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The equate-to-differentiate's way of seeing the prisoner's dilemma ☆

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Abstract

In this paper we advocate the application of the equate-to-differentiate rule to the prisoner's dilemma. As an alternative to the family of expected utility theory, the equate-to-differentiate approach [S. Li, A behavioral choice model when computational ability matters, Applied Intelligence 20 (2004) 147–163; S. Li, Equate-to-differentiate approach: an application in binary choice under uncertainty, Central European Journal of Operations Research 12 (3) (2004) 269–294] posits that the mechanism governing human risky decision making has never been one of maximising some kind of expectation, but rather some generalisation of dominance detection. In the light of the proposed representation system to describe uncertain alternatives, a decision maker's cognitive representation of the choice alternatives in the prisoner's dilemma situations is described by reference to two dimensions. The choice behaviour is thus modelled as a process in which the individual equates offered differences between alternatives on one dimension, but differentiates another one-dimensional difference as the determinant of the final choice. The predictions derived from these theoretical developments are empirically tested in six experiments with new data introduced to determine if people follow the theoretical prescriptions. In all these experiments, choices could be explained as a consequence of radically simplifying decision information.

Keywords: Sure-thing principle; Sunk cost; Windfall gain; Multi-investment; Non-compatriot player

1. The problem and the approach

von Neumann and Morgenstern [25] formalised the modern expected utility (EU) theory in the course of developing their game theory, the same theory that launched research on decision making under risk. One of

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the most famous of game theory games, prisoner's dilemma illustrates the conflict between individual and group interest. In an archetypal prisoner's dilemma situation, two players separately have two choices, a "cooperative" choice C and a "defective" choice D. The situation is like this: the police arrest two suspects and keep them isolated from each other. Each prisoner is told that if only one of them confesses, the one who confesses will go free but the one who remains silent will receive a severe sentence of 10 years. They are also told that if they both confess, each will receive a moderate sentence of five years, and if neither confesses, each will receive an even milder sentence of one year. The essentials of the game are diagrammed in Table 1 as a payoff matrix. The paradoxical (and problematic) aspect is that both partners could have been better off jointly if they had chosen the cooperative move that both keep quiet. The peculiar irony of the prisoner's dilemma is the fact that rationality in both players produces a far from optimal outcome for both.

Prisoner's dilemma highlights and embodies a conflict between individual and group interests that lies at the heart of many important real-life situations. In this paper we advocate the application of the equate-to-differentiate rule to the prisoner's dilemma. As an alternative approach to human decision making, the equate-to-differentiate model [15,16] is proposed as a means by which the dominance rule can be made applicable in more general cases. Weak dominance states that if alternative A is at least as good as alternative B on all attributes, and alternative A is definitely better than alternative B on at least one attribute, then alternative A dominates alternative B (cf. [8,26]). The model postulates that in order to utilize the very intuitive or compelling rule of *weak* dominance to reach a binary choice between A and B in more general cases, the final decision is based on detecting A dominating B if there exists at least one j such that $U_{Aj}(x_j) - U_{Bj}(x_j) > 0$ having subjectively treated all $U_{Aj}(x_j) - U_{Bj}(x_j) < 0$ as $U_{Aj}(x_j) - U_{Bj}(x_j) = 0$, or, detecting B dominating A if there exists at least one j such that $U_{Bj}(x_j) - U_{Aj}(x_j) > 0$ having subjectively treated all $U_{Bj}(x_j) - U_{Aj}(x_j) < 0$ as $U_{Bj}(x_j) - U_{Aj}(x_j) = 0$, where x_j ($j = 1, \ldots, M$) is the objective value of each alternative on Dimension j (for an axiomatic analysis, see [13]). This decision rule proposes that, in one-shot two-person PD games, much human choice behaviour involves a process in which people seek to equate offered differences between alternatives on one player's payoff dimension, so as to differentiate another player's payoff dimensional difference as the determinant of the preferred alternative [9].

To appreciate how this decision approach helps make sense of choice under risk and uncertainty, we begin by analysing two well-demonstrated violations of Savage's [20] sure-thing principle (STP): one involves behaviour under risk and the other involves behaviour under competition. Both are linked historically and theoretically to von Neumann and Morgenstern's monumental *Theory of Games and Economic Behavior* (1947).

Let us first consider the well-known Allais paradox [1]. The observed preference pattern in Allais' first pair of choices ($1M$, 1.0) vs ($5M$, .10; $1M$, .89; 0, .01), implies: $u(1M) > .10u(5M) + .89u(1M)$ or $(1-.89)u(1M) > .10u(5M)$, while the preference pattern in the second pair of choices ($1M$, .11; 0, .89) vs ($5M$, .10; 0, .90), implies the reverse inequality: $.11u(1M) < .10u(5M)$.

Table 1
A typical payoff matrix representing the Prisoner's dilemma

			Player B	
			p_D	$p_C = 1 - p_D$
			Defect	Cooperate
Player A	p_D	Defect	5 (A) / 5 (B)	0 (A) / 10 (B)
	$p_C = 1 - p_D$	Cooperate	10 (A) / 0 (B)	1 (A) / 1 (B)

Note: You find the payoff of A in upper left corner and the payoff to B in the lower right corner.

If Allais' [1] two pairs of choice problems are represented, for convenience, by only using two dimensions (the best and the worst possible outcome dimensions), the equate-to-differentiate account can most easily be understood with the aid of a graphical representation, as shown in Figs. 1 and 2. We can see that the construction of the gambles will render the equating of difference on the "best possible outcome" dimension easier than that on the "worst possible outcome" dimension for the first pair of choices, but vice versa for the second, assuming a negatively accelerated (concave) utility function. In other word, regardless of the fact that the gambles in the second pair are just the gambles in the first pair, each minus a constant which is common to the gambles being considered, the gamble parameters are designed to encourage participants to differentiate the subjectively greater difference (the difference between the bad-outcome ($0) of Alternative B and the certain outcome ($1m) of Alternative A) on the *worst* possible outcome dimension in the first pair of choices, but to differentiate the subjectively greater difference (the difference between the good-outcome ($5m) of Alternative D and the good-outcome ($1m) of Alternative C) on the *best* possible outcome dimension in the second pair. The paradox arises because the final choice is *not* consistently based on a single fixed dimension in each pair of choices.

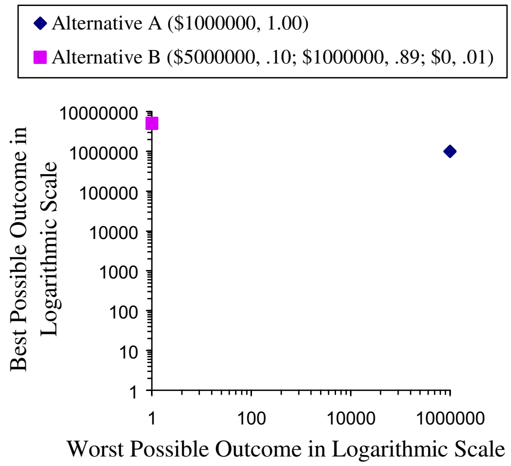

Fig. 1. The representation of Allais' first pair of choice problems (represented with omitting the second best possible outcome) by applying a logarithmic utility function.

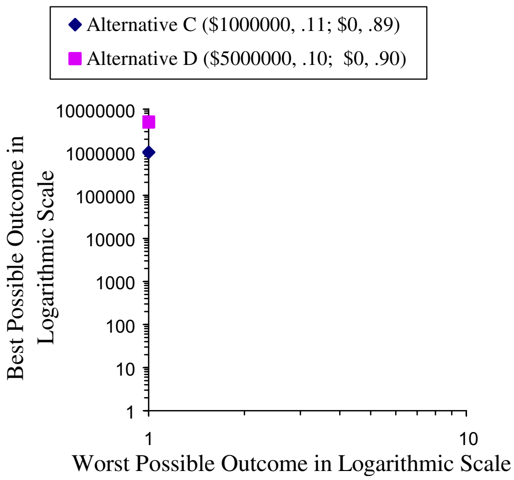

Fig. 2. The representation of Allais' second pair of choice problems by applying a logarithmic utility function.

Secondly, let us turn to Shafir and Tversky's [22] disjunction effect, which demonstrates a violation of Savage's sure-thing principle in the prisoner's dilemma game, where many participants compete when they know that the opponent has competed, and when they know that the opponent has cooperated, but cooperate when they do not know the opponent's response.

In consideration of a simpler way of representing the tension between what is good for the decision maker and what is good for the group, we arbitrarily assign two dimensions, "one's own payoff dimension" and "other player's payoff dimension", to represent the prisoner's choices. When faced with a situation of knowing the other player's decision, there is only one column of the PD table which is relevant. The choice between C and D, whether the other player has decided to cooperate (see Fig. 3) or to compete (see Fig. 4), always involves a simple conflict because D is better on one's own dimension whilst C is better on the other player's

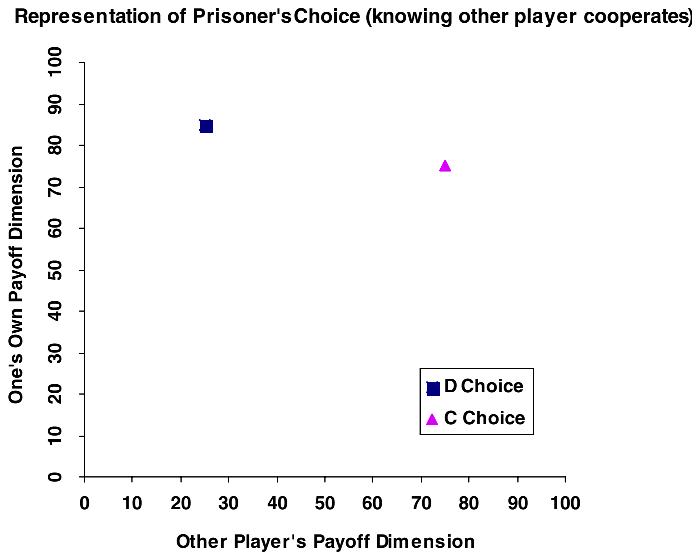

Fig. 3. The payoff matrix is the one adopted by Shafir and Tversky [22] study on disjunction effect.

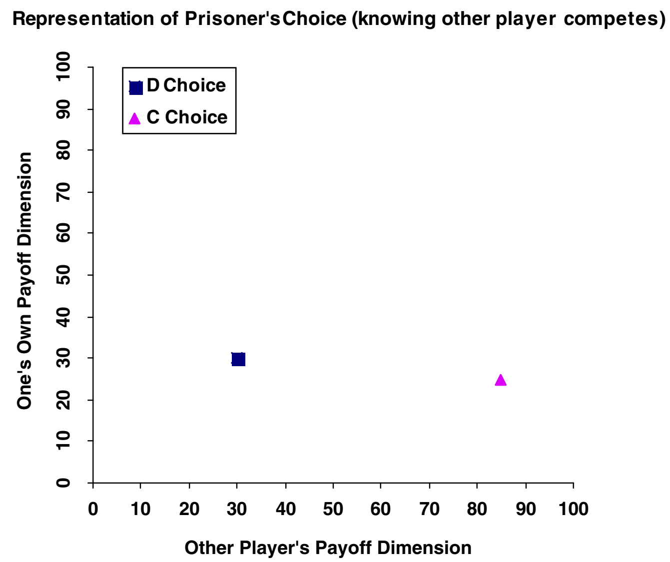

Fig. 4. The payoff matrix is the one adopted by Shafir and Tversky [22] study on disjunction effect.

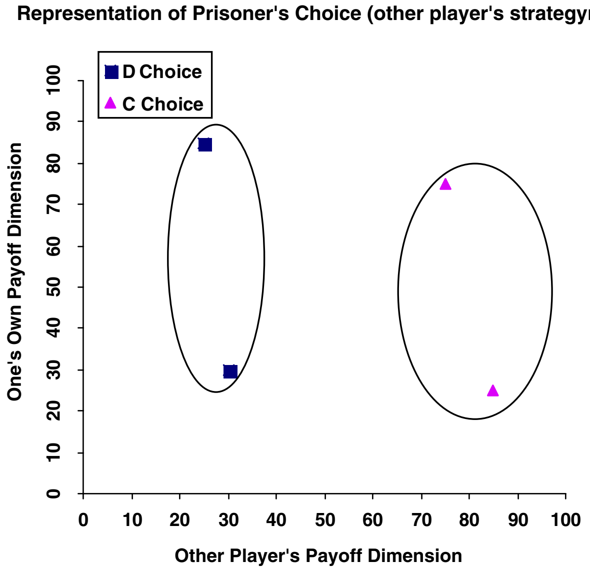

Fig. 5. The payoff matrix is the one adopted by Shafir and Tversky [22] study on disjunction effect.

dimension. If the equate-to-differentiate hypothesis works, we expect, in such a case of conflict, that people tend to base their final choice on only one dimension, i.e., either on one's own possible payoff dimension or on the other player's possible payoff dimension, having treated the values on the other dimension as if they were equal.

When faced with a situation of *not* knowing the other player's decision, both columns of the PD table are relevant. However, attention should be drawn to the fact that the adding of the second column information does change the simple conflict structure (see Fig. 5). What we really ascertain is that the ordinal relation between C and D remains unchanged along the other player's dimension but is changed along one's own dimension. That is, on the other player's payoff dimension, move C jointly dominates move D in the sense that whatever the other player's decision is, C is always better than D. On one's own payoff dimension, however, move D does *not* jointly dominate move C, in the sense that not every possible payoff of move D is better than that of move C. In such a case, we expect that compared with the two conditions where the other player's strategy was known, the equating effort would be similarly made on the other player's dimension but more easily made on one's own dimension. As a result, a number of players who are unwilling to choose C when knowing the other's strategy would possibly turn out to make a cooperative decision when not knowing the other's strategy.

Taken together, the violations alluded to in the preceding paragraphs (on decision making under risk and under competition) are both interpreted by the equate-to-differentiate model as an indication that the equate-to-differentiate strategy (deciding which dimensional difference is to be equated and which is to be differentiated) is caused to change by the experimental conditions applied. It is therefore expected that when an effort is made to increase the subjective difference on the other player's dimension but reduce the subjective difference on one's own dimension, the dilemma (the equilibrium payoff is not Pareto optimal) will vanish or even be reversed. The steeper the curve of the other player's utility, the greater the difference on the other player's payoff dimension, and the larger the region of choice C will be. Thus, regardless of whether cooperative or defective behaviour is assumed to be the paradox, both types of behaviour will be found in experimental studies and both types will be, and have to be, explained.

To test this, the following experiments were designed to test PD games in its standard version, i.e., when not knowing the opponent's strategy, by manipulating the dimensional differences. In particular, the manipulation was performed from changing a common payoff (Experiment 1), to changing a payoff matrix (Experiment 2), to changing utility curvature by placing sunk cost (Experiment 3), to changing utility curvature by placing windfall gains (Experiment 4), to changing utility curvature by shifting the conditions of single vs multiple-investment (Experiment 5) and to changing utility curvature by shifting the relationship of the two players (Experiment 6). It was hoped that the testing of the compliance of the equate-to-differentiate model with the resulting data would provide additional insights into the underlying cognitive mechanisms that govern choice behaviour in conflict situations.

2. Six experiments and their results

2.1. Experiment 1

Our first conjecture was that if the final decision is only based on one-dimensional difference, then it is possible to shift the player's choice by changing a common payoff shared by the two offered alternatives. Such a way of manipulation is somewhat similar to that used in the Allais paradox, where the alternative chosen appears to be dependent on the value of the common outcome. In doing this we devised two hypothetical questions. One contained a scenario in which a common outcome is added to the player's own payoff; the other contained a scenario in which a common outcome is added to the other player's payoff. When a common outcome was added proportionately to the payoff matrix, the payoff difference would be moved from the lower to the upper range along the payoff dimension. The underlying assumption is that, the payoff difference on the upper side is likely to be judged to be less than that on the lower side, because the utility function which transforms the objective payoffs is a negatively accelerated (concave) one-to-one mapping function over the range of concern. Thus, what appears to be equivalent are the payoffs with the common outcome added. Participants who select to compete rather than to cooperate would consider the payoffs along the "other player's" dimension rather than "one's own" dimension to be *subjectively* equivalent or "equated", and vice versa. If the equate-to-differentiate's one-dimensional difference account is correct, then adding a common outcome on the "equated" dimension will *not* change the equate-to-differentiate strategy and hence the final decision but a common outcome on the "unequated" dimension will. The present experiment represents an attempt to carry out such a test.

2.1.1. Method

2.1.1.1. Participant. The participants in the present experiment were 84 undergraduate students from various disciplines at the University of New South Wales. They participated to fulfill course requirements. The participants were unfamiliar with game theory or research on decision-making prior to the study.

2.1.1.2. Materials and procedure. In this and all subsequent experiments, the stimuli were presented in booklets.[1] The PD scenario and matrix used by Bolle and Ockenfels [4] was used almost in its original form (Question 1), and also modified to include an additional decision situation (Question 1A or 1B). Both the original and the added situations concerned a choice between ordering a large size and a small size of bottle filling machines. The modified problem, which we might call the Bottle Problem, reads as follows:

Question 1. Imagine you and *X* are the only owners of sources of mineral water in the country. There are no imports of mineral water. The price of mineral water is the same for both you and the other supplier. The larger the aggregate supply, the lower the selling price is.

There are two sizes of bottle filling machines. ***A*** signifies the large machine, ***a*** signifies the small machine. If both suppliers order the small machine, then a small quantity will be supplied and the market price of mineral water will be high. Both producers will then have a profit of 50. If both order the large machine, then a larger quantity will be produced and the market price will be lower. Both producers will then have a profit of 10. If

[1] As pointed out by an anonymous referee, players in this experiment and in all subsequent experiments were faced only with hypothetical questions. This, on one hand, might raise concerns of some readers. On the other hand, similar experiments have shown that there were no differences between hypothetical and real payoffs when evaluating the disjunction effect and testing the sure-thing principle in repeated gambles (e.g. [7]).

you order the large machine and X orders the small one, then you will have a profit of 75 and X a profit of 0, and vice versa.

Both you and X decide at the same time, i.e., without knowing the decision of each other to order a particular bottle filling machine. The results of these are indicated in the following table. In every box, your profit is shown in the upper row and the profit to the other producer in the lower row.

		Other Producer's Choice	
		a	***A***
Your Choice	***a***	You: 50 Other: 50	You: 0 Other: 75
	A	You: 75 Other: 0	You: 10 Other: 10

How would you decide? Please tick the ***A*** (the larger machine) or ***a*** (the small machine) of your choice and indicate your confidence about your decision:

Choice: *A* **a** / **Confidence Rating**: 1 2 3 4 5 6 7

Question 1A. Now that you have made your decision, you learn that the above results of decisions made by the suppliers are simply determined by ignoring whether the new machines (either ***A*** or ***a***) are matched with the assembly line or not. If one's new machine is matched with the existing assembly line while the other's is not, an extra profit of 30 will be added to the owner of the matched machine.

Suppose now you know your existing assembly line is matchable but you don't yet know the decision of the other producer. The re-estimated results of decisions of the suppliers are indicated in the following table:

		Other Producer's Choice	
		a	***A***
Your Choice	***a***	You: 50 + 30 Other: 50	You: 0 + 30 Other: 75
	A	You: 75 + 30 Other: 0	You: 10 + 30 Other: 10

How would you decide? Please tick the ***A*** (the larger machine) or ***a*** (the small machine) of your choice and indicate your confidence about your decision:

Choice: *A* **a** / **Confidence Rating**: 1 2 3 4 5 6 7

Question 1B. Now that you have made your decision, you learn that the above results of decisions made by the suppliers are simply determined by ignoring whether the new machines (either ***A*** or ***a***) are matched with the assembly line or not. If one's new machine is matched with the existing assembly line while the other's is not, an extra profit of 30 will be added to the owner of the matched machine.

Suppose now you know *X*'s existing assembly line is matchable but you don't yet know the decision of the other producer. The re-estimated results of decisions of the suppliers are indicated in the following table:

		Other Producer's Choice	
		a	***A***
Your Choice	***a***	You: 50 Other: 50 + 30	You: 0 Other: 75 + 30
	A	You: 75 Other: 0 + 30	You: 10 Other: 10 + 30

How would you decide? Please tick the ***A*** (the larger machine) or ***a*** (the small machine) of your choice and indicate your confidence about your decision:

Choice: *A* **a** / **Confidence Rating**: 1 2 3 4 5 6 7

The actual questionnaire presented to participants in this experiment contained only two questions, either Question 1 and Question 1A or Question 1 and Question 1B. About half of the participants responded to Questions 1 and 1A and another half Questions 1 and 1B. Participants were urged to give the problem a few minutes thought prior to responding. Participants were also instructed that there were no right or wrong answers, and that the experimenters were interested in the participant's own, thoughtful answer. When the completed questionnaires were collected, the participants were then debriefed.

2.1.2. Results and discussion

The violation of sure-thing principle has been viewed by Tversky and Kahneman [24] as a result of its application being not transparent. They concluded that, like other normative principles of decision making, STP is generally satisfied when its application is transparent, but is sometime violated when it is not. The term 'non-transparent' is, however, itself a subject of some contention. It has referred to the framing illusion [24] which masks the common outcome shared by the two alternatives, and to the presence of uncertainty [22] which makes it difficult for participants to focus sharply on any single branch of the relevant decision tree. In the present experiment, a cautious attempt has been made to make these transparency variables in favour of the consistent choices. That is, conditions have been set up to avoid masking the commonality and to hold the degree of (un-) certainty unchanged.

There are two possible ways of seeing the extra profit of 30 when thinking through an event tree. One is to see it as a certain or riskless outcome, presumably an irrelevant coordinate that can be cancelled. The other is to incorporate it into the uncertain outcomes of each branch of decision tree as shown in Fig. 6. By using such a tree diagram Shafir and Tversky [22] offer an indicative explanation on the disjunction effect. That is, the majority of participants choose to compete at the upper branch (when the other cooperates) as well as at the lower branch (when the other competes). Contrary to STP, however, many cooperate when they do not know on which branch they are. Shafir and Tversky [22] suggest that the presence of uncertainty make it difficult to focus sharply on any single branch; broadening the focus of attention in this way results in a loss of acuity. The failure to appreciate the force of STP, therefore, is attributed to people's reluctance to consider all the outcomes, or to their reluctance to formulate a clear preference in the presence of uncertainty about those outcomes.

It should be noted that the common consequence, the extra profit of 30, in this task was described "transparently" by (1) using wording which stressed the commonality: "If one's new machine is matched with the existing assembly line while the other's is not, an extra profit of 30 will be added to the owner of the matched machine" and by (2) isolating the common outcome shared by presenting the common outcome in a separated formulation (e.g., 50 + 30) rather than in a combined formulation (e.g., 80) which simplified the presentation

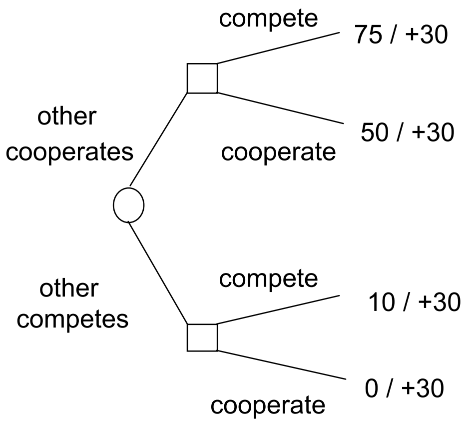

Fig. 6. A tree diagram illustrating the disjunction effect. Decision nodes and chance nodes are denoted by squares and circles respectively. (The authors thank Li-Bo LI, an UNSW Actuarial Student, for depicting this diagram.)

but masked the presence of the common outcome. If such presentation can help to make the extra profit of 30 clearly stand out, then it could be discarded by cancellation operation regardless of whether it is seen as a certain or an uncertain outcome. Be that as it may, it appears that the participant will think through exactly the same event tree when faced with Questions 1 and 1A (1B).

On the other hand, if the extra profit of 30 is perceived as not able to be cancelled, the participant will think through two different event trees which differ in the outcomes of each branch. Such a difference is seemingly unimportant to the disjunctive effect's 'uncertainty' account, but is important to equate-to-differentiate's one-dimensional difference account. It is vital to the equate-to-differentiate hypothesis because the equate-to-differentiate strategy will be relatively changed by varying the dimensional difference. It is unimportant to the transparency hypothesis because the addition of an extra 30 profit does not yet change the required condition for violations of STP in a simple disjunctive situation, in the sense that it does not change the structure of the tree, such as the number of branches, the number of outcomes of each branch, the ordering of each outcome in the tree, and the degree of uncertainty. Shafir [21, p. 404] argued that a necessary condition for violations of STP in simple disjunctive situations is people's failure to see through the underlying disjunctions. If the cooperative behaviour in the PD games arose because the failure to consider appropriately each of the relevant branches of a decision tree, then the failure rate, and hence the cooperation rate, will remain approximately unchanged across the present two choices.

Moreover, it is important to note that the decision tree on which the disjunctive effect presumably depends completely ignores the other player's outcomes. It is true that the two trees are different in the branch outcomes when the extra profit of 30 is added to one's self and when no extra profit is added, but the two trees will remain the same when the extra profit of 30 is added to the other player. If Tversky and Shafir's explanation of the disjunction effect in terms of non-consequentialist decision making is itself sufficient to explain choice behaviour under non-transparent conditions, it is then reasonable to predict that the addition of the extra profit of 30 to one's self is more likely to cause choice reversal than the addition of an extra profit of 30 to the other player does, but not otherwise.

As such, whether the extra profit of 30 is seen as a certain outcome or an uncertain outcome, and whether it is seen as cancellable or not, the transparency account will tend to suggest that the decision outcomes across the two choices will be consistent: people who cooperate (compete) in Question 1 will remain cooperative (competitive) in Question 1A (1B).

For purposes of data analysis, a variable called *strength of choice*, which was the product of the variables choice (+1 for selecting large machine ***A*** and −1 for selecting small machine ***a***) and confidence of judgment (ranging from 1 to 7), was constructed. The resulting variable ranges from −7 to +7. A positive score on the new variable indicates that ***A*** is more likely to be chosen and a negative score indicates that ***a*** is more likely to been chosen. An analysis of variance was used to examine the strength of choice. Fig. 7 shows the mean

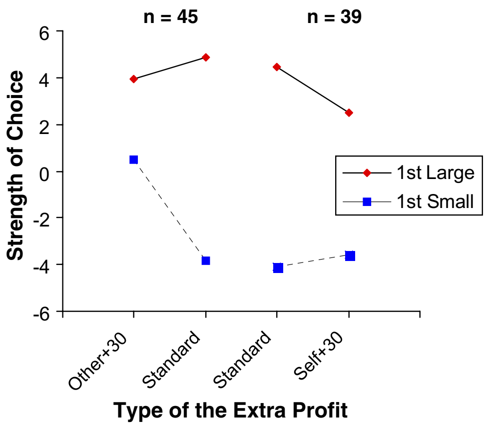

Fig. 7. Mean *strength of choice* by pattern of responses to the trial and by extra profit, where the participants' responses to Question 1 and 1A version ($N = 39$) are shown in the right half of the diagram while responses to Question 1 and 1B version ($N = 45$) are shown in the left half of the diagram.

strength of choice we actually observed, by type of additional profit (with additional profit vs without additional profit) and pattern of first trial (participants whose first choice was large machine vs participants whose first choice was small machine).

Note that there was indeed a significant two-way interaction (type of additional profit × pattern of first trial), $F(1,37) = 7.74$, $p < .01$, revealed by participants who responded to Question 1 and 1A version ($N = 39$). The character of the interaction was consistent with that predicted by the equate-to-differentiate hypothesis. That is, the decisions made by participants whose first choice was small machine were unaffected by whether the additional profit was absent or present, $t(13) = 1.69$, ns, while the decisions made by participants whose first choice was large machine changed markedly when the additional profit was added, $t(24) = 2.56$, $p < .02$. In the introduction, it is reasoned that the adding of additional profit will shift the original choice depending on whether the additional profit is added to the "equated" or "unequated" dimension. The highly significant two-way interaction corroborates this line of reasoning.

The results found in Question 1 and 1B version ($N = 45$) are similar. The two-way interaction (type of additional profit × pattern of first trial), which is expected to reveal the opposite outcome compared with Question 1 and 1A version, was significant, $F(1,43) = 22.94$, $p < .001$. That is, it was the decisions made by participants whose first choice was large machine that were unaffected by whether the common symptom (one flexion crease) was absent or present, $t(32) = 1.81$, ns, while the decisions made by participants whose first choice was small machine changed markedly when the common one flexion crease was added, $t(11) = 3.77$, $p < .01$. That is, the consistent judgments between the presence and absence of the additional profit results from Small-Machine-first-Chosen participants but not from Large-Machine-first-Chosen participants. The more profound two-way interaction for Question 1 and 1B than for Question 1 and 1A version suggests that, it is easier to shift the differentiating from other's payoff dimension (selecting ***a***) to one's own dimension (selecting ***A***) than from one's own to an other's. As the adding of extra profit to other player's payoff rather than to self payoff would cause the stronger choice reversal, the decision tree account provided by Shafir and Tversky [22] will be mute on the question of what makes the extra profit work.

This interesting interaction can also be seen from Table 2 where, among those who chose large machine first, none of the 33 subjects shifted their choices when the extra profit of 30 was added to the other producer but seven out of 25 shifted their choices when the extra profit of 30 was added to oneself. On the contrary, among those who chose small machine first, we see that six out of 12 subjects shifted their choices when the extra profit of 30 was added to the other producer but two out of 14 shifted their choices when the extra profit of 30 was added to oneself. In both cases, a 2 (type of additional profit) × 2 (response) χ^2 test revealed a significant relationship between type of additional profit and response. Thus, the hypothesis that shifts in choice can be attributed to the change of equate-to-differentiate strategy is supported.

Table 2
Choice by pattern of responses to the trial and by extra profit

Type of additional profit	Pattern of responses to the first trial without an extra profit of 30			
	Large-Machine-first-Chosen		Small-Machine-first-Chosen	
	a (the small machine)	***A*** (the larger machine)	***a*** (the small machine)	***A*** (the larger machine)
An extra profit of 30 will be added to you	7	18	12	2
An extra profit of 30 will be added to the other producer	0	33	6	6
	$\chi^2(1) = 10.51$, $p < .01$		$\chi^2(1) = 3.87$, $p < .05$	

In conclusion, when the transparency variables were manipulated to advocate or maintain the consistent choices while the payoff differences were manipulated to promote the inconsistent choices, our data favoured the equate-to-differentiate hypothesis over the transparency account and added to a growing body of evidence that the presence of STP did not depend on the transparency of the information presentation [18,5].

2.2. Experiment 2

The fact that a common outcome being added to the player's own payoff and to the other player's payoff does make the participants behave differently in a ‘‘common consequence’’ situation led us to doubt that the participants might also behave differently if the payoff differences are manipulated to change in a more direct way.

To address this issue, two mirror-image games were constructed in the present experiment. The structure of one game was to make the other's payoffs less differentiable while the other one was to make one's own payoffs less differentiable. A testable implication of the model is that, if one and only one player's payoff difference were narrowed (an extreme case being that either competition or cooperation will make no difference to that player's payoffs), it would render the final decision easier to base on other player's payoff dimension. That is, when one's own payoff difference was narrowed, the differentiating process would be encouraged to carry out on the other player's payoff dimension, i.e., the payoff with greater gain value (C) is more likely to be selected. Likewise, when the other player's payoff difference was narrowed, the differentiating process would be encouraged to carry out on one's own payoff dimension, i.e., the payoff with greater gain value (D) is more likely to be selected.

2.2.1. Method

2.2.1.1. Participants. Seventy-one undergraduates from the Fujian Finance and Accounting Management Cadre College volunteered to participate in the present experiment.

2.2.1.2. Materials and procedure. The problem used was also a variant of Bolle and Ockenfels' [4] Bottle Problem. It read as follows:

B_1 and B_2 are the only owners of sources of mineral water in the country. There are no imports of mineral water. The price of mineral water is the same for both suppliers. The larger the aggregate supply is, the lower the price.

There are two sizes of bottle filling machines. ***A*** signifies the large machine, ***a*** signifies the small machine. If both suppliers order the small machine then a small quantity will be supplied and the market price of mineral water will be high. Both producers will have a larger profit. If both order the large machine then a larger quantity will be produced and the market price will be lower. Both producers will have a smaller profit. If B_1 orders the large machine and B_2 the small one, then B_1 will have a largest profit but B_2 a profit of 0, and vice versa.

Both B_1 and B_2 decide at the same time, i.e., without knowing the decision of each other to order a particular bottle filling machine. The results of these are indicated in the following table. In every box, your profit is shown in the upper row and the profit to the other producer in the lower row.

If you were B_1, how would you decide?

		Other Producer's (B_2) Choice	
		a	***A***
Your (B_1) Choice	***a***	You: 50 Other: 50	You: 40 Other: 55
	A	You: 55 Other: 0	You: 45 Other: 10

Please indicate your choice by circling a number on the nine-point scale given below, where 1 = Definitely choosing ***a*** (the small machine); 5 = Indifferent; 9 = Definitely choosing *A* (the larger machine):

1 2 3 4 5 6 7 8 9

If you were B_2, how would you decide?

		Other Producer's (B_1) Choice	
		a	***A***
Your (B_2) Choice	***a***	You: 50 Other: 50	You: 0 Other: 55
	A	You: 55 Other: 40	You: 10 Other: 45

Please indicate your choice by circling a number on the nine-point scale given below, where 1 = Definitely choosing ***a*** (the small machine); 5 = Indifferent; 9 = Definitely choosing *A* (the larger machine):

1 2 3 4 5 6 7 8 9

Note that in order to make the game a conventional prisoner's dilemma, it has been assumed that the two players receive R points if both cooperate and only P points if both defect; but a defector exploiting a cooperator gets T points, while the cooperator receives S (with $T > R > P > S$ and $2R > T + S$). Although the present experiment is based on an asymmetric game for a purpose of testing the "one-dimension" account, the two payoff matrixes offered satisfy the requirement alluded.

A within-subjects experimental design, with the order of the problem presentation being counterbalanced, was utilized. That is, the problems were presented in two different versions. Approximately half of the participants were randomly assigned to respond to either of the two versions. The two versions differed only in the order of choice presentation. Participants were asked to firstly act as B_1 in one version while to act firstly as B_2 in the other.

2.2.2. Results and discussion

The results obtained showed that participants were more likely to order the small size of the bottle filling machine when one's own payoffs were narrowed ($M = 5.38$) than when the other's payoffs were narrowed ($M = 6.94$). This difference was statistically significant, $t(70) = 2.77$, $p < .01$. The observed difference in cooperative–competitive behaviour between the two games was generally consistent with the predictions of the one-dimension account.

2.3. Experiment 3

The fact that the likelihood of cooperating, in the first two experiments, is changed by varying the relative dimensional difference suggests a new guideline as to the route further research might take. In searching for such a relative payoff change in what are perhaps more latent terms, the manipulation of utility curvature of the two players is considered in the following experiments. In this experiment, in particular, the impact of sunk cost on utility curvature was then assumed and tested.

The sunk cost effect manifests itself in a greater tendency to continue an endeavour once an investment in money, effect, or time has been made [2,19]. There are several potential explanations available for explaining such a paradoxical behaviour phenomenon. We can see that, the sunk cost effect does provide a mechanism for describing why decision makers stick with options to which they have made initial commitments; however, it does not provide any mechanism for explaining or predicting the decision outcome if the payoff matrix offered in the PD game is seen as a future return yielded by a prior investment. It would therefore be interesting to see what would happen if we placed sunk cost within the context of PD games.

Yet the equate-to-differentiate way of seeing the sunk cost effect in the PD game is quite simple: a prior investment will cause the investor's utility curve to become steeper, thus rendering the differentiation of difference between options on the investor's payoff dimension easier than on the other player's. To test this we devised two alternative decision conditions. One was that the player has made prior investments; the other was that the player has *not* made prior investments.

2.3.1. Method

2.3.1.1. Participants. The participants in this study were 60 volunteers who were senior executives working at the Bank of China, Fujian Branch.

2.3.1.2. Materials and procedure. The problem considered by participants was a variant of the original Bottle Problem (Question 1 of Experiment 1). The only difference was that the participants were asked to choose the same payoff matrix offered by the original problem twice, given that the participants were faced with two imaginary situations where the proposed sunk cost was manipulated. Following is the additional statement and instruction:

> Both Producers' backgrounds are similar except that, before the mineral resource was developed, one producer had made a sizeable investment in time, money and effect to advertise the water and protect the nearby environment whereas the other producer had not.
>
> - Suppose you are the producer who had made a lot of investment! How do you decide?
> - Suppose you are the producer who had *not* made a lot of investment! How do you decide?

For this and all subsequent experiments, participants were asked to indicate their choice by circling a number on the nine-point scale as were in Experiment 2.

A within-subjects design was also used. The order of the question presentations was counterbalanced in two different versions (sunk/non-sunk and non-sunk/sunk versions). Approximately half of the participants were randomly assigned to respond to each of the two versions. No participants responded to more than one version. When the completed questionnaires were collected, the participants were then debriefed.

2.3.2. Results and discussion

The results obtained showed that participants who presumably had made a sizeable investment were more likely to order larger machine ($M = 7.53$) than those who presumably had not ($M = 5.93$). This difference was statistically significant, $t(59) = 3.29$, $p < .01$. Thus, it appears that the cooperative–competitive behaviour is affected by the sunk costs in the Prisoner Dilemma game. The demonstration of "have too much invested to quit" in preferential choice turns out to be, in this case, one of "have too much invested to cooperate" in choice under competition, a finding which contradicts the normative principles that imply that decision makers' choices should be affected solely by the costs and benefits that are expected to arise from the choice of each option.

In addition, Tan and Yates' [23] research suggests that sunk cost effects are mitigated by an important factor that is often present in real-world decision situations but omitted in most sunk cost research paradigms—explicit estimates of the future returns the given options might yield. However, the present data indicate that the “explicit return estimates” account could be questioned in that, the presumed investment is influencing participants’ choice markedly, even though the future return or benefits are well presented in the present choice situation.

2.4. Experiment 4

Normative economic theory suggests that the consumer might consider the purchase of goods and services to be a contest between the worth of the dollar in hand and the worth of the item to be bought. The purchase should be made if the item is deemed more valuable than the dollar, whereas the purchase should not occur if the dollar is considered to be worth more than the item. However, psychological studies on windfall gains [3,6] and money-earning time and money-exchanging route [14] suggest that the axiomatic nature of this analysis is questionable and that the history of the dollar seems to influence participant’s willingness to part with it.

In this experiment, we placed the windfall gains in the PD game situation. This was not intended to further enhance our understanding of why the source of the fund influenced consumer’s preferences, but sought to test its possible role in varying the utility curvature of the players. We assume that, in the PD game, people who are offered windfall payoffs would show more cooperation than people who are offered *non*-windfall payoffs, just because the subjective value of windfall payoff would be less than the subjective value of *non*-windfall payoff.

In determining what defines a gain as a windfall, it has become commonplace to acknowledge that the key feature of windfall gains is that such gains are unearned. According to Arkes et al. [3], a defining characteristic of a windfall gain seems to be its unanticipated status. Accordingly, a scenario was designed in the present experiment. It is hypothesised that when the gain is earned rather than *un*earned, it would influence the decision in a way much like the sunk cost did.

2.4.1. Method

2.4.1.1. Participant. Fifty students majoring in Accounting at the Fujian Building Material Engineering Institute volunteered to participate in this experiment.

2.4.1.2. Materials and procedure. The cover story and the payoff matrix used in Experiment 4 was identical to that used in Experiment 3, which examined the sunk cost effect, except that the added statement and instruction were replaced by the following:

> Both Producers’ backgrounds are similar except that, one producer has to accumulate money by hard work to have both the water and the machine while the other producer does not. This is because the other producer has something to do with a recent grand manoeuvre: he was compensated a lot of money by the military for commandeering his land and the mouth of a spring was unearthed by accident during the manoeuvre.
>
> - Suppose you are the producer who gained the water resource and machine because of the manoeuvre! How do you decide?
> - Suppose you are the producer who gained the water resource and machine because of the primitive accumulation of capital! How do you decide?

Using a between-subjects design, the problem was presented to participants in two different versions, which counterbalanced the order of the two questions presented. About half of the participants received the version of windfall/*non*-windfall order while the other half the *non*-windfall/windfall order. No participants responded to more than one version. When the completed questionnaires were collected, the participants were then debriefed.

2.4.2. Results and discussion

An analysis comparing the two conditions exhibited a marked preference difference between ordering the large and the small machines. Participants were more likely to cooperate in windfall situation ($M = 4.60$) than in *non*-windfall situation ($M = 7.12$). This difference was statistically significant, $t(49) = 3.35$, $p < .01$. It appears that the tendency to order a large or small machine is different according to whether the player is spending windfall or *non*-windfall funds. The result demonstrates an additional violation of the fundamental economic assumption of fungibility—the proposition that the source of money should make no difference in its consumption [25, p. 8].

2.5. Experiment 5

In this experiment, we varied the utility curvature by manipulating the conditions of single-investment and multiple-investment. The rationale behind such a manipulation is that having all the eggs in one's own one basket will make the investor more sensitive to the payoff difference while all the eggs in the other investor's one basket will not. We predict that, when the condition under consideration is changed from that of self-single-investment to that of self-multiple-investment, the player's utility curvature will become flatter. Such a change will make the payoff difference relatively less differentiable, thus increasing the likelihood of a decision which emphasises the other player. It is worth noting that, although they apparently look the same, the manipulation of ''multiple-investment'' is not an equivalent to that of ''too much invested to quit'' in the sunk cost effect. This is because the sunk cost effect involves people being more risk-seeking after making an initial investment, which will make the investor's utility curve steeper (i.e., seeing gains and losses more sensitively), compared with that, the windfall effect will make the utility curve flatter (i.e., seeing gains and losses less sensitively).

2.5.1. Method

2.5.1.1. Participants. Seventy staff members of the Bank of China enrolled in the short economics and credit courses held at Fuzhou in Spring 1997 participated. They all participated as volunteers.

2.5.1.2. Materials and procedure. As used in Experiment 4, the Bottle Problem considered by the present participants was also identical to that used in Experiment 3 except that the added statement and instruction were replaced by the following:

> Both producers' backgrounds are similar except that one producer invested all his/her money in producing the mineral water, whereas the other producer has also made investments in some food industries other that the mineral water.

- Suppose you are the producer who has invested all your money in the mineral water business! How do you decide?
- Suppose you are the producer who has invested in other food industries as well! How do you decide?

The problem was presented to participants in two different versions, which counterbalanced the order of the two questions presented. About half of the participants received the version of single/multiple-investment order while the other half the multiple/single-investment order. No participants responded to more than one version.

2.5.2. Results and discussion

The results show that single-investment and multiple-investment conditions differ in their impact on the tendency to cooperate in PD games. In agreement with the equate-to-differentiate approach's prediction, participants were more likely to cooperate in a self-multiple-investment situation ($M = 5.74$) than in a self-single-investment situation ($M = 7.00$). This difference was statistically significant, $t(69) = 2.94$, $p < .01$. Thus, it appears that participants were affected by the number of investments, a sort of the history of the funds.

2.6. Experiment 6

In this experiment, we attempted to explore another way of varying the utility curvature—changing the relationship of the two players. It is hypothesised that the utility curves of self and the other player will become closer when the other player's status is changed from a non-compatriot to a compatriot, as depicted in Fig. 8.

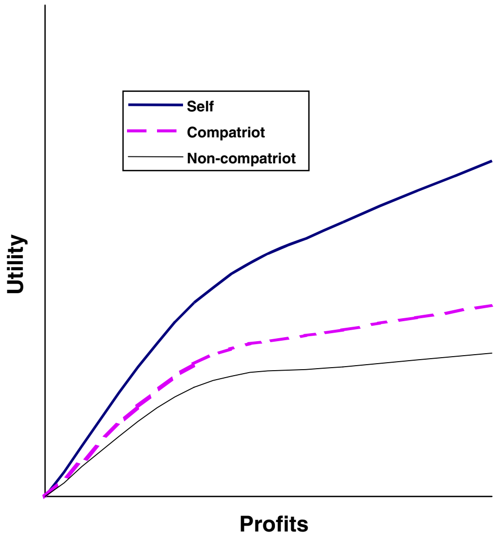

Fig. 8. Hypothesised relation between profits and utility or subjective value as a function of the status of the players.

If the equate-to-differentiate account were correct, those whose competitor was a compatriot would be more likely to cooperate than those whose competitor was a non-compatriot, for the reasons outlined in the previous experiments.

2.6.1. Method

2.6.1.1. Participants. Booklets were administered to 98 Chinese participants and 80 Australian participants. The Chinese were students from the Psychology Department of Zhejiang University while the Australians were students from University of New South Wales who were enrolled in General Psychology courses.

2.6.1.2. Materials and procedure. The Bottle Problem which participants were faced with was identical to that used in Experiments 3, 4 and 5 except that the added statement and instruction were replaced by the following, where the italicised words were for the Australians only while the words in brackets were for Chinese only.

> Imagine that you are an *Australian* (Chinese) investing in *an Asian country* (Australia). You and *X* (who may be either a Chinese or an Australian) are the only owners of sources of mineral water in the country.
> - If the other supplier *X* is not a local *Asian* (Australian) but an *Australian* (Chinese) compatriot, how would you decide?
> - If the other supplier *X* is not an *Australian* (Chinese) compatriot but a local *Asian* (Australian), how would you decide?

This, therefore, is a $2 \times (2)$ between groups repeated factorial design, involving the participant's group (self is Australian vs self is Chinese) and the other player's status (the other is a compatriot vs the other is a non-compatriot). The order of the question representing is counterbalanced both in the Chinese version and the Australian version. About half of the Chinese (Australian) participants received the compatriot/non-compatriot order while the other half of the Chinese (Australian) the non-compatriot/compatriot order.

2.6.2. Results and discussion

The main findings of this experiment are depicted in Fig. 9. The analysis of variance yielded a very significant main effect for the status of the other player, $F(1,176) = 10.03$, $p < .01$, suggesting that being a compatriot or a non-compatriot differ in their impact on cooperation in the Prisoner Dilemma game problem. The difference between the Chinese group and the Australian group was not significant, $F(1,176) = 2.73$, ns. There was no significant two-way interaction, $F(1,176) = .89$, ns, suggesting that the effect of compatriot was evenly

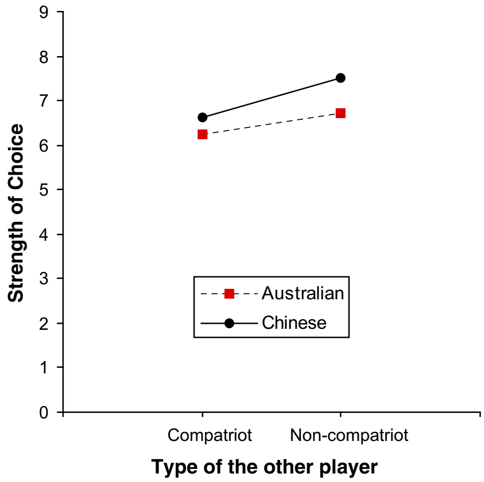

Fig. 9. Mean *strength of choice* as a function of participant's group (self is Australian vs self is Chinese) and the other player's status (the other is a compatriot vs the other is a non-compatriot). Indifferent choice has a value of 5, smaller values denote the smaller machine preferred choice, larger values denote the larger machine preferred choice.

strong for the Chinese and for the Australian. A further analysis reveals that the orders of the question representing did not differ significantly in their impact on the two ratings ($t_{\mathrm{compatriot}}(176) = .468$, ns; $t_{\mathrm{noncompatriot}}(176) = .552$, ns).

3. General discussion

The six experiments reported in this paper, departing from the main trend, have led us to gain some new insight into the general issue of human decision making behaviour in PD games. First, we might therefore be aware that there could be an alternative way of seeing the inconsistence between the preferences shown by human participants and the ordering implied by any kind of utility-integration calculations, such as subjective expected utility (SEU) maximising. Humans are inhomogeneous and complex hence their behaviour is not expected to be explained by a single criterion. When being confronted with such an inconsistency, the theoretical avenue we take might not necessarily be to modify the maximising criterion so as to make the chosen alternative the greatest "something", but to seek to understand what other role the utility will play if it has not been one of expectation maximising. Considering the limited cognitive ability of a human decision maker, it is the present contention that inconsistency is inevitable and predictable because the equate-to-differentiate rule best reflects actual human practice.

Second, guided by the equate-to-differentiate thinking, it has been assumed that all risk attitudes (e.g., either risk-seeking or risk-averse) should be observed when people's equate-to-differentiate strategy is caused to change by the experimental conditions applied. Such a manipulation of risky preference is empirically proposed and tested over a variety of troublesome decision phenomenon in decision under risk, i.e., preference reversal PR [10], certainty effect [17], reflection effect [11], framing effect [12]. In the same vein, a more general framework for further studies on decision making under competition would suggest that all sorts of behaviour in PD situations, such as economic vs social man's behaviour, collaborative vs competitive choice, and egotistic vs altruistic choice, are all thus similarly determined.

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