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EFFECTS OF PRIOR INVESTMENT AND PERSONAL RESPONSIBILITY IN A SIMPLE NETWORK GAME

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ABSTRACT

The present study has two purposes. First, we wish to test the descriptive power of the Nash equilibrium solution in a traffic network game with a new population of participants and a different experimental procedure. Second, we wish to determine whether the effects of prior investment and personal responsibility, that may lead people to commit to a failing project, may be generalized from individual to interactive decision tasks. For these two purposes, we implement a computer-controlled traffic network game in which the addition of a cost-free line segment to the network may, in equilibrium, increase the travel cost of all the network users.

INTRODUCTION

When people invest resources in a project that turns out to be unsuccessful, they tend to commit to the failing project by making additional investments. Social psychologists have studied this tendency under the rubrics of sunk cost (Arkes & Blumer, 1985), entrapment (Rubin & Brockner, 1975), or escalation (Staw, 1976; Teger, 1980). For example, the sunk cost effect refers to "a greater tendency to continue an endeavor once an investment of money, effort, or time has been made" (Arkes & Blumer, 1985, p. 124). Two major factors have been identified as facilitating a commitment to a failing course of action: *prior investment* (e.g., Arkes & Blumer, 1985) and *personal responsibility* (e.g., Staw, 1976). Although there have been numerous experimental studies of sunk cost, entrapment, and escalation, most of them have employed scenario experiments with no costs or payoffs (e.g., Arkes & Blumer, 1985, except Exp. 2; Heath, 1995; Karlsson, Garling, & Bonini, 2005). In the few cases where real costs were involved (e.g., Brockner, Shaw, & Rubin, 1979; Rubin & Brockner, 1975), the experiments employed the same setup in an individual decision task (i.e., waiting in line).

The present study extends this line of research in several directions. First, and most importantly, we extend previous research from an individual to an interactive decision task, where the payoff for each participant is determined by her decision as well as the decisions of all other members of her group. The effect of prior investment and personal responsibility may differ when the decision task is interactive rather than individual. This is particularly the case if the group includes multiple members ($n > 2$), thereby necessarily diluting the effect of personal responsibility. For testing the effects of these two constructs, we employ a novel traffic network game that has recently been studied by Rapoport, Kugler, Dugar, and Gisches (2005; in press) and Rapoport, Mak, and Zwick (2006). We refer to these studies as "RKDG" and "RMZ," respectively. Secondly, we extend the investigation to a non-cooperative n-person game in which the failure of one's course of action is due to coordination behavior that results in an inefficient outcome rather than to environmental uncertainty. Thirdly, we explore the evolvement of the effects of personal responsibility and prior investment by iterating the network game over time. Our purpose is both to test the descriptive power of the equilibrium solution in a new population of participants, and to determine whether personal responsibility and prior investment, as operationalized in the present study, are manifested in this interactive decision task.

The paper is organized as follows. We first describe the network game that was originally designed to test the implications of a paradox first discovered by Braess (1968). We then review experimental findings that strongly support the implications of the Braess Paradox (BP). We conclude the paper by describing the experimental method, summarizing the results of the experiment, and briefly discussing their implications.

The Braess Paradox

It seems intuitively obvious that adding one or more routes to an existing transportation or communication network, thereby increasing its capacity, should decrease, or at worst not change, the travel time or cost of network users wishing to traverse the network from a common source to a common destination. The obvious happens to be true when the network is not overly congested. But, as first shown by Braess (1968), when the network is subject to congestion, the obvious need not always be true (e.g., Cohen & Kelly, 1990).

The Network Game

To describe the network game in some generality, we first introduce notation. The network that we consider is modeled by a directed graph G = (V, E, O, D), where V is a finite set of vertices, E is a finite set of edges (links), and O (for origin) and D (for destination) are two distinct vertices in V. An edge e (an element of E) has a tail t(e) (an element of V) and a head h(e) (an element of V). We interpret the edge e as a one-way road segment from t(e) to h(e). A path (route) in the network is an unbroken sequence of the form v[0], e[1], v[1], ..., v[g-1], e[g], v[g], where v[0], v[1], ... , v[g] are distinct vertices, e[1], e[2], ... , e[g] are edges satisfying t(e[i]) = v[i-1] and h(e[i]) = v[i], i = 1, 2, ... , g, v[0] = O, and v[g] = D. (The numbers and symbols in brackets are usually expressed with subscritps)

Costs are assigned to edges in the following way. We denote by c[ij] the cost for each user of traversing along the edge e[ij] that connects vertices i (= j - 1) and j, given that the number of users traversing this edge is f[ij]. This cost structure allows for the effects of congestion, if c[ij] is taken to represent the travel cost (e.g., time, money) for the road segment e[ij] when it is traversed by f[ij] users. To introduce a cost structure that is both reasonable and easy to explain to the participants, we assume linear cost functions:

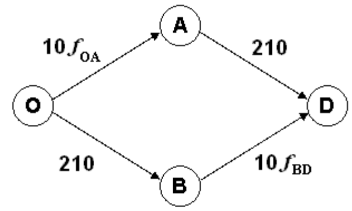
c[ij] x (f[ij]) = a[ij] x (f[ij]) + b[ij] for each e (an element of E),

where a[ij] > 0 and b[ij] > 0. The linear cost function has two components: b[ij] is a fixed component interpreted as the cost of traversing the edge e[ij] by a single user. It is unaffected by congestion. There is also a variable cost a[ij] that, when positive, accounts for the increase in travel cost due to congestion. The network game is played by a group of n users, each of whom has to independently choose a route from O to D. The joint choice of routes determines the congestion on each road segment and, consequently, the travel cost for each user. Users choose routes independently in an attempt to minimize individual cost of travel.

Figure 1A is the simplest example of such a network with V = {O, A, B, D} and cost functions:

c[OA] x f[OA] = 10 x f[OA] + 0,
c[BD] x f[BD] = 10 x f[BD] + 0,
c[AD] x f[AD] = c[OB] x f[OB] = 210.

Under this cost structure, road segments (O, A) and (B, D) are susceptible to congestion (e.g., consider them to be narrow roads) but road segments (A, D) and (O, B) are not. There are only two routes to choose from, namely, (O, A, D) and (O, B, D). Assume n = 18. Then, it is quite obvious from the symmetry of the network that there are multiple pure-strategy equilibria in which n/2 = 9 users choose route (O, A, D) and 9 other users choose (O, B, D). The individual travel cost is 300 (i.e., 10 x 9 + 210). We refer to the network in Figure 1A as the *basic game*.



Figue 1A. The Basic Game

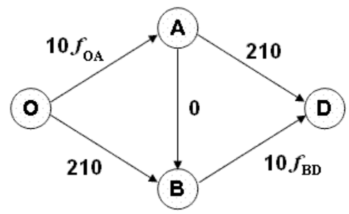


Figure 1B. The Augmented Game

Next, consider the network game in Figure 1B, called the *augmented game*. It only differs from the basic game by the addition of one-way link connecting A and B. There are now three routes to choose from in the augmented game, namely, (O, A, D), (O, B, D) and the new route (O, A, B, D). To sharpen the effect of the BP, the cost of traversing from A to B is set at zero: c[AB] = 0 regardless of the number of users of this road segment. It is easy to verify, although not immediately obvious, that in equilibrium all n = 18 users choose the route (O, A, B, D). The resulting equilibrium travel cost is 360 (i.e., 18 x 10 x 2). Note that 360 > 300, where 300 is the equilibrium cost in the basic game. The equilibrium analysis implies that adding a cost-free road segment to the basic game in Figure 1A, without imposing any constraints on route choice, increases travel cost by 20 percent. To verify the equilibrium solution, notice that unilateral deviation by one of the n users from (O, A, B, D) to (O, A, D) increases travel cost from 360 to 390. Similarly, a unilateral deviation of a single user from (O, A, B, D) to (O, B, D) increases travel cost from 360 to 390.

There is a flip side to the BP that some may find even more counterintuitive. Rather than starting with the basic game in Figure 1A, augmenting it by adding a new link, and showing an increase in travel cost for all users, start with the game in Figure 1B, delete the link (A, B), and note a decrease in equilibrium travel cost from 360 to 300. Under this framing, all n = 18 users greatly benefit from the degradation of the network.

Three brief comments about the BP are in order. First, the conclusion that any augmentation of the basic network results in a higher travel cost is clearly false. Whether the BP is realized depends critically on the choice of the parameter values. For example, if n = 10, rather than n = 18, in Figure 1, all users will benefit from the addition of the link (A, B). Second, the BP may occur even if the new route (O, A, B, D) is not a dominant strategy. This is the case, for example, if n = 24 in Figures 1A and 1B (see RMZ, 2006). Thirdly, the BP is not restricted to a two-route network, to symmetric networks, or to the addition of only a single link (see, e.g., RKDG, 2005; in press).

Previous Experimental Studies on BP

Two previous studies of the BP are directly relevant to our study. RKDG (2005, Exp. 1) implemented the network games in Figures 1A and 1B with the same cost parameters and n = 18. Three groups of participants (USA students) first played the basic game in a computer-controlled experiment for 40 identical rounds, and then the augmented game for 40 additional rounds (Condition ADD). Three other groups played the two network games in the reverse order (Condition DELETE). In both conditions, participants registered their route choices and then were informed of the frequency of users choosing each route and their payoff for the round. To determine their payoff, individual travel cost for each round was subtracted from an endowment that assumed the same value of 420 for each round in both games. Consequently, the equilibrium payoff per round was decreased by 50 percent from 120 in the basic game (420 - 300 = 120) to 60 in the augmented game (420 - 360 = 60). The results showed no differences between Conditions ADD and DELETE. The equilibrium solution accounted extremely well for the mean frequency of route choice (i.e., 9) in the basic game with no support for mixed-strategy play. In support of the BP, by round 40 all the players in the six sessions playing the augmented game chose route (O, A, B, D) and consequently sustained a considerable loss of payoff.

Using a within-group design, RMZ (2006) conducted another test of the BP with three different group sizes (n = 10, 20, 40). Consider the case n = 20, which is most relevant to our study. When n = 20, the equilibrium travel costs in games 1A and 1B are 310 and 400, respectively. RMZ (2006) provided a fixed endowment of 490 points per round resulting in equilibrium payoffs of 180 and 90 for games 1A and 1B, respectively. Twelve groups of n = 20 (Hong Kong students) only played the augmented game. Once again, the results supported the BP. Although all group members working in concert would have doubled their payoff from 90 to 180 by dividing themselves equally between the two (non-equilibrium) routes (O, A, D) and (O, B, D), they did not do so. Rather, all converged to the choice of route (O, A, B, D) and consequently sustained heavy losses.

Overview of the Present Study

Eight groups of n = 18 users each played the basic and augmented games in Figures 1A and 1B for multiple rounds. In Phase I, the basic game was iterated 40 times. At the end of this phase, the participants were introduced to the augmented game and were given the option to switch and play it for additional 40 rounds. In Phase II, the participants played the augmented game for 40 additional rounds. At the end of Phase II, they were again asked for their preference between playing games 1A or 1B for additional rounds. The augmented game was played for 40 more rounds in Phase III, followed by a post-experimental questionnaire. Prior investment and personal responsibility were manipulated by dividing the eight groups into four conditions, as explained below.

METHOD

Participants

The participants were 144 undergraduate and graduate Japanese students (mostly male). They were recruited by written announcements posted on campus and a laboratory web site promising payoff contingent on performance. The announcement sheet listed the time slots in which experimental sessions would be conducted and emphasized the monetary reward for participation. All the participants voluntarily contacted the experimenter for the monetary reward. The experimenter determined the schedule.

Experimental Conditions

The subjects were randomly assigned to one of four conditions (two sessions in each condition).

Condition CONT

Condition CONT was a control condition involving neither personal responsibility nor prior investment. Because of the difference in subject population (USA students in RKDM and HK students in RMZ) and in the experimental procedure (three rather than two phases with preference choice points between phases), it was deemed important to test for possible cultural and procedural differences in the convergence/non-convergence to equilibrium behavior and for the dynamics of play. Participants were asked for their preference for playing additional rounds of game 1A or 1B at the end of Phase I, but were subsequently instructed that they would play game 1B in Phase II regardless of their responses.

Condition PR

Condition PR involved personal responsibility and no prior investment. At the end of Phase I, the participants were instructed that they would play one of the two games preferred by more than x of the group members. After registering their preferences, it was announced that the augmented game would subsequently be played because more than x group members had, in fact, preferred it. Eighteen of 36 participants expressed preference for playing the augmented game; they were thus led to believe that they were partly responsible for playing this game in Phase II.

Condition PI

Condition PI involved prior investment but no personal responsibility. The participants were instructed that they would play the augmented game in Phase II. Prior investment was manipulated by collecting a mandatory fee (investment) of 200 yen from each participant to allegedly subsidize the construction of link (A, B).

Condition PR&PI

This condition involved both personal responsibility and prior investment. These two constructs were experimentally implemented by asking the participants not only to indicate their preference for which game to play in Phase II, but also their reservation value (maximum amount they are willing to pay) for the game they preferred. The participants were instructed that the reservation values for playing the augmented game would be collected, and that the game would be played only if the sum exceeded a pre-determined threshold value y. After assessing the preferences and reservation values, it was announced that the augmented game would be played in Phase II as the value of y was, in fact, exceeded. Thus, participants in this condition preferring to play the augmented game in Phase II not only made prior investment but also were collectively responsible for its implementation.

Procedure

Participants were seated in separate cubicles connected by a computer network and provided with written instructions. The instructions explained the basic game and the calculation of individual payoffs. At the end of Phase I, the participants were presented with the augmented game, and asked to determine which game they would prefer to play in Phase II. Half of them were instructed that the game to be played in Phase II was chosen collectively (Conditions PR and PR&PI). Participants in Conditions PI and PR&PI were instructed that their reservation values or fees would be subtracted from their final earnings. After completing 40 rounds of the augmented game in Phase II, the participants were asked once again to state their preference between further playing one of the two games (second choice point). They were then instructed that they would play the game preferred by at least x group members (same as in Condition PR). The majority of the participants in each session preferred to switch back to the basic game on Phase III. Then, all the eight groups played the basic game in Phase III for 40 more rounds, and answered a brief post-experimental questionnaire (Appendix A). Altogether, they completed 120 rounds of play in three phases that lasted about two hours.

At the end of the session, four rounds in each phase were randomly chosen for payment. Actual payoffs were determined by multiplying the total number of points across the 12 rounds by 4, converting them to yen, and adding a show-up bonus of 1000 yen. Mean payment across all four conditions was 4302 yen.

RESULTS

Mean Payoff in the Basic and Augmented Games

The endowment in each round was set at 400 points. Participants adhering to equilibrium play would have earned 100 and 40 points in games 1A and 1B, respectively, a drop of 60 percent. Deviations from equilibrium play in game 1A could only decrease mean individual payoffs, whereas deviations from equilibrium play in game 1B could result in higher-than equilibrium payoffs. Mean payoffs in Condition CONT across all 40 rounds were 95.54 and 46.51 for games 1A and 1B, respectively, in complete agreement with the previous results reported by RKDG and RMZ. In switching from the basic game in Phase I to the augmented game in Phase II, as implied by the BP, the participants lost, on average, more than 50 percent of their payoff. The results for the three other conditions were very similar: 94.88 vs. 59.40 in Condition PR, 95.29 vs. 47.51 in Condition PI, and 93.38 vs. 55.57 in Condition PR&PI. Differences among the four conditions further decrease when mean payoffs are only computed across the last twenty rounds in each phase. Using the participant, rather than the group, as the statistical unit of analysis, the null hypothesis of equal median payoffs (in rounds of 21 - 40) of all four conditions in Phase I could not be rejected, Chi-squre(df = 3) = 3.65, ns. The same median test detected a significant difference among the four conditions, Chi-squre(df = 3) = 36.58, p < 0.001. This result is mostly due to a single participant in Condition PR, who consistently deviated from equilibrium play. This participant raised the median payoff to 65. Note, however, that the mean payoff was still below the mean payoff in Phase I. We further note that each of the 144 players earned more in Phase I than in Phase II.

Phase III was mainly introduced to allow the participants increasing their payoffs after the substantial relative losses they all had suffered in Phase II. The mean payoffs across all the 40 rounds in Phase III were 96.32, 96.29, 96.03, and 95.10, for Conditions CONT, PR, PI, and PR&PI, respectively. They do not differ significantly from the ones observed in Phase I by a paired-sample t-test with the group as the unit of analysis, t(7) = 1.42, ns.

Dynamics

Consistent with the results of the previous studies, the participants' route choice patterns provided strong support to the BP. In game 1A, the number of participants choosing route (O, A, D) fluctuated around the equilibrium (i.e., 9). In game 1B, as the play proceeded the number of participants choosing route (O, A, B, D) converged to equilibrium (i.e., 18), although there were a few anomalous participants choosing other than route (O, A, B, D) until the end of the game. It can be concluded that the present study with a Japanese sample basically replicated the previous studies with samples from the U.S. (RKDG, 2005) and H.K. (RMZ, 2006) in terms of the dynamics of play. (Interested readers may send an e-mail to the second author for the figures depicting the dynamics of play in this experiment.)

Commitment to a Failed Course of Action

Table 1 shows that 20 of the 36 participants in Condition CONT expressed preference to switch games and subsequently played the augmented game in Phase II. Almost the same proportions were observed in Condition PR and PI. Only when both personal responsibility and prior investment were combined in Condition PR&PI, did this proportion increase to 0.72. Our hypothesis asserts that preference for playing the augmented game at the second choice point is elicited by preference for this game in the first choice point. The relative frequencies of commitment to a "failed course of action" were 0.05 (= 1/20), 0 (= 0/18), 0.16 (= 3/19), and 0.23 (= 6/26) for Conditions CONT, PR, PI, and PR&PI, respectively. The null hypothesis of equality of the proportions of preference for the augmented game was rejected at the marginal significant level of p = 0.08 (Chi-square(3) = 6.64.)

Table 1. Number of Participants Preferring the Augmented Game (Game 1B) at the First and Second Choice Points

Condition	First Choice Point	Second Choice Point
CONT	20 (0.56)	1 (0.03) [1]
PR	18 (0.50)	0 (0.00) [0]
PI	19 (0.53)	3 (0.08) [3]
PR&PI	26 (0.72)	6 (0.17) [5]

Note. The numbers in parentheses are relative frequencies of participants preferring the augmented game. The ones in brackets are frequencies of participants who also prefer the augmented game at the previous choice point.

To further explore this (weak) effect, we conducted a series of sign tests designed to determine whether the observed frequencies of preference for the augmented game in Conditions PI and PR&PI exceeded the same proportion recorded in Condition CONT. For this purpose, we assumed that the probability of observing this preference choice due to error was 0.05 (= 1/20). The results showed that the proportions of obtaining the observed data patterns in Conditions PI and PR&PI were 0.067 and 0.009, respectively. Thus, the difference between Conditions PI and CONT was only marginally significant, and the one between Conditions PR&PI and CONT highly significant. This result suggests that prior investment, but not personal responsibility, was primarily responsible for the commitment to continue playing the augmented game even after the substantial drop in mean individual payoff due to coordination on the inefficient equilibrium.

Post-experimental Questionnaire

The post-experimental questionnaire included three questions asking the participants which traffic network it would be better to construct in reality. Because the responses to the three questions were highly correlated (Cronbach's coefficient alpha = 0.84), the ratings for the three questions were averaged separately for each participant to yield a single measure of preference rating for game 1B. These individual ratings were then submitted to a 4 (condition) x 2 (preference on the first choice point) ANOVA. The analysis resulted in a marginally significant interaction effect ($F(3, 136) = 2.50$, $p < 0.06$). A series of post-hoc tests showed that the interaction effect was due to the participants in Condition PR&PI who chose the augmented game at the first choice point and expressed a higher preference for it than the participants choosing the basic game ($F(1, 136) = 6.96$, $p < 0.01$). This result is consistent with the previous result showing the strongest support for commitment to the "failing course of action" in Condition PR&PI.

DISCUSSION

We report two major findings. First, our results provide strong support for the Braess Paradox in a different population of participants and a different experimental procedure that allows participants to express their preference to continue choosing routes in either the basic or augmented network. Also, participants in the present study played the basic game twice. As explained in the results section, there was a small effect of prior experience on the dynamics of play. As shown in the previous studies, many participants kept switching between the two routes, and even when the equilibrium (i.e., 9-9 split) was achieved incidentally, it was not maintained in Phase III. More importantly, the results of RKDG, RMZ, and the present study imply that the BP is not just a theoretical curiosity. Rather, and inconsistent with intuition, when one or more links are added to an existing network with appropriately chosen cost parameters, users in different populations, who disregard the negative externalities they impose on others, may selfishly choose routes that are individually and collectively harmful.

Secondly, our results suggest that the effect of prior investment, but not personal responsibility, may be generalized from individual to interactive decision tasks where the reason for the failed course of action is purely strategic (rather than to chance). Additional experiments are called for to determine whether stronger effects may be obtained with prior investments of a larger size. We attribute the failure to generalize the effect of personal responsibility to the large size of our groups. Clearly, the larger the group the more diluted is the personal responsibility of any of its members for the joint outcome, positive or negative. This explanation implies stronger effects of personal responsibility in groups of smaller size, a hypothesis that is experimentally testable.

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APPENDIX A: ITEMS IN THE POST-EXPERIMENTAL QUESTIONNAIRE

Imagine that roads connecting points O and D are planned to be constructed in reality. The currently viable options are networks like Game 1A and Game 1B. Please indicate your opinions regarding the construction of the two types of traffic network.
Item 1: Which network it would be better to construct?
Item 2: Which network would be more effective?
Item 3: Which network would increase the public benefits?

Response Alternatives
Absolutely Game 1A [value = 1]
Game 1A [value = 2]
Neither [value = 3]
Game 1B [value =4]
Absolutely Game 1B [value = 5]

APPENDIX B: DESCRIPTIVE STATISTICS AND CORRELATIONS AMONG THE THREE ITEMS USED IN ANOVA

	Mean	SD	Item 1	Item 2
Item 1	2.38	1.37	--	
Item 2	2.25	1.29	.80**	
Item 3	2.73	1.39	.55**	.58**

Note. ** p<.01.

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