
Period 16-20	0.37	1.00	1.00	0.97	0.63	0.07	0.20	0.97	0.13	0.20	0.97	0.83	1.00	0.64
All Periods	0.42	0.98	0.93	0.89	0.56	0.12	0.35	0.88	0.33	0.40	0.99	0.63	0.88	0.64
	Deterministic - Subsidy													
	Group Number													
	3	4	14	16	17	25	26	27	40	41	42	43	44	Average
Period 1-5	0.73	0.70	1.00	0.53	0.43	0.70	0.83	0.97	0.53	0.53	0.93	0.40	1.00	0.72
Period 6-15	0.73	0.85	1.00	0.77	0.75	0.55	0.98	0.98	0.57	0.50	0.95	0.45	1.00	0.78
Period 16-20	0.60	0.80	1.00	0.33	0.47	0.57	1.00	0.97	0.53	0.40	0.97	0.47	0.97	0.70
All Periods	0.70	0.80	1.00	0.60	0.60	0.59	0.95	0.98	0.55	0.48	0.95	0.44	0.99	0.74

It is instructive to ask whether the expectations regarding the cooperation rate differed between subsidized and unsubsidized players. The rational theory discussed in the beginning of the paper predicts that the unsubsidized players would increase their expectation of the coordination rate when realizing that the two subsidized players would probably choose A. The subsidized players would also predict a higher coordination rate for the same reason. Bounded rationality and 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 the unsubsidized players, because the subsidized players actually received a rebate if they chose A. Iin contrast the unsubsidized group who were told that others were able to incur a lower cost of investing in A than they were (Hertwig et al., 2007).

The random effect (individual subjects) regression results in Table 6 confirm these predictions. Compared with the players in the Baseline conditions, unsubsidized players in the Subsidy condition had inflated expectations on how many others players would choose A (p=0.01), confirming the tipping theory. Their expectations, however, were lower than the expectations of those subsidized players, consistent with the bounded rationality predictions. 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=0.05, one-tail z test). As will be shown in Figure 3, in some groups, this expectation and behavior change resulted in the whole group tipping toward the All-A equilibrium. Similar results are found when using data from the 1st period, or from the first five periods only.

Comment [K22]: Where do we see this in Table 6 and how does it confirm the tipping theory? Can you summarize individiuals data for subsidized and unsubsidized players to show how expectations compared with rea;lity over time?

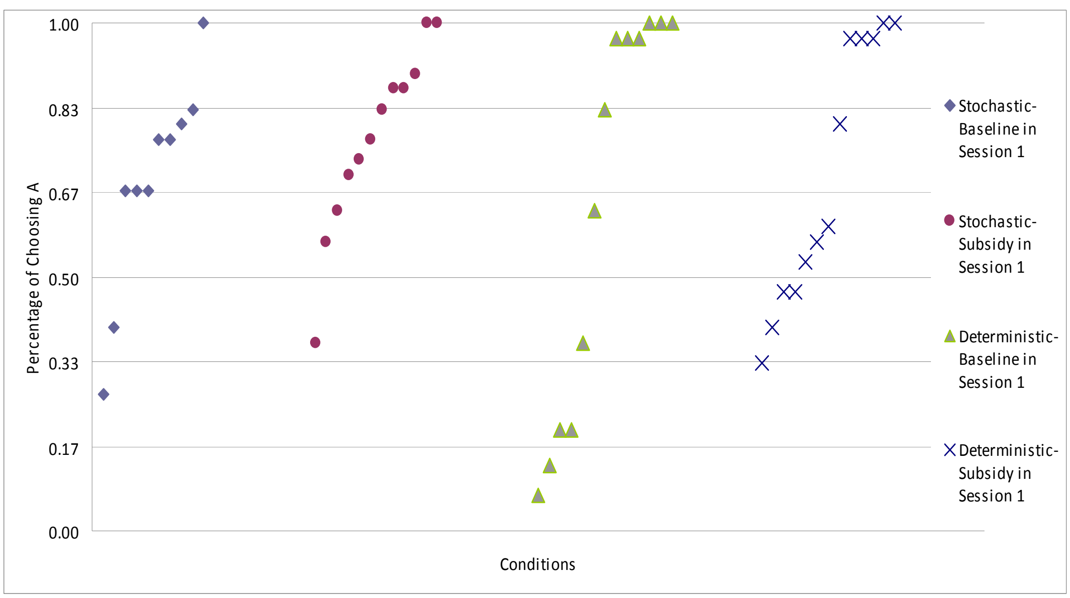
Table 6. Subsidy Effects on Expectations

Variable	Coefficient	Standard Error	t value	Pr(>|z|)
Dependent Variable				
Expectation on the number of others choosing A				

Independent Variables				
Constant	3.57	0.11	33.72	0.00
Players in Baseline Condition	-0.30	0.12	-2.74	0.01
Subsidized Players in Subsidy Condition	0.08	0.04	2.16	0.03
Stochastic Game	0.09	0.12	0.76	0.45
Period	0.01	0.002	6.30	0.00
Log likelihood		-8302		
Sample size		5760		

We now turn to differences in reaching successful coordination in the last five periods for the four different conditions. Figure 3, showing average cooperation rates in Period 16-20 of Session 1, reveals interesting and important similarities and differences between the stochastic and deterministic games. First, there is a clear pattern that subsidy did improve the cooperation rates in both 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 with subsidy in either games, because, as the payoff graphs shows in Figure 1, for the two subsidized players, choosing A is always preferable than B, even when there are no other players choosing A. The data confirm that the subsidized players chose option A 91% of the time.

Figure 3: Cooperation Rate in Groups in Period 16-20 in Session 1



Third, as the theory predicted, subsidy tipped some groups toward the Pareto-superior equilibrium. Recall that the tipping point for choosing A based on the rational theory prediction is the expectation that 4 other players will choose A. Hence we define an efficient equilibrium as 5 or more players choosing A (i.e., cooperation rate equal to or greater than 0.83) in the last 5 periods, and an inefficient equilibrium as 2 or fewer players choosing A (i.e., cooperation rate equal to or smaller than 0.33) in the last 5 periods.

Comment [K23]: This iimplies that some of the subsidized players will not choose A even though it was in their best interest to do so no matter what others did. Can you say something about this? HK

The tipping effect of the subsidy is clearly illustrated in the stochastic game. In the Stochastic-Baseline condition, only 2 out of 10 groups (20%) had a cooperation rate over 0.83, only one group converged on the inefficient equilibrium, and the majority of the groups were stuck in middle, between the two NEs. In the Stochastic-Subsidy condition, however, 6 out of 12 groups (50%) successfully reached the efficient equilibrium.

Fourth, although subsidy also improved the average cooperation tendency in the deterministic game, there is a noticeable difference in the patterns of how subsidy functioned in the two games. 13 of the 15 groups in the Deterministic-Baseline condition reached the predicted NEs, consistent with previous research (Van Huyck et al., 1997; more ...). In particular, 7 groups reached the efficient equilibrium, and 4 groups clustered at the inefficient equilibrium, and only 2 groups settled between the two NEs. In the Deterministic-Subsidy condition, the majority of the groups had 2-4 players choosing A, i.e., no group converged into the inefficient equilibrium; however, fewer groups reached the efficient equilibrium than in the baseline condition.

Comment [K24]: Did any non-sbusidized player coperate in te deterministic-subsidy conditon? HK

To summarize, subsidy improved coordination in the stochastic game by tipping half of the groups towards the efficient equilibrium, and by diverting one third of the groups away from the inefficient equilibrium. 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 game?

Comment [K25]: Where do we see this? HK

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. Players' decision in the stochastic game depends not only on their expectation of what others will do, but also their own risk preferences. The risk preference data collected in our post-game survey confirmed that the more risk-averse a player was, the more likely she would choose Strategy A to reduce her chance of suffering a 100-Taler loss ($p<0.01$) whether or not she was subsidized. 78% 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, explaining why we observed only two groups reaching the All-A equilibrium.

Comment [K26]: How often did you have an All-B outccome in the Deterministic Baseline case?

How does subsidy function differently in the deterministic and stochastic game? To answer that question, we first analyze how subsidy changes the decisions of the divided groups??? and encourage them to reach the efficient equilibrium in the stochastic game. On the one hand, subsidy encourage subsidized players to choose A, because, at a cost of 32 Talers, some players may be willing to take the risk instead of paying the cost, while others prefer to pay the cost to reduce the risk. With the subsidy, those who would have chosen B without subsidy now consider the cost level of 10 Talers to be worth it for the risk reduction, and switch to A. On the other hand, the tipping process discussed earlier may be at work to encourage unsubsidized players to choose A in that the unsubsidized players foresee the changes in the subsidized players, increase their expectation of the number of players choosing A, and 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 worthy 32 Talers to reduce the risk of losing 100 Talers from 75% to 59%. Assume that this player is not subsidized but believes that 2 subsidized players will choose A. She is now willing to pay 32 Talers to reduce her risk from 61% to 36%. This is not the case in the deterministic game. The expectation question data proves that the average expectation of the efficient groups in the stochastic game is significantly lower than that in the deterministic game (4.5 vs. 4.1, $p<0.01$), indicating that a lower tipping point is probably required to change players' strategy from B to A in the stochastic game.

Note that in the above example, an unsubsidized player increases her expectation of others choosing A from one player to three players by adding two subsidized players. That is, we assume that the unsubsidized player is a naïve decision maker and does not take into account of 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 (2 in this case) to the expectation. People may add a fraction of 2, or adjust it only when their initial expectation is below 2. They may even decrease their expectation if their initial expectation is above 2 and they suspect the existence of a crowding-out effect, as mentioned in the literature review. The fact that fewer groups reached the efficient equilibrium in the Deterministic-Subsidy condition than in the Deterministic-Baseline condition is an indication that there might be a crowding-out effect for some groups. We will revisit the crowding-out effect later in the data analysis for Session 2.

Comment [K27]: I found the logic here difficult to follow. Can you clarify why people behave differently in the stochastic and deterministic cases and how the tipping process is at work?

Comment [K28]: Clarify this point. Are you saying that in the stochastic game people feel that only 4.1 players need to cooperate to tip the others while 4.4 need to do this in the deterministic game?/

Comment [K29]: Do we need this paragraph? If so, please clarify as it was difficult for me to follow the argument. HK

4.3 Results in Session 2

Combined data from Sessions 1 and 2 were used to test H2, the *Subsidy Carry-over Effect Hypothesis*, 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 ($p<0.01$). Participants in the deterministic game were significantly less likely to choose A after the subsidy was removed than with subsidy ($p<0.01$), but those in the stochastic game sustained the same level of coordination without subsidy as with the subsidy ($p>0.10$)[2].

[2] The results of a second regression, similar to the one reported in Table 5, to test the subsidy carry-over effect in

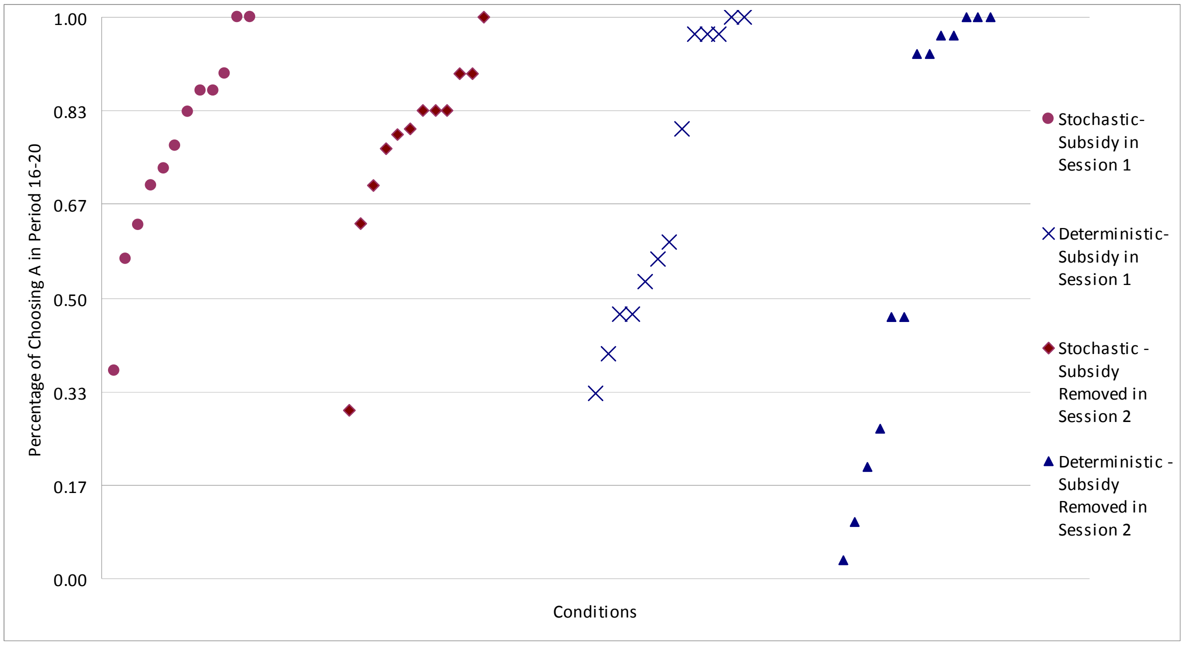
Table 7. Random Individual Logit model for Choosing Strategy A in the Subsidy Condition

Variable	Coefficient	Standard Error	z value	Pr(>|z|)
Dependent Variable				
Choosing A				
Independent Variables				
Constant	2.50	0.33	7.52	0.00
Stochastic Game	0.62	0.47	1.31	0.19
Subsidy Removed	-0.51	0.10	-4.98	0.00
Fixed Effects				
Period	-0.02	0.007	-4.25	0.00
Interaction				
Stochastic Game X Subsidy Removed	0.49	0.16	3.11	0.001
Rho	7.22	2.69		
Log likelihood		-2227		
Sample size		5988		

The interaction between the game type and the subsidy carry-over effect can be shown more clearly when we look at cooperation rates in greater detail, as in Figure 4. The red symbols show groups in the stochastic game, while the blue symbols show groups in the deterministic game. Figure 4 shows that almost all 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 the same dichotomous pattern observed in the Deterministic-Baseline condition (the green dots in Figure 3), 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.

Figure 4: Cooperation Rates in Period 16-20 with Subsidy and without Subsidy in Subsequent Session as a Function of Game Type.

the stochastic game are available upon request.



Why is there a difference in the subsidy carry-over effect in the deterministic vs. stochastic game? Our post-game survey showed that in the deterministic game, consistent with the motivation crowding-out theory (Frey and Jegen, 2001), 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. Once the subsidy was removed, those players probably expected fewer players to choose A, and decided to choose B. Hence, some divided groups tipped toward the inefficient equilibrium all-B. In the stochastic game, only 22% of players viewed paying a lower cost as the only reason for choosing A. 78% of the players simply regarded A as a safer option, and assumed that others also preferred reduced risk, once the subsidy helped the group reach a higher number of players choosing A. 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.

5. Conclusions

Prior research shows that people often have difficulty reaching the efficient equilibrium in coordination games with multiple Pareto-ranked Nash Equilibria. The current study investigates the function of subsidy in a coordination game, both in a deterministic and 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' expectation and behavior, so that some groups are tipped towards 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. A post-game survey indicated that decision justifications differ between deterministic and stochastic payoff settings. Temporary subsidies seem to promote lasting coordination in risk reduction, whereas in a deterministic setting, subsidy may be counterproductive, because it crowds out other bases for coordination.

The experimental results in this paper have important public policy implications. 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 based on social expectation. Another implication is that instead of playing down the uncertain factors in a coordination scenario, as public policy makers often do, we may be able to utilize people's natural tendency to be risk averse to encourage efficient and lasting risk reduction cooperation by emphasizing the uncertainty existing in the problem.

Comment [K30]: What do you mean by *social expectation?*

IT WOULD BE GOOD TO HAVE A PARAGRAPH ON FUTURE RESEARCH BUILDING ON THESE FINDINGS. MIN: HAVE YOU THOUGHT ABOUT THE NEXT PHASE OF THIS RESEARCH THAT MIGHT BE NOTED HERE?

Appendix A: Average Rate of Choosing A in each Group in Session 2

Table 8: Average Rate of Choosing A in each Group in Session 2

	Stochastic - Subsidy										
	Group Number										
	6	7	9	10	22	23	30	31	32	33	Average
Period 1-5	0.97	0.63	0.47	0.70	0.87	0.87	0.93	0.93	0.63	0.83	0.78
Period 6-15	0.93	0.77	0.53	0.57	0.80	0.90	0.87	0.90	0.73	0.83	0.78
Period 16-20	0.87	0.77	0.43	0.50	0.83	0.83	0.73	0.80	0.73	0.83	0.73
All Periods	0.93	0.73	0.49	0.58	0.83	0.88	0.85	0.88	0.71	0.83	0.77

	Stochastic - Baseline												
	Group Number												
	5	11	12	13	18	19	20	21	35	37	38	39	Average
Period 1-5	0.80	0.83	0.70	0.73	0.57	0.60	0.97	0.87	0.80	1.00	0.53	0.93	0.78
Period 6-15	0.77	0.83	0.77	0.85	0.73	0.68	1.00	0.93	0.85	1.00	0.43	0.82	0.81
Period 16-20	0.70	0.83	0.63	0.77	0.79	0.83	0.90	0.90	0.83	1.00	0.30	0.80	0.77
All Periods	0.76	0.83	0.72	0.80	0.70	0.69	0.97	0.91	0.83	1.00	0.43	0.84	0.79

	Deterministic - Subsidy													
	Group Number													
	1	2	15	24	28	29	34	36	45	46	47	48	49	Average
Period 1-5	0.67	1.00	1.00	0.93	0.77	0.70	0.50	0.97	0.63	0.60	1.00	0.83	0.97	0.81
Period 6-15	0.55	1.00	1.00	0.95	0.87	0.48	0.37	1.00	0.63	0.45	1.00	0.95	0.97	0.79
Period 16-20	0.37	1.00	1.00	0.93	1.00	0.53	0.40	1.00	0.40	0.40	0.97	1.00	1.00	0.77
All Periods	0.53	1.00	1.00	0.94	0.88	0.55	0.41	0.99	0.58	0.48	0.99	0.93	0.98	0.79

	Deterministic - Baseline													
	Group Number													
	3	4	14	16	17	25	26	27	40	41	42	43	44	Average
Period 1-5	0.80	0.37	1.00	0.97	0.30	0.93	0.93	0.97	0.73	0.33	0.90	0.67	1.00	0.76
Period 6-15	0.55	0.22	1.00	0.82	0.17	1.00	0.95	1.00	0.55	0.18	0.77	0.32	1.00	0.66
Period 16-20	0.47	0.03	0.97	0.93	0.10	1.00	0.93	1.00	0.47	0.27	1.00	0.20	0.97	0.64
All Periods	0.59	0.21	0.99	0.88	0.18	0.98	0.94	0.99	0.58	0.24	0.86	0.38	0.99	0.68

Appendix B: Instruction Sample in the Stochastic- Subsidy Condition

Instructions

In this study, you will be randomly matched with 5 persons to play 6-person games in which the outcomes of your decisions depend not only on what you do, but also on what others do.

You will be given 2000 Talers at the beginning of the study (2000 Talers = $40 or 1 Taler = 2 cents). The amount of Talers you keep may determines your final payoff. Two persons will be **chosen at random** to receive the dollar equivalent of the Talers they have at the end of the study, plus a $10 show-up fee.

To illustrate, suppose that Participant 3 and 5 are randomly chosen to be paid for their Talers. Suppose at the end of the game, Participant 3 has 900 Talers and Participant 5 has 800 Talers. Participant 3 will be paid $18 (900 Talers) + $10 showup fee = $28. Participant 5 will be paid $16 (800 Talers) + $10 showup fee = $26. Other people will be paid $10 for showing up.

The Game

There are 20 rounds in the game. You will be playing with the **SAME** 5 other people in all 20 rounds. In each round, all players will independently make a decision about whether to choose Option A or Option B. Your outcome depends on how many of the other 5 players choose **Option A** and how many of the other 5 players choose **Option B** .

There are two kinds of players, Player X or Player Y. In each round, the computer randomly assigns 4 players to be X, and 2 players to be Y. The assignment lasts for one round only. Assignments in each round are independent. That is, in each round, you have 2/3 chance of being X, and 1/3 chance of being Y.

The following illustrates possible outcomes of Player X and Y respectively. You should be familiar with both, because you probably will play both as X and Y during the 20-round game.

For Player **X**:

Table 1 illustrates possible outcomes in each round for Player X. For example, if you choose Option A, it costs 32 Talers. If no players out of the other 5 players choose **Option A**, you have a 67% probability of losing 100 Talers, in addition to paying 32 Talers (the cost of A). If one out of the other 5 players choose **Option A**, you have a 59% probability of losing 100 Talers, in addition to paying 32 Talers. All other possible outcomes are presented in Table 1 in the Option A row.

If you choose Option B, it costs zero Talers. If no players out of the other 5 players choose **Option A**, you have an 80% probability of losing 100 Talers. If one out of the other 5 players choose **Option A**, you have 75% probability of losing 100 Talers. All other possible outcomes are presented in Table 1 in the Option B row.

Table 1: Probabilities of Losing 100 Talers for Player *X*

		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%

For Player **Y**:

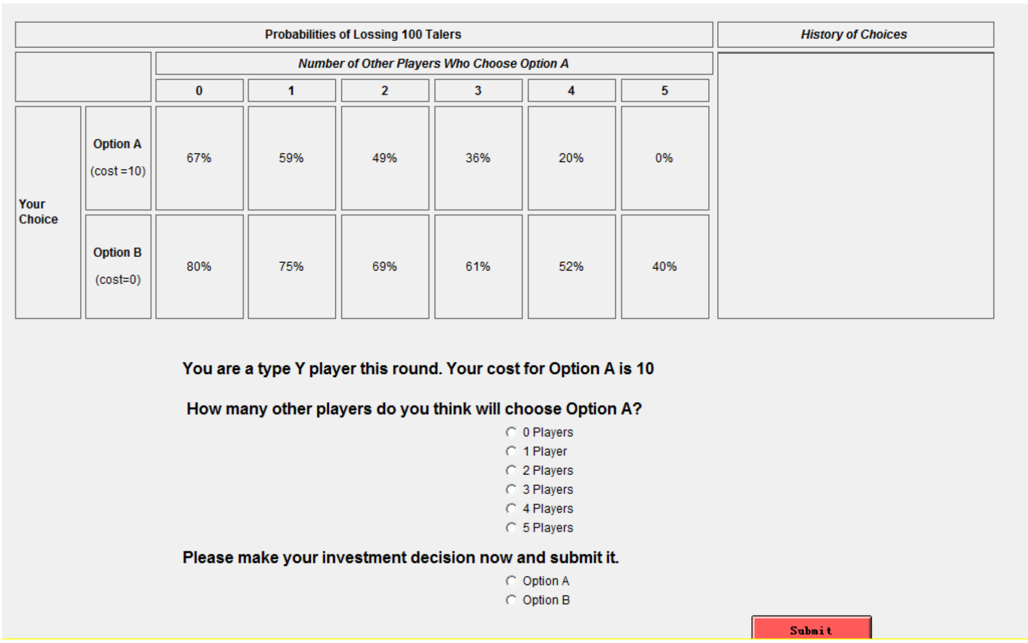
The major difference between Player X and Y is that the cost of Option A for Player Y is 10 Talers instead of 32 Talers. Table 2 illustrates possible outcomes in each round for Player Y

Table 2: Probabilities of Losing 100 Talers for Player *Y*

		Number of Other Players Who Choose Option A					
		0	1	2	3	4	5
Your Choice	**Option A** (cost= 10)	67%	59%	49%	36%	20%	0%
	Option B (cost= 0)	80%	75%	69%	61%	52%	40%

Procedure

You will not know the decision of other players until the end of the round.
Here is an example of the decision page for **the first round** for a Player Y:



After all players have made a decision, the computer will randomly generate a number between 1 and 100 to decide whether you have suffered a loss.

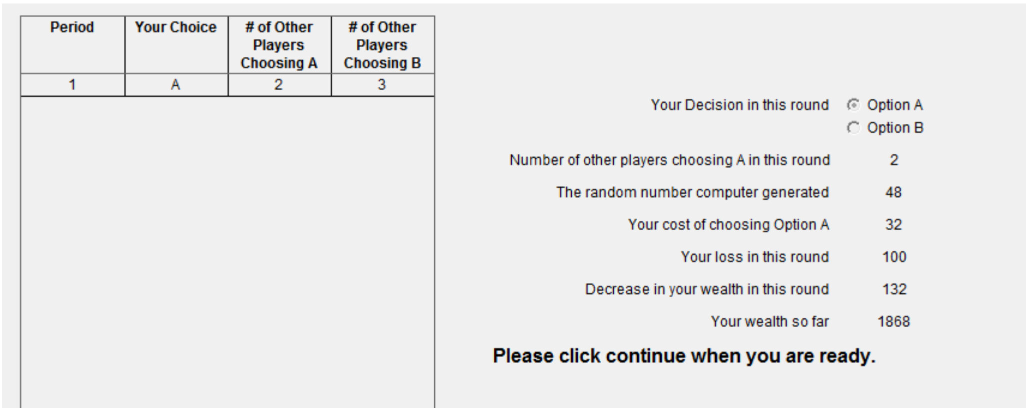
For example, suppose that in one round, you choose Option A, and 3 out of the other 5 players have chosen A as well. According to Table 1, you have 36% chance of losing 100, plus paying 32 for the cost of Option A. If the random number is less than or equal to 36, you suffer the 100 Talers loss. That is, you will have to pay 100+32=132 Talers in that round. If the random number is greater than 36, however, you will pay the cost of Option A only (32 Talers).

The general rule is that if the random number is less than or equal to your chance of losing 100 Talers (in percentage), you will suffer a loss of 100 Talers, plus paying whatever cost your choice incurs (32 for A or 0 for B). Note that in each round, the computer generates only one random number. That is, the same random number is compared to all players' respective probabilities to determine who suffer a loss.

There is no strict time limit on how long you can spend on making a decision. But please keep in mind that **everyone** in this room will have to wait for you if it takes too long for you to make a decision. A reminder will appear on the top right of the screen if fail to make your decision within 60 seconds.

Before starting the next round, you will be given feedback on your loss in the current round, your total wealth so far, and how many players (including you) have chosen A and how many have chosen B.

Here is an example of the feedback page for a Player X:



Period	Your Choice	# of Other Players Choosing A	# of Other Players Choosing B
1	A	2	3

Your Decision in this round: (•) Option A ( ) Option B

Number of other players choosing A in this round: 2

The random number computer generated: 48

Your cost of choosing Option A: 32

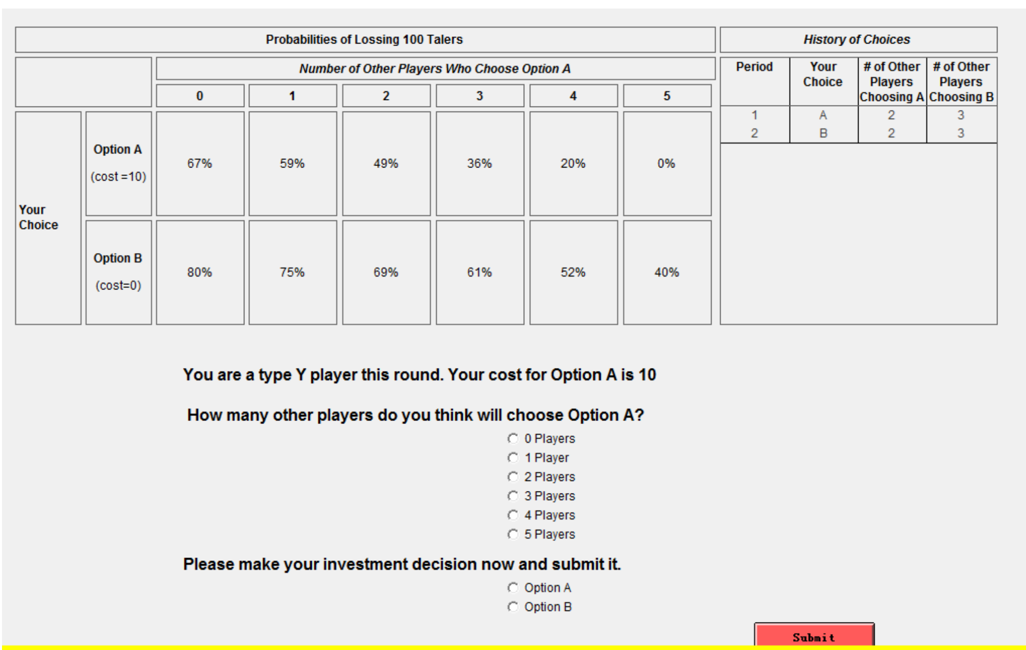
Your loss in this round: 100

Decrease in your wealth in this round: 132

Your wealth so far: 1868

Please click continue when you are ready.

Starting the 2nd round, you will be given information on how many players have chosen A and B respectively in each of previous rounds. Here is an example of the decision page for the 3rd round for a Player Y:



Probabilities of Lossing 100 Talers

		Number of Other Players Who Choose Option A					
		0	1	2	3	4	5
Your Choice	Option A (cost =10)	67%	59%	49%	36%	20%	0%
	Option B (cost=0)	80%	75%	69%	61%	52%	40%

History of Choices

Period	Your Choice	# of Other Players Choosing A	# of Other Players Choosing B
1	A	2	3
2	B	2	3

You are a type Y player this round. Your cost for Option A is 10

How many other players do you think will choose Option A?

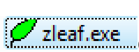
( ) 0 Players
( ) 1 Player
( ) 2 Players
( ) 3 Players
( ) 4 Players
( ) 5 Players

Please make your investment decision now and submit it.

( ) Option A
( ) Option B

Submit

Please **raise your hand** if you have any question. Otherwise, please **open Zleaf**



on your desktop to start quiz.

Reference to be added

Lepper, M.R., Greene, D. & Nisbett, R.E. (1973) Undermining children's intrinsic interest with extrinsic rewards: A test of the overjustification hypothesis. *Journal of Personality and Social Psychology*, 28(1), pp. 129-137.

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