Findings

Biased but Efficient: An Investigation of Coordination Facilitated by Asymmetric Dominance

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In several marketing contexts, strategic complementarity between the actions of individual players demands that players coordinate their decisions to reach efficient outcomes. Yet coordination failure is a common occurrence. We show that the well-established psychological phenomenon of asymmetric dominance can facilitate coordination in two experiments. Thus, we demonstrate a counterintuitive result: A common bias in individual decision making can help players to coordinate their decisions to obtain efficient outcomes. Further, limited steps of thinking alone cannot account for the observed asymmetric dominance effect. The effect appears to be due to increased psychological attractiveness of the dominating strategy, with our estimates of the incremental attractiveness ranging from 3%–6%. A learning analysis further clarifies that asymmetric dominance and adaptive learning can guide players to an efficient outcome.

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1. Introduction

What type of product warranty should a manufacturer offer when product failure depends on both product quality and buyer care (Cooper and Ross 1985; see also Padmanabhan and Rao 1993)? How much should a partnering firm invest in its cross-functional alliances (Amaldoss et al. 2000)? In making such strategic marketing decisions, it is important that a firm consider not only firm-related factors but also the likely behavior of other players because the optimal actions of a firm are positively related to the actions of the other players. Such strategic complementarity between individual actions necessitates that players coordinate their decisions to reach efficient outcomes. Yet, decision makers typically fail to coordinate—that is, players do not select the equilibrium that yields the highest payoff from the set of available equilibria (e.g., Cooper et al. 1990; Van Huyck et al. 1990, 1991).

In this paper, we show how a common bias in human decision making may help decision makers to better coordinate their decisions and attain efficient outcomes. More specifically, we show that the well-documented psychological bias called the *asymmetric dominance effect* occurs in strategic game settings and can facilitate coordination. Next, we briefly outline the asymmetric dominance effect, provide an overview of our research, and then clarify its contribution to the literature on coordination games.

1.1. The Asymmetric Dominance Effect

Consider the case where an individual has to choose between two undominated choices, namely, A and B. Add to this set a new alternative A' that is dominated by A, but not by B. The regularity assumption in random utility theory implies that the addition of a new alternative to a choice set should not increase the choice probability of any option in the original set, implying $p(A \mid \{A, B, A'\}) \leq p(A \mid \{A, B\})$. However, Huber et al. (1982) showed that the addition of the asymmetrically dominated alternative A', which is dominated by A but not by B, can actually *increase* the probability of choosing the dominating alternative A. That is, $p(A \mid \{A, B, A'\}) > p(A \mid \{A, B\})$. This effect, called the asymmetric dominance effect (or attraction effect), is very robust and has been replicated in dozens of studies in many individual decision-making (as opposed to strategic decision-making) contexts, including gambles (Wedell 1991), services (Wedell and Pettibone 1996), job applications (Highhouse 1996), and product choices (Simonson 1989, Simonson and Tversky 1992, Tversky and Simonson 1993, Dhar and Simonson 2003; see Heath and Chaterjee 1995 for a review of the experimental literature). The effect is robust in both between-participant and within-participant experimental designs (Rieskamp et al. 2004) and persists even when participants are financially motivated to make utility-maximizing choices (Herne 1999). Interestingly, animals such as honeybees

and gray jays are also susceptible to such asymmetric dominance effects, implying that the effect could be perceptual and automatic, without requiring much cognition (Shafir et al. 2002). More generally, this body of research has strongly shown that preferences are context dependent, in that they depend upon the particular set of options presented to the decision maker.

1.2. Overview

In this paper, we address two questions: Will adding an asymmetrically dominated strategy systematically influence the choice probabilities of nondominated strategies in strategic decision-making contexts that involve coordination of decisions? Will asymmetric dominance improve coordination to an equilibrium that yields a higher payoff (Pareto superior equilibrium)? We search for answers to these questions in a stylized strategic decision-making context. Specifically, we investigate in two laboratory studies the effect of asymmetric dominance in a class of coordination games called the *Leader game*, originally identified by Rapoport and Guyer (1966). In the Leader game, it is in each player's mutual interest for one of them to become the leader and for the other to be the follower. From an individual player's perspective, it is more profitable to be the leader rather than the follower. If both players attempt to become the leader, however, then they earn a lower payoff. This game has a mixed-strategy equilibrium and two pure-strategy equilibria that give higher payoffs than the mixed-strategy equilibrium. That is, the pure-strategy equilibria are Pareto superior to the mixed-strategy equilibrium. Hence, Row and Column players want to coordinate to a pure-strategy equilibrium (social motive), but they differ on which pure-strategy equilibrium they would like to reach (individual motive). The mixed-motive Leader game allows us to (1) investigate asymmetric dominance effects in a strategic context (as opposed to an individual decision-making context), and (2) explore whether players can better coordinate their decisions in the presence of such asymmetric dominance effects.

Study 1 examines whether the asymmetric dominance effect can induce coordination in a demanding strategic decision-making task where players are not provided feedback about the outcome of their decisions and the game has mixed motives. In the absence of feedback about the outcome of their decisions, there is no scope for our participants to update their beliefs about the population of opponents and better coordinate their decisions. Further, the structure of the Leader game is less conducive to coordination than the *pure* coordination games studied by Mehta et al. (1994), where there is no conflict between the social and individual motives. In Study 1 we investigate how the addition of an asymmetrically (weakly) dominated strategy to the strategy set of the Row player

changes behavior in the Leader game. More precisely, the additional strategy is (weakly) dominated by one choice but not by the other choice in the strategy set of the Row player. Consistent with prior research in individual decision making, we detect an asymmetric dominance effect in the aggregate behavior of participants, with magnitude comparable to that observed in individual decision-making research. Importantly, we saw no evidence that participants could coordinate their choices to a pure-strategy equilibrium when no feedback was provided. This raises an interesting question: Will the asymmetric dominance effect grow in size if participants are given an opportunity to play several iterations of the game and learn from experience? On the one hand, participants could learn to correct the bias in their choices over time, and consequently the asymmetric dominance effect potentially could disappear. On the other hand, the effect may help participants to reach an efficient equilibrium. Hence, in Study 2 we examined whether feedback about the outcome of the game could sufficiently reinforce the asymmetric dominance effect and thereby improve coordination.

Consistent with prior experimental literature in coordination games (e.g., Cooper et al. 1990, 1992), in Study 2 participants were provided feedback about the outcome of their decisions at the end of every trial and played 40 iterations of the one-stage game against randomly assigned opponents. The asymmetric dominance effect grew stronger in this study, and participants systematically shifted away from the mixed-strategy solution and moved toward a Pareto-dominant equilibrium in directions consistent with the asymmetric dominance effect. In the absence of an asymmetrically dominated strategy, however, participants failed to coordinate to a pure-strategy equilibrium and their behavior was closer to the mixed-strategy solution. Thus, the asymmetric dominance effect can grow in size with feedback, and an asymmetrically dominated strategy may serve as a coordination device.

Next, we examined whether the observed behavior can be accounted for by limited steps of thinking. Using the cognitive hierarchy (CH) model (Camerer et al. 2004), we show that limited thinking alone cannot explain the asymmetries in the empirical distribution of choices. However, when we extended the CH model to allow for increased psychological attractiveness of the dominating choice, it provided a better account of the experimental results.

Using the experience-weighted attraction (EWA) learning model (Camerer and Ho 1998), we investigated the learning dynamics of our participants. This additional analysis clarified that Row players were predisposed to choose the dominating option, as predicted by the asymmetric dominance effect. Although

Column players did not anticipate this effect, they were quick in learning from experience and moved toward the pure-strategy equilibrium consistent with the asymmetric dominance effect.

Thus, we demonstrate that a (weakly) dominated option can systematically influence strategy choices in the direction predicted by asymmetric dominance. We also show that the players are more likely to select a Pareto-dominant equilibrium in the presence of an appropriately designed asymmetrically dominated option, implying that a dominated option can serve as a coordination device.

The rest of this paper is organized as follows. Section 2 presents predictions for the effects of asymmetric dominance for the Leader game and discusses the experimental results of Study 1. Section 3 outlines Study 2, in which we examine whether feedback moderates the effect of the asymmetric dominance effect. Section 4 examines the application and extension of the CH model to our results. Section 5 investigates whether the dynamics in the choices of our participants can be explained by adaptive learning. We conclude the paper in §6 by discussing the implications of the findings and outlining directions for further research.

2. Study 1

Prior experimental research on coordination games with mixed motives has typically allowed participants to play several iterations of the one-shot games with outcome feedback at the end of every trial (e.g., Cooper et al. 1990, 1992; Van Huyck et al. 1990, 1991). A clear result emerging from this body of experimental research is that payoff dominance is not a strong focal principle that guides equilibrium selection (Ochs 1995, Shelling 1960). That is, we cannot be confident that players will select the Pareto-dominant equilibrium in a game with multiple Pareto-ranked equilibria. At a more fundamental level, as originally noted by Arrow (1986) and later highlighted by Ochs (1995), the rationality required in these games is a social phenomenon, and it needs to be based on the common understanding of the players. It is important to understand this phenomenon devoid of any contamination due to adaptive learning. That is, we want to record the strategy choices of our participants without giving them an opportunity to modify their actions based on the observed behavior of other participants. Hence, in Study 1 we investigate whether adding an asymmetrically dominated strategy increases the choice of the dominating strategy when players are not provided feedback about the outcome of their decisions. That is, we examine whether the asymmetric dominance effect holds in strategy choice and whether the dominating strategy becomes a strong focal point

for players. We also explore whether the asymmetric dominance effect is strong enough to override the mixed-motive structure of the decision-making context and produce sufficient coordination in the absence of replication and feedback about outcome.

2.1. Overview and Predictions

To focus our discussion, consider an illustrative strategic decision-making context. In the payoff matrix presented in Table 1 Matrix(a), $a > b > c > d > 0$ and $a \geq x \geq d$. In this two-person nonzerosum game, the Row player's choice set is $\{A, B, A'\}$, where A' is (weakly) dominated by A but not by B. The Column player's choice set is {Left, Right}. After deleting the dominated strategy choice A', the reduced game has a symmetric (completely) mixed-strategy solution, where $p(A) = p(\text{Left}) = (b - d)/(a + b - c - d)$ and $p(B) = p(\text{Right}) = 1 - p(A)$. In addition, the reduced game has two asymmetric pure-strategy equilibria. The ordered pairs (A, Right) and (B, Left) are the two pure-strategy equilibria, because neither player can deviate from them given the strategy chosen by the other player. The Row player, however, would prefer the pure-strategy equilibrium (B, Left). On the other hand, the Column player would prefer the other pure-strategy equilibrium (A, Right). Both these pure-strategy equilibria are Pareto superior to the mixed-strategy solution.

The reduced version of this illustrative game is the *Leader game* originally reported in Rapoport and Guyer (1966; see Game 68). In the Leader game, it is in each player's mutual interest for one of them to become the leader and for the other to be the follower. From an individual player's perspective, it is more profitable to be the leader rather than the follower. However, if both players attempt to become the leader, then they receive the lowest possible payoff. This game is different from the Battle of the Sexes, where $b > a > c > d$ (Luce and Raiffa 1957). The game is also distinct from the game of Chicken, where $a > c > b > d$ (Russell 1959).

Table 1   Illustrative Two-Person Nonzerosum Games

	Column player	
Row player	Left	Right
Matrix(a)		
A	c, c	b, a
B	a, b	d, d
A'	d, x	b, x
Matrix(b)		
A	c, c	b, a
B	a, b	d, d
B'	b, x	d, x

The implication of the asymmetric dominance effect in this game is that the Row player is likely to select the (weakly) dominating choice A more often. If the Column player anticipates the Row player's choice of A, then she might choose Right. If the Row player in turn expects the Column player to choose Right, then it reinforces the decision to choose A. Such reasoning could help coordinate choices to the pure-strategy equilibrium (A, Right).

Next, consider the payoff matrix in Table 1 Matrix(b), where B' is (weakly) dominated by B but not by A. Because the values of a, b, c, and d remain as in Table 1(a), the equilibrium predictions do not change. The implications of the asymmetric dominance effect, however, do change. Now the Row player should select the dominating choice B more often. Compared to the earlier choice probabilities, we should have $p(B \mid \{A, B, B'\}) > p(B \mid \{A, B, A'\})$ and $p(A \mid \{A, B, A'\}) > p(A \mid \{A, B, B'\})$. Further, if participants reason through the implications of asymmetric dominance, they might coordinate to the pure-strategy equilibrium (B, Left). Thus, in the above nonzerosum game with multiple equilibria, it is possible that the asymmetric dominance effect might facilitate coordination to a Pareto-superior equilibrium, and this equilibrium might differ depending upon the nature of the dominated strategy. Hence, we argue that dominated strategies, rather than being eliminated and having no effect on strategic choices, can systematically affect individuals' choices and the resulting equilibrium behavior.

To test these ideas, we considered four sets of ABA'–ABB' matrices, as shown in Table 2. The ABA'–ABB' design helps us to empirically assess the asymmetric dominance effect *independent* of the equilibrium solution. In particular, as noted above, if the asymmetric dominance effect is present, we should observe that $p(A \mid \{A, B, A'\}) > p(A \mid \{A, B, B'\})$ and $p(B \mid \{A, B, B'\}) > p(B \mid \{A, B, A'\})$. This asymmetry should not occur if participants delete the (weakly) dominated strategy and then mix strategies as implied by the mixed-strategy solution. That is, in equilibrium, $p(A \mid \{A, B, A'\}) = p(A \mid \{A, B, B'\})$ and $p(B \mid \{A, B, A'\}) = p(B \mid \{A, B, B'\})$.[1]

[1] For example, in the ABA' matrix of set 1, it is easy to see that the Row player should (weakly) prefer to play strategy A instead of A' irrespective of whether the Column player chooses Left or Right. If the Column player were to choose Left, then the Row player will earn 14 instead of 10 by choosing A instead of A'. But if the Column player chooses Right, then the Row player will be indifferent between choosing A and A'. Hence, choosing A' is *weakly* dominated by choosing A. Consequently, the Row player should eliminate A' from her strategy space, and thereby the 3×2 game reduces to a 2×2 game. (Note that it is the Row player who needs to eliminate the (weakly) dominated strategy. The Column player's payoff corresponding to the dominated choice was set to be x irrespective of

Table 2   Payoff Matrices Used in Study 1

	ABA' matrices			ABB' matrices	
	Column player			Column player	
Row player	Left	Right	Row player	Left	Right
Set 1					
Up (A)	14, 14	18, 26	Up (A)	14, 14	18, 26
Middle (A')	10, 22	18, 22	Middle (B)	26, 18	10, 10
Down (B)	26, 18	10, 10	Down (B')	18, 22	10, 22
Set 2					
Up (A)	16, 16	18, 22	Up (A)	16, 16	18, 22
Middle (A')	10, 22	18, 22	Middle (B)	22, 18	10, 10
Down (B)	22, 18	10, 10	Down (B')	18, 22	10, 22
Set 3					
Up (A)	16, 16	20, 24	Up (A)	16, 16	20, 24
Middle (A')	8, 12	20, 12	Middle (B)	24, 20	8, 8
Down (B)	24, 20	8, 8	Down (B')	20, 12	8, 12
Set 4					
Up (A)	12, 12	20, 28	Up (A)	12, 12	20, 28
Middle (A')	8, 12	20, 12	Middle (B)	28, 20	8, 8
Down (B)	28, 20	8, 8	Down (B')	20, 12	8, 12

Notes. The asymmetrically dominated choice A' is in the Middle row of the ABA' matrices; it is dominated by A, which appears in the Up row. The asymmetrically dominated choice B' is in the Down row of the ABB' matrices; it is dominated by B, which appears in the Middle row.

2.2. Method

2.2.1. Participants. Two hundred and forty undergraduate and graduate students participated in the study. Participants were promised a monetary reward contingent on their performance in a decision-making experiment. On average, participants earned $14 for participating in the study.

2.2.2. Procedure. Participants who agreed to take part in the study were e-mailed the link to a website and a password to access the site. After they logged on, the participants read an overview of the instructions for the experiment. Because the game would be presented in matrix form, it was important that participants understood how to read a payoff matrix. To facilitate this, a sample payoff matrix was described. Then, participants were asked to answer two questions to assess whether they understood how to read a payoff matrix. Those who faced any difficulty in reading the payoff matrices could revisit the examples again.

After the participants correctly read the sample payoff matrix, they played the games. Participants were assigned the role of either Column or Row player, and their role remained fixed throughout the

whether the Column player chooses Left or Right. Further, we let the Column player's payoff corresponding to the dominated choice fall within the range of payoffs possible in the game, namely, $a \geq x \geq d$. Hence, in theory, the addition of the dominated choice should not influence the behavior of the Column player.)

experiment. One hundred and twenty participants were assigned the role of Column player and another 120 participants played the role of Row player. Then, the participants were randomly presented the eight 3×2 payoff matrices shown in Table 2. The position of the dominated strategy was rotated so that it was not the same in all the eight matrices. It is useful to note that in choosing the payoff matrices, we selected cases where the mixed-strategy equilibrium was such that $p(A) \neq p(B)$. Such a probability distribution helps to rule out random choice as an explanation for equilibrium behavior.

For each of the matrices, the Column players had to indicate their strategy by clicking the Left or Right button on the screen, whereas the Row players had to click on the Up, Middle, or Down button to indicate their choices. Participants were told that they competed with a different player on each trial, and this message was repeated after every trial. Participants were also informed that their identity would not be revealed to their competitors and that all their decisions would remain anonymous throughout the experiment. These precautions were taken so that there was no room for reputation effects in our games. Further, there was no opportunity for any two participants to collude. Also, participants were not provided any information about the choices of their competitors after each trial, and there was no scope for adaptive learning in our one-shot games.

After all the participants completed the entire experiment, the payoffs were computed. To compute the payoffs, each Row player was post facto matched with a different Column player for each matrix, and the payoffs were assessed based on the corresponding decisions of the Row and Column players. The cumulative earnings of each participant were converted to U.S. dollars at the rate of one dollar for 10 units of experimental currency, and participants were paid accordingly.

2.3. Results
We examined the aggregate distribution of choices of Row players to assess whether participants chose the dominating alternatives more often. The empirical evidence suggests that Row players were susceptible to the asymmetric dominance effect. The Column players, on the other hand, did not seem to anticipate this effect. We also observed substantial individual-level differences in the behavior of participants.

2.3.1. Aggregate Distribution of Choices. Table 3 presents the aggregate distribution of choices. The asymmetric dominance effect predicts that alternatives that enjoy a dominating relationship with A' or B' should be chosen more often. This implies that $p(A \mid \{A, B, A'\}) > p(A \mid \{A, B, B'\})$ and $p(B \mid \{A, B, B'\}) > p(B \mid \{A, B, A'\})$. If the Row players eliminated the

Table 3 **Frequency Distribution of the Choices of Row Player in Study 1**

Set	Matrix	Observed behavior (%)			Nash prediction (%)		
		A	B	Dominated choice (A'/B')	A	B	Dominated choice (A'/B')
1	ABA'	**46.67**	48.33	5	**40**	60	0
	ABB'	35.83	**53.33**	10.83	40	**60**	0
2	ABA'	**60**	34.17	5.83	**57.14**	42.86	0
	ABB'	51.67	**40**	8.33	57.14	**42.86**	0
3	ABA'	**68.33**	30	1.67	**60**	40	0
	ABB'	56.67	**39.17**	4.17	60	**40**	0
4	ABA'	**43.33**	50.83	5.83	**42.86**	57.14	0
	ABB'	39.17	**60**	0.83	42.86	**57.14**	0
Overall	ABA'	**54.58**	40.83	4.59	**50**	50	0
	ABB'	45.83	**48.13**	6.04	50	**50**	0

Note. The frequencies corresponding to the dominating choices are presented in boldface type.

dominated alternatives and then played according to the mixed-strategy equilibrium (that is, if there were no asymmetric dominance effect), then across the four sets of matrices we should find that

$$p(A \mid \{A, B, A'\}) = p(A \mid \{A, B, B'\}) = 0.5$$

and

$$p(B \mid \{A, B, B'\}) = p(B \mid \{A, B, A'\}) = 0.5$$

(see columns 6 and 7 of the last two rows of Table 3). In actuality, across the four sets of matrices, $p(A \mid \{A, B, A'\}) = 54.58\% > p(A \mid \{A, B, B'\}) = 48.13\%$. A paired comparison of the two conditional probabilities at the level of each subject rejected the null hypothesis that these probabilities were the same ($t = 3.4$, $p < 0.01$). Our participants also chose B more often when it was the dominating choice. Specifically, $p(B \mid \{A, B, B'\}) = 48.13\%$, and it was more than $p(B \mid \{A, B, A'\}) = 40.83\%$ ($t = 3.0$, $p < 0.01$). Thus, the overall behavior of our participants was consistent with the asymmetric dominance effect, with approximately an 8% difference in strategy choice as a function of the asymmetric dominance relationship.

According to the mixed-strategy solution, we should also observe that

$$p(A \mid \{A, B, A'\}) = p(A \mid \{A, B, B'\}) = 0.5$$

and

$$p(B \mid \{A, B, B'\}) = p(B \mid \{A, B, A'\}) = 0.5$$

across sets 1 and 3 as well as across sets 2 and 4. Although participants chose A more often when it was the dominating strategy in these sets, a

paired comparison test of the conditional probabilities revealed that the difference was statistically significant in sets 1 and 3 ($t = 2.6$, $p < 0.011$), but not in sets 2 and 4 ($t = 1.88$, $p < 0.063$). Similarly, we found that $p(B \mid \{A, B, B'\})$ was more than $p(B \mid \{A, B, A'\})$. Although the difference was significant in sets 2 and 4 ($t = 2.29$, $p < 0.024$), it was not significant in sets 1 and 3 ($t = 1.69$, $p < 0.095$).

Moving to the level of individual matrices, we note that $p(A \mid \{A, B, A'\})$ was significantly greater than $p(A \mid \{A, B, B'\})$ in matrix sets 1 and 3, but not significantly greater in sets 2 and 4 (set 1: $t = 2.42$, $p < 0.02$; set 2: $t = 1.84$, $p < 0.07$; set 3: $t = 2.65$, $p < 0.01$; set 4: $t = 0.92$, $p > 0.2$). Similarly, the difference between $p(B \mid \{A, B, B'\})$ and $p(B \mid \{A, B, A'\})$ was in the predicted direction for all four sets and was significant in sets 3 and 4 (set 3: $t = 2.11$, $p < 0.04$; set 4: $t = 2.02$, $p < 0.05$), but not in sets 1 and 2 ($p > 0.1$).

Asymmetric dominance makes a clear prediction for the choice of the Row players, and actual choice behavior was consistent with that prediction. What is its implication for the Column players? If the Column players anticipated that the Row players would choose the dominating strategy, then the payoff maximizing choice for the Column players is obvious: the Column players should play Right in the case of ABA' matrices and Left in the case of ABB' matrices. For example, consider the ABA' matrix in set 1 (see Table 2). If the Row player were to choose Up (because it dominates Middle), then the Column player should choose Right. Using a similar line of argument, it is easy to see why a Column player who anticipated an asymmetric dominance effect should choose Left in the ABB' matrices.

In Table 4, we note that the Column players chose Right and Left with almost equal probability. Specifically, they played Left in the ABB' matrices with an

average frequency of 48.96% (see the last row) and chose Right in the ABA' matrices with an average probability of 49.17% (see the second to last row). Thus, in these one-shot games with no feedback, we observed no evidence that the Column players anticipated the asymmetric dominance effect in the behavior of the Row players and accordingly changed their choices.[2]

2.4. Discussion

The results of Study 1 demonstrated that the asymmetric dominance effect can be observed in strategic decision-making contexts. Strategies that (weakly) dominated another strategy were chosen more frequently than strategies that were undominated. As noted by Cooper et al. (1990), participants did not behave as if dominated strategies were eliminated without affecting their strategy selections. On the contrary, their behavior was influenced as predicted by asymmetric dominance.

Mehta et al. (1994) note that a slim popularity advantage for everyday objects such as flowers or colors can grow into a larger advantage in strategic contexts, where people have to coordinate their choices. In Study 1, the magnitude of the asymmetric dominance effect observed in the choices of the Row players is comparable to that observed in individual decision-making research. However, we see no strong evidence that the Column players systematically changed their choices to accommodate the shifts in the behavior of the Row players. Consequently, participants were not able to coordinate their choices to a pure-strategy equilibrium when no feedback was provided.[3]

In general, the presence of asymmetrically dominated options leads to increased attention to and choice of the dominating option. In a decision-processes study, Hamilton (2003) shows that people understand and use this notion to attempt to influence others' choices by designing choice sets for others that include asymmetrically dominated options. Then, why did the Column players fail to recognize

Table 4 Frequency Distribution of the Choices of Column Player in Study 1

Set	Matrix	Observed behavior (%)		Nash prediction (%)	
		Left	Right	Left	Right
1	ABA'	44.17	**55.83**	40	**60**
	ABB'	**46.67**	53.33	**40**	60
2	ABA'	64.17	**35.83**	57.14	**42.86**
	ABB'	**52.5**	47.5	**57.14**	42.86
3	ABA'	55	**45**	60	**40**
	ABB'	**56.67**	43.33	**60**	40
4	ABA'	40	**60**	42.86	**57.14**
	ABB'	**40**	60	**42.86**	57.14
Overall	ABA'	50.84	**49.17**	50	**50**
	ABB'	**48.96**	51.04	**50**	50

Note. The frequencies corresponding to the pure strategies consistent with the asymmetric dominance effect are presented in boldface type.

[2] At the level of individual participants, we found substantial variation in behavior. For example, the number of dominating strategies chosen by a Row player ranged from two to eight, with the modal frequency being four. Similarly, the number of occasions an individual chose the undominated choices ranged from zero to six, with the modal frequency again being four. The distribution of Row players making undominated choices, however, was skewed to the left.

[3] Note that in the Leader game, both Row and Column players want to coordinate to a pure-strategy equilibrium (social motive), although they differ on which pure-strategy equilibrium they would like to reach (individual motive). But there is no such mixed motive in coordinating the selection of a flower or color in the Mehta et al. (1994) study. This structural difference may explain in part the lower level of coordination observed in Study 1.

the asymmetric dominance effect? Perhaps our stimulus was more complex. We also did not provide participants any opportunity to learn from experience. However, in many strategic contexts people have an opportunity to learn from experience. This led us to ask whether the asymmetric dominance effect would grow in size if subjects were allowed to play several iterations of the game with performance feedback at the end of every trial. Further, would the increase in the asymmetric dominance effect facilitate participants to reach a higher level of coordination?

3. Study 2

In Study 2 we examine whether outcome feedback moderates the effect of asymmetric dominance on strategy choices. There are two conflicting hypotheses. One potential implication of providing feedback to participants is that they may correct their individual-level bias. For example, if the Column players play according to the mixed-strategy solution and fail to recognize the bias in the choices of the Row players, then over time the Row players too may shift toward the mixed-strategy equilibrium. In this case, the asymmetric dominance effect could disappear after a few iterations of the game. Alternatively, the effect may grow in strength and become a coordinating device when feedback is provided. For example, in the nonzerosum games studied earlier (see Table 1), we discussed how participants might coordinate their choices to a pure-strategy equilibrium consistent with the reasoning implied by the asymmetric dominance effect. That is, in the ABA' matrix, players might coordinate to (A, Right), whereas they might coordinate to (B, Left) in the ABB' matrix. In addition, we included a control condition where participants played the reduced game that did not include the dominated choice (AB matrices). This would allow us to contrast the behavior observed in the ABA' and ABB' matrices against that in the control condition.

3.1. Method

3.1.1. Participants. One hundred and eight participants were recruited by advertisements posted on campus newsgroups promising monetary rewards contingent on performance in a decision-making experiment. Each session lasted $1-1\frac{1}{2}$ hours and subjects earned approximately $17.

3.1.2. Procedure. We tested two of the four sets of the $ABA'-ABB'$ matrices covered in Study 1, namely, sets 1 and 3 (see Table 2). We label these two as sets 5 and 6, respectively, for Study 2. In the current study, we also considered a control condition where participants played the reduced game that did not include the dominated choice. Thus, each set of matrices in Study 2 included an ABA', an ABB', and

an AB matrix. Six different groups of 18 participants played the six matrices in a between-subjects experiment ($6 \times 18 = 108$ participants).

At the start of the experiment, participants were randomly assigned to a computer booth and provided the written instructions for the experiment (see the Technical Appendix that can be found at http://mktsci.pubs.informs.org/). A sample payoff matrix was discussed in the instructions so that participants understood how to read a payoff matrix. After all the participants completed reading the instructions, the supervisor entertained questions from individual subjects. Very few questions were asked.

Participants were assigned the role of either Row or Column player, and their role remained fixed throughout the 40 trials of the experiment. Participants were told that the competitor changed from trial to trial, and they were not informed of the identity of their competitors. Thus, participants remained anonymous throughout the experiment. Such a random pairing of participants reduced the potential for building any reputation in our experiment.

At the end of every trial, each participant was informed about his/her competitor's choice and the earnings for that trial. We did not provide participants any practice trials because their initial behavior might contain some useful information about their natural predisposition in these games. At the end of the fortieth trial, the cumulative earnings were converted to U.S. dollars at the rate of two dollars for 100 units of experimental currency. Subsequently, participants were paid and dismissed.

3.2. Results

3.2.1. Aggregate Distribution of Choices. Table 5 summarizes the aggregate distribution of choices of

Table 5 Frequency Distribution of the Choices of Row Player in Study 2

Set	Matrix	Observed behavior (%)			Nash prediction (%)		
		A	B	Dominated choice (A'/B')	A	B	Dominated choice (A'/B')
5	ABA'	**52.22**	35.83	11.94	**40**	60	0
	ABB'	11.94	**85.28**	2.78	40	**60**	0
	AB	39.17	60.83	—	40	60	0
6	ABA'	**66.67**	28.33	5	**60**	40	0
	ABB'	18.89	**81.11**	0	60	**40**	0
	AB	55.28	44.72	—	60	40	0
Overall	ABA'	**59.45**	32.08	8.47	**50**	50	0
	ABB'	15.42	**83.12**	1.39	50	**50**	0
	AB	47.22	52.78	—	50	50	0

Notes. The frequencies corresponding to the dominating choices are presented in boldface type. The dominated choices for the Row players in the ABA' and ABB' matrices are A' and B', respectively.

Table 6 Frequency Distribution of the Choices of Column Player in Study 2

Set	Matrix	Observed behavior (%)		Nash prediction (%)	
		Left (A)	Right (B)	Left (A)	Right (B)
5	ABA'	12.22	**87.78**	40	**60**
	ABB'	**70.28**	29.72	**40**	60
	AB	35.28	64.72	**40**	60
6	ABA'	41.94	**58.06**	60	**40**
	ABB'	**80**	20	**60**	40
	AB	61.11	38.89	**60**	40
Overall	ABA'	27.08	**72.92**	50	**50**
	ABB'	**75.14**	24.86	**50**	50
	AB	48.19	51.81	**50**	50

Notes. The frequencies corresponding to the pure strategy consistent with the asymmetric dominance effect are presented in boldface type. The figures in parentheses are the actual number of choices made by 9 column players over 40 trials.

the Row players. The asymmetric dominance effect predicts that the Row players should select the dominating choice more often in the presence of an asymmetrically dominated choice. One implication of this prediction is that we should observe $p(A \mid \{A, B, A'\}) > p(A \mid \{A, B, B'\})$ and $p(B \mid \{A, B, B'\}) > p(B \mid \{A, B, A'\})$ in our data. Another implication is that we should observe $p(A \mid \{A, B, A'\}) > p(A \mid \{A, B\})$ and $p(B \mid \{A, B, B'\}) > p(B \mid \{A, B\})$.

We began our analysis by examining the first implication of the asymmetric dominance effect. On aggregating the data across the two sets of matrices presented in Table 5, we found that the Row players selected A more often when it was the dominating choice. Specifically, $p(A \mid \{A, B, A'\}) = 59.45\%$, which is greater than $p(A \mid \{A, B, B'\}) = 15.42\%$. A paired comparison of these probabilities in each of the 40 trials rejects the null hypothesis that both the probabilities were drawn from the same distribution ($t = 19.57$, $p < 0.001$). Similarly, we observed $p(B \mid \{A, B, B'\}) = 83.12\%$, significantly greater than $p(B \mid \{A, B, A'\}) = 32.08\%$ ($t = 20.34$, $p < 0.001$). We obtained similar results within each set of matrices, as shown in Table 5 ($p < 0.01$ for all comparisons). These shifts in the conditional probability of choosing A and B are consistent with the asymmetric dominance effect, but inconsistent with the mixed-strategy solution. Note that these asymmetric dominance effects are substantially larger than those observed in Study 1. Thus, the presence of feedback seemed to strengthen the effect.

Next, we assessed the second implication of the asymmetric dominance effect by comparing the empirical distribution of choices in the ABA' and ABB' matrices against those in the corresponding control condition (the AB matrix). Across sets 5 and 6, participants chose the dominating choice more often in the presence of an asymmetrically dominated option.

We found that $p(A \mid \{A, B, A'\}) = 59.45\%$, significantly more than $p(A \mid \{A, B\}) = 47.22\%$ ($t = 5.50$, $p < 0.001$). Similarly, $p(B \mid \{A, B, B'\}) = 83.12\%$ is greater than $p(B \mid \{A, B\}) = 52.78\%$ ($t = 12.25$, $p < 0.001$). These results also hold in each set of matrices, with $p < 0.001$ for all comparisons. These comparisons between the treatment and control conditions reaffirm the asymmetric dominance effect detected in our earlier analysis.

For completeness, we also contrasted the observed behavior with the mixed-strategy solution. According to the mixed-strategy solution for matrix set 5, choice A should be played with a frequency of 40%. However, participants chose A with a probability of 52.22%, 11.94%, and 39.17% in the ABA', ABB', and AB matrices of that set, respectively. The departures from the equilibrium prediction were statistically significant in the case of matrices ABA' and ABB', but not AB (ABA': $t = 5.5$, $p < 0.001$; ABB': $t = 12.79$, $p < 0.001$; AB: $t = 0.39$, $p > 0.20$). In equilibrium, B should be played with a probability of 60%; yet it was selected with a frequency of 35.83% and 85.28% in the ABA' and ABB' matrices of set 5 (ABA': $t = 9.55$, $p < 0.001$; ABB': $t = 9.33$, $p < 0.001$). In the control condition (AB matrix), participants chose B on 60.83% of the occasions, which was not significantly different from the equilibrium prediction ($t = 0.39$, $p > 0.60$), implying that in the absence of an asymmetrically dominated choice, they might conform to the mixed-strategy equilibrium prediction. However, in the presence of an asymmetrically dominating choice, the distribution of choices systematically moved away from the mixed-strategy equilibrium prediction.

In set 6, participants should play A with a probability of 60% according to the mixed-strategy equilibrium. In actuality, participants chose A with a probability of 66.67%, 18.89%, and 55.28% in the ABA', ABB', and AB matrices, respectively. Again, the deviations from equilibrium prediction were significant in the ABA' and ABB' matrices (ABA': $t = 3.11$, $p < 0.01$; ABB': $t = 15.54$, $p < 0.001$). Although the behavior observed in the AB matrix was close to the mixed-strategy prediction, the difference was still significant (AB: $t = 2.26$, $p < 0.03$). Similarly, although players should choose B with a probability of 40%, they played B with a frequency of 28.33%, 81.11%, and 44.72% in the ABA', ABB', and AB matrices, respectively (ABA': $t = 5.76$, $p < 0.001$; ABB': $t = 5.543$, $p < 0.001$; AB: $t = 2.26$, $p < 0.03$). Across the two sets of matrices, the observed behavior significantly deviated from the average mixed-strategy equilibrium prediction; that is, $p(A \mid \{A, B, A'\}) = 59.45\%$ and $p(B \mid \{A, B, B'\}) = 83.12\%$ are greater than the predicted 50%. These findings suggest that asymmetric dominance shifts the empirical distribution of choices away from the mixed-strategy equilibrium prediction.

Focusing on the Column players, we note that across the two sets of matrices, participants should choose Left with an average probability of 50% (see Table 6). However, they played Left with a probability of 27.08% and 75.14% in the ABA' and ABB' matrices, respectively ($t = 16.36$, $p < 0.001$). These departures were in the direction of the pure-strategy equilibria consistent with the asymmetric dominance effect, namely, (A, Right) for ABA' and (B, Left) for ABB'. In the AB matrices, however, participants on average played Left with a probability of 48.19%, which is not very different from 50% ($t = 1.15$, $p > 0.25$). We obtain similar results in matrix sets 5 and 6. In the ABA' matrix of set 5, Column players chose Right with a probability of 87.78%, although the equilibrium prediction was 60% ($t = 16.10$, $p < 0.001$). In the ABB' matrix of the same set, Column players chose Left with a probability of 70.28%, which was significantly more than the predicted 40% ($t = 11.82$, $p < 0.001$). These departures were as predicted by the asymmetric dominance effect. Similarly, in set 6 the observed conditional probabilities $p(\text{Right} \mid \{A, B, A'\}) = 58.06\%$ and $p(\text{Left} \mid \{A, B, B'\}) = 80\%$ were more than the predicted 40% and 60%, respectively (ABA': $t = 7.13$, $p < 0.001$; ABB': $t = 8.47$, $p < 0.01$). Thus, providing feedback to participants strengthened the asymmetric dominance effect and moved participants away from the mixed-strategy solution toward the pure strategy systematically related to asymmetric dominance. In the control condition, even in the presence of feedback, participants remained closer to the mixed-strategy equilibrium and failed to converge on any of the pure-strategy equilibria. In the AB matrix of set 6, participants chose Left with a probability of 61.11%, while the mixed-strategy prediction was 60% ($t = 0.48$, $p > 0.60$). In the AB matrix of set 5, however, Column players played Left on 35.28% of the occa-

sions, which is lower than the mixed-strategy prediction of 40% ($t = 2.28$, $p < 0.03$).

To better appreciate the joint distribution of the choices made by the Row and Column players, we present in Table 7 the cell frequencies for the two sets of matrices. These data make apparent that participants moved away from the mixed-strategy solution, but toward the pure-strategy solution that was consistent with the asymmetric dominance effect. For example, the participants who played ABB' matrices should choose the strategy pair (B, Left) with a probability of 24% according to the mixed-strategy solution, but the observed frequency was 59.72% and 66.67% in matrix sets 5 and 6, respectively (set 5: $t = 9.39$, $p < 0.001$; set 6: $t = 12.14$, $p < 0.001$). Similarly, the participants who played ABA' matrices should choose the strategy pair (A, Right) with a frequency of 24% according to the mixed-strategy solution. In actuality, (A, Right) was chosen with a frequency of 46.11% and 37.22% in sets 5 and 6, respectively (set 5: $t = 5.62$, $p < 0.001$; set 6: $t = 3.51$, $p < 0.01$). Thus, asymmetric dominance systematically affected the frequency of choosing (A, Right) and (B, Left). In the control condition, we did not observe such a marked shift toward the pure-strategy equilibria. In the AB matrix of set 5, for example, participants played (A, Right) and (B, Left) with a probability of 26.11% ($t = 0.69$, $p > 0.2$) and 22.22% ($t = 0.65$, $p > 0.2$), respectively. Similarly, (A, Right) and (B, Left) were played with a probability of 18.33% ($t = 2.39$, $p < 0.03$) and 24.17% ($t = 0.05$, $p > 0.2$), respectively, in the AB matrix of set 6.

The preceding analysis of the joint distribution of strategy choices highlights an important implication of the asymmetric dominance effect: strategic context can systematically change the role played by the Row and Column players. In the presence of A', the Row players played the role of Follower and accordingly chose A,

Table 7   Cell Frequencies for the Games in Study 2

	ABA' matrix				ABB' matrix				AB matrix		
	Left (%)	Right (%)	Marginal (%)		Left (%)	Right (%)	Marginal (%)		Left (%)	Right (%)	Marginal (%)
Set 5											
A	6.11 (16)	**46.11 (24)**	52.22 (40)	A	8.61 (16)	3.33 (24)	11.94 (40)	A	13.06 (16)	**26.11 (24)**	39.17 (40)
B	4.72 (24)	31.11 (36)	35.83 (60)	B	**59.72 (24)**	25.56 (36)	85.28 (60)	B	**22.22 (24)**	38.61 (36)	60.83 (60)
A'	1.39 (0)	10.56 (0)	11.94 (0)	B'	1.94 (0)	0.83 (0)	2.78 (0)	Marginal	35.28 (40)	64.72 (60)	
Marginal	12.22 (40)	87.78 (60)		Marginal	70.28 (40)	29.72 (60)					
Set 6											
A	29.44 (36)	**37.22 (24)**	66.67 (60)	A	13.33 (36)	5.56 (24)	66.67 (60)	A	36.94 (36)	**18.33 (24)**	55.28 (60)
B	10.83 (24)	17.50 (16)	28.33 (40)	B	**66.67 (24)**	14.44 (16)	81.11 (40)	B	**24.17 (24)**	20.56 (16)	44.72 (40)
A'	1.67 (0)	3.33 (0)	5 (0)	B'	0 (0)	0 (0)	0 (0)	Marginal	61.11 (60)	38.89 (40)	
Marginal	41.94 (60)	58.06 (40)		Marginal	80 (60)	20 (40)					

Notes. The figures in parentheses are the mixed-strategy equilibrium predictions. In addition to the mixed strategy, the game has two pure-strategy equilibria, namely, the choice pairs {A, Right} and {B, Left}. The most frequently observed choice pair is presented in boldface type.

while the Column players assumed the role of Leader and chose Right. However, in the presence of B', their roles were reversed, with the Row player assuming the Leader role and the Column player taking the Follower role. Individual-level differences observed in the behavior of our participants over the 40 replications of the game are reported in the Technical Appendix (see Rapoport and Amaldoss, 2000 and 2004).

3.3. Discussion

In sum, Study 2 showed that the asymmetric dominance effect did not wear out over the several replications of the game. On the contrary, the effect grew in strength in the nonzerosum games considered in our study. Further, the asymmetric dominance effect helped players to better coordinate their decisions toward a Pareto superior pure-strategy equilibrium in the contexts considered in the study.

Prior research has found that in many games, players typically do not choose the Pareto-dominant equilibrium (e.g., Cooper et al. 1990; Van Huyck et al. 1990, 1991). In an attempt to reduce such coordination failures, researchers have designed several mechanisms, such as preplay communication with costly signals (Kreps and Sobel 1994), mere availability of costly signals (Ben-Porath and Dekel 1992), forward induction (Cachon and Camerer 1996), cheap talk (Parkhurst et al. 2004), and reputation formation (Dale et al. 2002). Our results suggest that coordination can be improved by appropriately designing a dominated option. Next, we examine whether the reported behavior of our participants could be accounted for by a very simple reason: Subjects failed to think deeply enough.

4. Limited Thinking and the Asymmetric Dominance Effect

We examine whether limited steps of thinking can account for the asymmetric dominance effects reported above. To accomplish this goal, we used the single-parameter CH model (Camerer et al. 2004) to investigate depth of thinking among our participants. The CH model assumes that players engage in iterative step-by-step reasoning. The iterative process starts with zero-step thinkers who make random choices. One-step thinkers best respond to zero-step thinkers. In general, k-step thinkers assume that their opponents are distributed over zero to $k-1$ steps. Further, the frequency distribution of k-step thinkers is given by a Poisson density function $f(k) = e^{-\tau}\tau^k/k!$, where the parameter τ is the mean and variance of the distribution. We estimated the value of τ for each of the matrices by minimizing the mean root squared deviation between the observed distribution of choices and the CH model prediction. For a detailed discussion of the CH model, see Camerer et al. (2004).

For this empirical investigation, we focus on Study 2, where the asymmetric dominance effect was established in a controlled laboratory setting using a repeated-trial design. Table 8 compares the CH model predictions against the corresponding observed frequency of choices. The CH model significantly underpredicted the frequency of choosing the dominating choice. For example, the CH model predicted that the Row players should choose the dominating choices A and B in matrices ABA' and ABB' of set 5 with a probability of 36.10% and 57.89%, respectively. The corresponding actual probabilities were significantly higher at 52.22% and 85.28%, respectively (ABA': $t = 6.1$, $p < 0.01$; ABB': $t = 14.7$, $p < 0.01$). For set 6, the CH model predictions for $p(A \mid \{A, B, A'\})$ and $p(B \mid \{A, B, B'\})$ were 57.89% and 41.68%, although the corresponding observed frequencies were 66.67% and 81.11%, respectively. Again, the differences between the predicted and observed frequencies were statistically significant (ABA': $t = 3.5$, $p < 0.01$; ABB': $t = 19.1$, $p < 0.01$). The estimated values of τ ranged from 1.137

Table 8   **CH Model Predictions for Study 2**

Player	Choice	Set 5 (%) ABA' CH pred.	Obs.	ABB' CH pred.	Obs.	Set 6 (%) ABA' CH pred.	Obs.	ABB' CH pred.	Obs.
Row player	A	**36.10**	**52.22**	31.43	11.94	**57.89**	**66.67**	55.27	18.89
	B	55.48	35.83	**57.89**	**85.28**	31.43	28.33	**41.68**	**81.11**
	Dominated (A'/B')	8.43	11.94	10.68	2.78	10.68	5	3.05	0
Column player	Left	40.60	12.22	47.51	70.28	52.49	41.94	56.79	80
	Right	59.40	87.78	52.49	29.72	47.51	58.06	43.21	20
CH estimates	τ	1.375	—	1.138		1.138	—	2.392	
	Log-likelihood	−574.47	—	−497.22		−542.38	—	−519.20	
	AIC	−575.47		−498.22		−543.38		−520.20	
	BIC	−578.76		−501.51		−546.67		−523.49	
	Pseudo-ρ^2	0.11		0.23		0.16		0.20	

Note. The frequencies corresponding to the dominating choices are presented in boldface type.

to 2.392, implying that most of the participants were thinking more than one step. These estimates of τ are within the range of values reported in Camerer et al. (2004, p. 878) for a wide variety of games.

This analysis suggests that limited thinking alone cannot account for the experimental results. This point can be even better appreciated in Figure 1, where we have plotted the CH model predictions for the two sets of matrices used in Study 2. Because the CH model predictions remain the same for the ABA' and ABB' matrices within a set, we present the graph for the ABA' matrix only. In all cases, the probability at which participants chose a dominating choice was higher than the CH model prediction. Most importantly, because the CH model predicts identical values for the ABA' and ABB' matrices, this model of limited thinking cannot account for the observed asymmetric shifts in the empirical distribution of choices between the ABA' and ABB' matrices within a set.

What could help account for the asymmetric dominance effect? Psychologists have considered several models to account for such context-dependent choices in individual decision making (e.g., Wedell 1991, Tversky and Simonson 1993, Wedell and Pettibone 1996, Kivetz et al. 2004). A key implication of this line of research is that the dominating choice is attractive not only for its monetary value but also for psychological reasons; that is, an option gains added value when it dominates another option. There is

also empirical support for such a psychological value-added model (Wedell and Pettibone 1996).

In an attempt to incorporate such a psychological feature into the CH model, we assumed that our participants derived an incremental nonmonetary utility of α if they chose a dominating choice. Thus, α captures the perceived incremental attractiveness of the dominating choice over and above its monetary value. The estimated values of α were 1 and 0.8 for the ABA' and ABB' matrices of set 5, implying that the psychological value of choosing the dominating choice was 6% and 3% of the monetary value of choosing A and B, respectively (these incremental values of 6% and 3% were computed on the basis of the pure strategy outcomes (A, Right) and (B, Left), respectively). In the case of set 6, the estimated values of α were 0.5 and 2.1 for the ABA' and ABB' matrices, and this translated into an average increment of 3% and 9% in the value of choosing the dominating choices, respectively. These estimates for sets 5 and 6 are roughly similar to the 6%–8% incremental values observed by Wedell and Pettibone (1996) in individual decision making.

The extended CH model fit the data better, based on fit statistics such as log-likelihood (LL), pseudo-ρ^2, Akaike Information Criterion (AIC), and Bayesian Inference Criterion (BIC). The extended model was especially good in predicting the frequency of choosing the dominating choices.[4] For example, the dominating choices were chosen on 52.22% and 85.28% of the occasions in the case of the ABA' and ABB' matrices of set 5. The corresponding predictions of the extended CH model were 52.08% and 83.08%, respectively. We cannot reject the null hypothesis that the predicted and actual frequencies are the same (ABA': $t = 0.05$, $p > 0.2$; ABB': $t = 1.18$, $p > 0.201$). Similarly, the extended CH model predictions for the ABA' and ABB' matrices of set 6 were 68.35% and 77.78%, respectively. The actual frequencies at which participants chose these dominating choices were 66.67% and 81.11%, respectively (ABA': $t = 0.67$, $p > 0.20$; ABB': $t = 1.61$, $p > 0.10$). Finally, although our empirical analysis focused on Study 2, the extended CH model also predicted the behavior observed in Study 1 with a higher degree of fit than the CH model.[5]

Figure 1   CH Model Predictions for Sets 5 and 6

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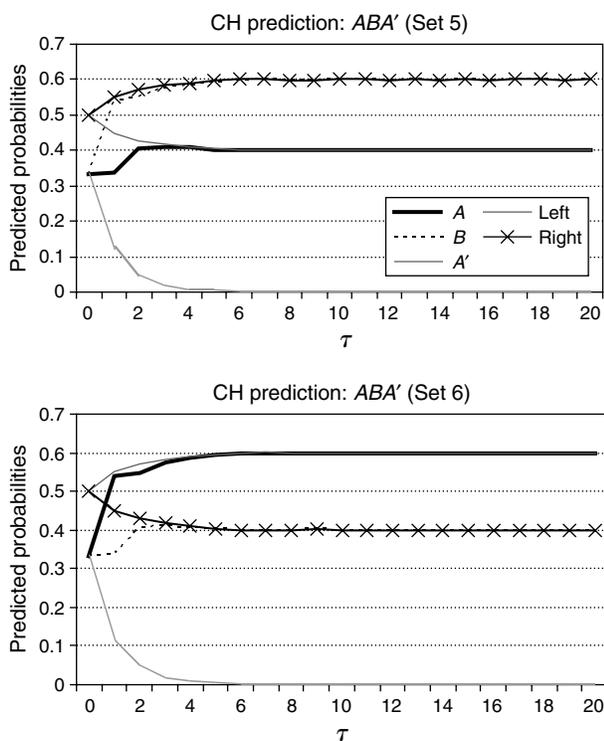
[4] $AIC = LL - k$ and $BIC = LL - (k/2) \times \log(M)$, where k is the number of degrees of freedom and M is the sample size. The pseudo-R^2 (ρ^2) is the difference between the AIC measure and the LL of a model of random choices, normalized by the random model LL.

[5] matrix sets 1 to 4, the actual values of $p(A \mid \{A, B, A'\})$ were 46.67%, 60%, 68.33%, and 43.33%, and the corresponding predictions of the extended CH model were 45.39%, 59.27%, 65.78%, and 42.53%, respectively. Similarly, the values of $p(B \mid \{A, B, B'\})$ were 53.33%, 40%, 39.17%, and 60% for sets 1–4, and the corresponding predictions of the extended CH model were 57.78%, 42.03%, 39.31%, and 62.94%, respectively.

4.1. Discussion

Although the basic CH model can address the lack of mutual consistency in the beliefs of participants, it cannot account for asymmetry in the choices of our participants. However, the extended CH model, which allowed for increased psychological attractiveness of dominating choices, better predicted the asymmetric dominance effects. This empirical analysis clarifies that limited thinking alone is not sufficient to account for the asymmetric dominance effect and highlights that the effect is a consequence of systematic shifts in the attractiveness of the dominating choices. One might wonder whether the quantal response equilibrium model (McKelvey and Palfrey 1995) can account for the data. Again, as this model of bounded rationality would also treat the ABA' and ABB' matrices symmetrically, it would not be able to account for the data.

Finally, the participants in Study 2 changed their choices over the several iterations of the game. Next, we examine whether a learning model can capture the dynamics in the choices of our participants over the several iterations of the game.

5. Trends in Choices and Adaptive Learning

In Study 2, we observed trends in the choices of both Row and Column players. It is easy to appreciate these trends in a plot of the average choice probabilities for each of 40 trials of the game (see Figure 2). In all but one case (the ABB' matrix of set 5), the Row players chose the dominating choice with a higher probability in the very first trial of the game. Further, in the ABB' matrices, there was a marked shift toward the pure-strategy solution (B, Left) by the *last* block of five trials: at least eight of the nine Row players chose B, and similarly at least seven Column players chose Left. In the ABA' matrices, there was greater variability in the choices, but the shift away from the mixed-strategy solution toward (A, Right) was still discernible. Next, we examine whether the dynamics in the choices of our participants can be parsimoniously explained by adaptive learning mechanisms.

Several adaptive learning models have been proposed in the experimental economics literature (e.g., Roth and Erev 1995; see Camerer 2003 for a recent review). In this section, we use the EWA learning model proposed by Camerer and Ho (1998) to understand the behavior of our participants. We chose the EWA model because it could shed light on two questions.

(1) *What adaptive mechanism can account for the behavior of our participants*? Two very important classes of learning mechanisms are *belief learning* and *classical reinforcement learning*. In belief learning, players choose their strategy based on past actions of their opponents. In reinforcement learning, on the other hand, strategy choices are made based on some weighted average of payoffs earned in the past. Thus, in reinforcement learning, players do not have to form beliefs about others, and this is a weaker information condition than that implied by the mixed-strategy equilibrium. The learning analysis can clarify to what extent the predictions of asymmetric dominance and mixed-strategy equilibrium may survive when players are only boundedly rational. We found that although the Row players formed some beliefs about the Column players, their behavior was more closely aligned with reinforcement learning. The Column players' choices were primarily guided by past reinforcements, and they were quick in learning from experience.

(2) *What was the prior disposition of our participants*? The EWA model allows us to better understand the prior disposition of our participants after accounting for the learning dynamics. We found that the Row players were predisposed to choosing the dominating strategy. The incremental attractiveness of the dominating strategy was estimated to be 6.95%, consistent with the finding reported in Wedell and Pettibone (1996) and our earlier extension of the CH model. The Column players, on the other hand, evinced no strong predisposition to play either Left or Right, a finding consistent with the results of Study 1. Thus, the asymmetric dominance effect, together with reinforcement learning, may be sufficient to achieve coordination.

5.1. Results of EWA Model Estimation

In the appendix, we provide a brief discussion of the EWA model structure and its implications. Here, we first discuss how the EWA model can account for the observed behavior of the Row players in the ABA' and ABB' matrices of sets 5 and 6. Later, we examine the behavior of the Column players in these matrices.

5.1.1. Behavior of the Row Players in the ABA' and ABB' Matrices. A total of 36 participants played 40 trials as the Row players across the two ABA' and two ABB' matrices in sets 5 and 6. In an attempt to parsimoniously account for the behavior of our participants, we fit a common model for all these four matrices. We calibrated the model using the strategy choices of 24 Row players (2/3 of the sample) and validated the model using the choices of the remaining 12 Row players (1/3 of the sample). The upper panel of Table 9 presents the fit statistics for the calibration sample, and the lower panel shows the corresponding statistics for the validation sample. To facilitate model comparison, we provide information on LL, AIC, BIC, pseudo-R^2, and χ^2 statistics.

Figure 2   Trends in Choices (Study 2)
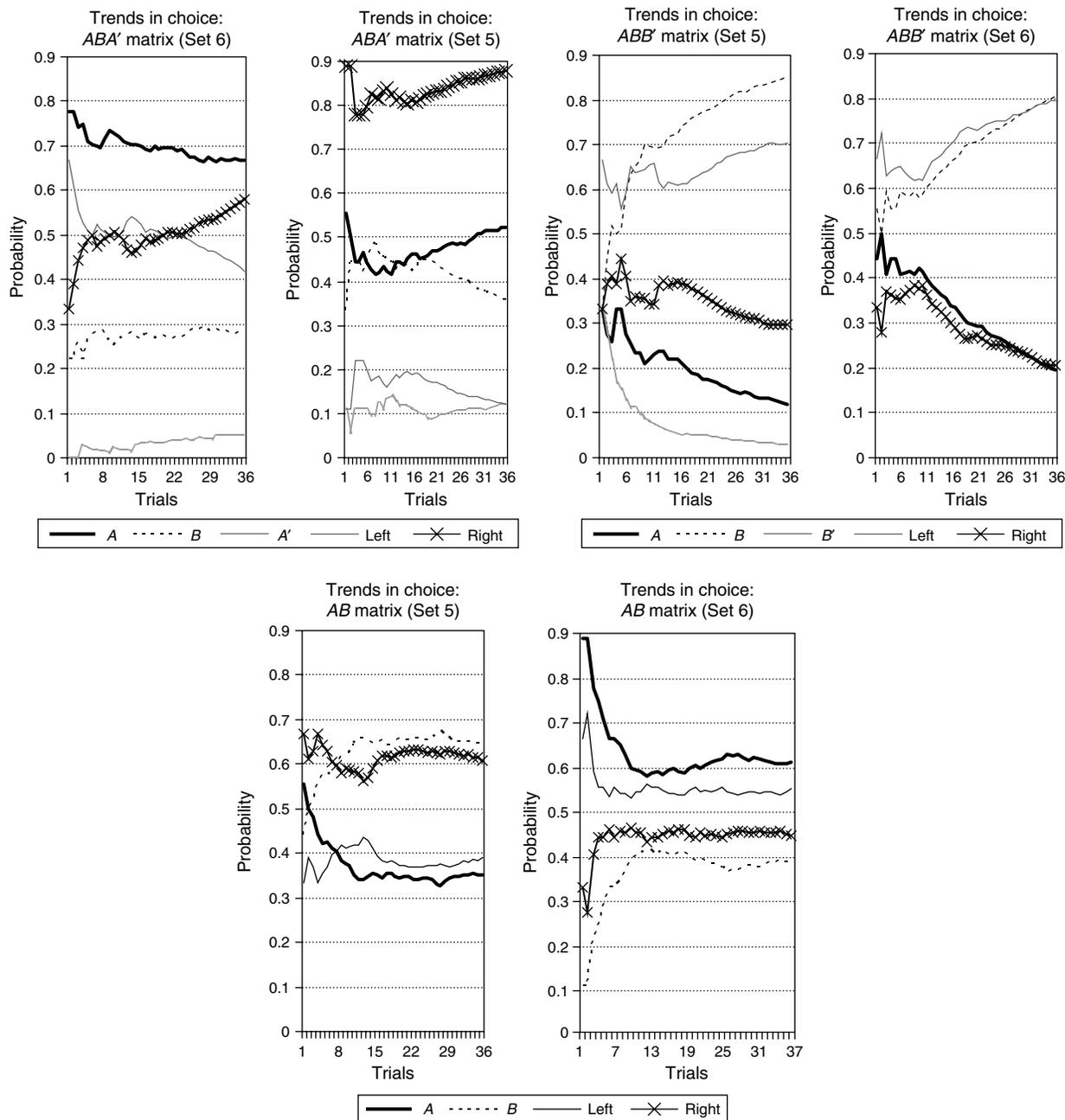
The EWA model tracked the behavior of the Row players quite well. It performed marginally better than reinforcement learning, but substantially outperformed pure belief learning. In the calibration sample, the LL of the EWA, reinforcement, and belief learning models were -534.733, -538.302, and -635.021, respectively. The pseudo-R^2 of the EWA model was 0.501, and the overall hit ratio of the EWA model was 76.14% in the calibration sample. In the four individual ABA' and ABB' matrices, the hit ratios ranged from 65.42% to 85.42%. These fit statistics compare favorably with the results reported in Camerer et al. (2002).

5.1.2. Interpretation of the Parameter Values. The parameter ϕ measures the extent to which participants depreciate past attraction of a strategy, whereas the parameter ρ captures the rate at which players discount past experience. The estimated value of $\phi = 0.882$ was greater than the estimate of $\rho = 0.507$, implying that our participants probably used some combination of "cumulative" performance and "average" performance to evaluate

Table 9   EWA Learning Model

Reward	Parameter	Row players			Column players		
		EWA	Reinforcement-based	Belief-based	EWA	Reinforcement-based	Belief-based
Calibration sample	ρ	0.507***	0.000	0.990	0.950***	0.000	0.625***
	φ	0.882***	0.845***	0.990***	0.549***	0.572***	0.653***
	δ	0.282***	0.000	1.000	0.000	0.000	1.000
	λ	0.065***	0.032***	0.894***	1.946***	0.075***	0.266***
	Log-likelihood	−526.733	−538.302	−635.021	−370.153	−377.300	−452.932
	AIC	−534.733	−544.302	−641.021	−378.153	−382.300	−458.932
	BIC	−554.200	−558.903	−655.622	−397.620	−394.467	−473.533
	Pseudo-ρ^2	0.501	0.490	0.398	0.444	0.433	0.319
	χ^2		23.139	216.576		14.295	165.559
	(*p*-value, d.o.f.)		0.000	0.000		0.003	0.000
	Overall hit ratio	0.761	0.754	0.722	0.822	0.828	0.770
Validation sample	Log-likelihood	−263.303	−267.313	−345.507	−206.999	−209.689	−246.874
	AIC	−271.303	−272.313	−351.507	−214.999	−214.689	−252.874
	BIC	−287.998	−281.014	−361.949	−231.694	−225.124	−265.395
	Pseudo-ρ^2	0.501	0.493	0.345	0.378	0.370	0.258
	χ^2		8.020	164.409		5.381	79.750
	(*p*-value, d.o.f.)		0.046	0.000		0.146	0.000
	Overall hit ratio	0.775	0.783	0.738	0.769	0.777	0.738

***Significant at 0.01 level.

strategies. In reinforcement learning, strategy choices are based on some weighted average of previously received payoffs, not foregone payoffs. The weight placed on foregone payoffs is indicated by the parameter δ. Consequently, $\delta = 0$ in the case of pure reinforcement learning. In belief models, on the other hand, the expected payoffs are equal to a weighted average of payoffs received from previously chosen strategies and foregone payoffs of strategies which were not chosen, implying that $\delta = 1$. Our estimate of δ was 0.282, implying that the Row players followed neither pure reinforcement learning nor pure belief learning. Rather, they pursued a hybrid learning mechanism that was much closer to reinforcement learning, as reflected in fit statistics such as LL, AIC, and BIC (see Table 9). Finally, the estimated size of λ was 0.065, suggesting that the players were modestly sensitive to payoff changes.

5.1.3.   Pregame Disposition. As discussed earlier, one potential explanation for the asymmetric dominance effect is that people are naturally attracted to the dominating option in the presence of an asymmetrically dominated choice. The EWA model allows us to examine the initial disposition of players to choose the dominating strategy at the commencement of the game and also to assess the strength of this predisposition. The Row players' initial attraction toward the dominated choice, dominating choice, and the undominated choice were found to be 1.800, 31.791, and 29.725, respectively. Thus, the dominating choice was 6.95% more attractive than the undominated choice, a finding again consistent with the 6%–8% incremental value reported in individual decision-making research (Wedell and Pettibone 1996). The

strength of this predisposition was 6.63, implying that it was strong enough to last for six trials. Overall, the pregame disposition of the Row players was consistent with the asymmetric dominance effect. In addition, it was strong enough to facilitate adaptive dynamics to further build on it and shift the Row players' choices toward the pure-strategy equilibrium consistent with the specific asymmetric dominance effect.

5.1.4.   Model Validation. The model was validated in the hold-out sample of 12 Row players. In the validation sample, the LL of the model, AIC, and BIC were, respectively, −263.303, −271.303, and −287.998. The pseudo-R^2 was 0.50, and the overall hit ratio was 77.5%. Thus, the performance of the EWA model in the validation sample was comparable to that in the calibration sample. In an attempt to discern whether the underlying learning process varied by type of matrix, we estimated a separate set of parameters for the ABA' matrices and another set for the ABB' matrices. This additional analysis revealed that in both cases, subjects were guided by hybrid learning, rather than pure reinforcement or pure belief learning. We present details of this additional analysis in the online technical appendix.

5.1.5.   Behavior of the Column Players in the ABA' **and** ABB' **Matrices.** In contrast to the choices of the Row players, the Column players' decisions can be better tracked by reinforcement learning. Note that AIC adjusts log-likelihood to account for the number of model parameters, while BIC modifies LL to better account for sample size as well as number of parameters. On both these criteria, reinforcement learning

performed far better than belief learning. It is only marginally better than the EWA model on BIC. Much like the preceding analysis of the Row players, we calibrated the model with the strategy choices of 24 Column players over 40 trials (2/3 of the sample) and validated the model with the data from the remaining 12 Column players (1/3 of the sample). In the calibration sample, the reinforcement model's pseudo-R^2 was 0.433, and its overall hit ratio was 82.81%. The hit ratios for the four individual matrices ranged from 77.92% to 89.16%.

5.1.6. Interpretation of the Parameter Values. The parameter estimates are presented in the right panel of Table 9. The estimated value of δ was zero, implying that the strategy choices of the Column players were primarily driven by some weighted average of previously received payoffs.[6] This is consistent with the poor performance of the pure belief learning model. The estimated size of λ was 0.075; thus, the payoff sensitivity of the Column players was comparable to that of the Row players (0.065). Further, the estimated value of $\phi = 0.549$ was lower than the corresponding estimate for the Row players (0.882), suggesting that the Column players were quicker in discarding old observations and relied more on recent observations for determining their strategy choices.

5.1.7. Pregame Disposition. If the Column players fully anticipated the asymmetric dominance effect on the Row players, then they should choose Right in the ABA' matrices but Left in the ABB' matrices. We found that the initial attraction of strategies consistent with the asymmetric dominance effect was 18.28, whereas the attraction of the opposite strategies, namely, Left in ABA' matrices and Right in ABB' matrices, was marginally higher at 18.61. This predisposition was strong (34.23). Thus, the Column players probably did not anticipate the asymmetric dominance effect. However, as indicated by the low ϕ, they learned quickly from experience.

5.1.8. Model Validation. In the validation sample, reinforcement learning also performed marginally better than the EWA model. The LL, AIC, and BIC of reinforcement learning were −209.689, −214.689, and −225.124, respectively. The pseudo-R^2 of reinforcement learning was 0.37, lower than that observed in

the calibration sample. Further, the overall hit ratio was 77.7%.

5.2. Discussion
In sum, the EWA model captured the major behavioral regularities observed in our data. The learning analysis showed that the predisposition of the Row players was in keeping with the asymmetric dominance effect. Although the Column players did not anticipate the effect, the Row players' predisposition was strong enough to steer the Column players toward the pure-strategy equilibrium in the direction of the asymmetric dominance effect. Further, the Column players were quick to learn from experience. For completeness, we also estimated the EWA model parameters for the AB matrices of sets 5 and 6, with the EWA model also performing well in tracking the behavior of those participants.[7]

6. Conclusion

Asymmetric dominance is a well-established psychological phenomenon in individual decision-making contexts. In this paper, we explored some potential implications of the phenomenon for strategic decision making. Specifically, our empirical investigation answers the following questions about asymmetric dominance effects.

(1) *Are players susceptible to asymmetric dominance effects in strategic contexts*? Our research shows that the answer is clearly yes. Consistent with the individual decision-making literature, participants in our two studies selected (weakly) dominating strategy choices more often. This implies that rather than deleting dominated choices without any consequence for strategy selection, noting the dominance relationship instead systematically increases the frequency of choosing the dominating choice. Cooper et al. (1990) highlighted the relevance of dominated strategies, but they did not anticipate this asymmetric dominance effect.

There are several important differences between our study and the work of Cooper et al. (1990). First, they investigated the Battle of the Sexes game with

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[6] When we allowed for heterogeneity among players, we found that some Column players were guided to some degree by foregone payoffs. If the EWA model is estimated for a representative agent, without allowing for heterogeneity, the value of δ tends to be biased downward (see Wilcox 2006 and Camerer and Ho 1998). Our results are consistent with this observation in the case of the Column players, but we do not observe such a bias in the case of the Row players, even after allowing for heterogeneity. We present the parameter values obtained by estimating the EWA model after allowing for latent classes in the online technical appendix.

[7] The Row players in the AB matrix of set 5: LL = −147.751, AIC = −155.751, BIC = −169.673, pseudo-R^2 = 0.44, hit ratio = 66%, λ = 0.356, ρ = 1, ϕ = 0.965, δ = 0. The Row players in the AB matrix of set 6: LL = −138.220, AIC = −146.220, BIC = −157.912, pseudo-R^2 = 0.45, hit ratio = 70%, λ = 0.077, ρ = 0.935, ϕ = 1, δ = 0.266. The Column players in the AB matrix of set 5: log-likelihood = −103.471, AIC = −111.471, BIC = −125.394, pseudo-R^2 = 0.608, hit ratio = 79%, λ = 0.624, ρ = 0.937, ϕ = 0.731, δ = 0.232. The Column players in the AB matrix of set 6: LL = −129.329, AIC = −137.329, BIC = −151.252, pseudo-R^2 = 0.51, hit ratio = 68%, λ = 0.405, ρ = 1, ϕ = 0.955, δ = 0.007. On examining the initial attractiveness of choices, we noted that the Column players were marginally predisposed to play Left. The Row players, on the other hand, do not have such a systematic predisposition across the two matrices.

an additional dominated strategy for both the Row and Column players (a 3×3 game). We studied the Leader game with a (weakly) dominated strategy for the Row player (a 3×2 game). Second, participants in their studies (Games 3–6) tended to choose a Pareto-inferior equilibrium, whereas our participants chose the Pareto-dominant equilibrium more often. Third, Cooper et al. (1990) offered two potential explanations for their results: existence of altruists and uncertainty about the rationality of opponents. Additional studies (Games 7 and 8) clarified that the behavior of their participants was probably driven by the expectation that some of their opponents were altruists. We offer a different explanation for our results: the Row players chose the dominating strategy because of its increased psychological attractiveness, as implied by the asymmetric dominance effect. The Column players also appreciated this point and accordingly shifted their choices to reach a Pareto-dominant equilibrium (Schelling 1960).[8] Finally, these shifts toward Pareto-dominant equilibria were in the directions predicted by the asymmetric dominance effect.

(2) *Can asymmetric dominance serve as a coordination device?* Study 2 indicates that with feedback participants can better appreciate the reasoning implied by the asymmetric dominance effect over the multiple iterations of a game, and the effect grows in strength. Consequently, we observe a greater level of coordination in Study 2. This raises the possibility that asymmetric dominance can facilitate coordination to a Pareto-dominant equilibrium. For example, consider the simple case where two symmetric firms have to simultaneously decide which of two markets to enter. In this case, it is beneficial if the two firms enter different markets rather than the same market. In such a situation, the presence of an asymmetrically dominated choice could focus attention on the dominating choice and thereby help players to coordinate their decisions.

(3) *What can account for the asymmetric dominance effects observed among the participants?* Our analysis suggests that limited steps of thinking alone cannot account for the experimental results. The CH model, for example, predicts the same results for our ABA' and ABB' matrices, and thus cannot account for the asymmetric effects we observe. More generally, any model that predicts the same effects for the ABA' and ABB' cases cannot account for our results.

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[8] Note that participants in our studies more often chose {*A*, Right} in the ABA' matrices but {*B*, Left} in the ABB' matrices. Clearly, equilibrium {*A*, Right} favors the Column players, but equilibrium {*B*, Left} is advantageous to the Row players, implying that who (Row/Column player) plays the role of an altruist is contingent on which is the dominating strategy. We argue that the attractiveness of the dominating strategy, rather than altruism, provides a better explanation for our results.

The literature in individual decision making suggests that a choice option accrues an incremental value if it dominates another option (Wedell and Pettibone 1996). After extending the CH model to allow for such increased psychological attractiveness of the dominating choice, we found that the model fit improved substantially. Our estimates of the incremental psychological attractiveness ranged from 3%–6%, comparable to the incremental values observed in individual decision making (Wedell and Pettibone 1996). A learning analysis of the choices of participants provided further evidence that the Row players were predisposed to choose the dominating strategy. This analysis also highlighted that this predisposition, along with adaptive learning, may be sufficient to produce a coordinated outcome.

(4) *What are some managerial implications of our research?* An implication of our research is that the psychological structure of a strategic decision-making context can influence the economic outcome (see also Lim and Ho 2007). Note that the Row players in our Leader game enjoyed more favorable outcomes when participants played ABB' matrices. If the Row player strategically anticipates such an outcome, then clearly the Row player can engineer the decision-making context to reflect the spirit of ABB' matrices. Even for the Column player, the outcome in the ABB' game is beneficial compared to the mixed-strategy outcome of the reduced game (without B'). This insight can be leveraged to help firms and consumers attain more efficient outcomes.

For example, consider products such as computer software, hardware, and many other high-tech products where the benefits derived on purchasing the product depend on how many other consumers use the product (Katz and Shapiro 1985). In such product categories, marketing a well-designed dominated option can systematically shift sales toward the dominating option and help consumers enjoy the benefits of a larger network of buyers. In this case, the asymmetric dominance effect along with positive network externality may increase consumer willingness to pay for the dominating option, and thereby improve firm's profit margin as well as sales.

As another example, consider warranties for products such as expensive electronic gadgets and cars. The performance of these products depends not only on their quality but also on consumer care. This presents two challenges. First, because firms are not able to monitor the care with which consumers use and maintain their products, consumers can shirk costly efforts to maintain the product, and firms cannot make their warranties conditional on consumer care. Second, because consumers are not able to directly observe product quality, it gives incentives for the firm to offer a lower-quality product in the

absence of warranties. Consequently, we may observe consumers shirking in their effort and firms offering a lower-quality product (compared to the full-information case, where quality is observable and consumers can be monitored). Perhaps firms could design an asymmetrically dominated warranty plan so that consumers purchase the dominating warranty plan, which leads to a higher level of product quality and consumer care. Future research can explore such applications of asymmetric dominance effects in product quality choices (Mitra and Golder 2006). Another avenue for future research is to develop inference procedures that can discern asymmetric dominance effects in choices commonly made by consumers (Kohli and Jedidi 2007).

Finally, in this research we have examined the implications of asymmetric dominance for Leader games, which is a class of coordination games. Future research might examine asymmetric dominance effects in other games such as zerosum mixed-strategy games (e.g., O'Neill's game). In zerosum games with a unique mixed-strategy solution, there is no scope for coordination. Further, the Column player would be motivated to exploit any potential bias in the Row player's thinking, and it is possible that the Row player could well anticipate such a behavior. As a result, asymmetric dominance may affect the distribution of choices in different ways than in the nonzerosum games studied above. Another avenue for future research is to explore the strategic implications of asymmetric dominance using more natural stimuli such as product descriptions. In a pure two-person coordination game, we could well present consumers descriptions of products corresponding to A, B, and A' (or, A, B, and B') options, as done in consumer research (e.g., Huber et al. 1982, Simonson 1989, Simonon and Tversky 1992). If both players privately choose the same product, they can be offered some payoff. In this game also, the asymmetric dominance effect should steer participants toward the dominating choice. Thus, we believe that the common decision-making bias of asymmetric dominance may play an important role in helping to coordinate decisions to efficient outcomes in a variety of strategic contexts.

Appendix

The EWA Learning Model. This model has been applied in several contexts and has been shown to have good predictive accuracy (see Camerer et al. 2002, Amaldoss and Jain 2002, and Rapoport and Amaldoss 2000). To facilitate exposition of the model, we focus our discussion on the strategies of the Row players, although the model also is later used to account for the behavior of the Column players. A Row player in the ABA' and ABB' matrices could choose one of three strategies in every trial: a dominated choice, a dominating choice, or an undominated choice. We denote these three choices by $x_i = 0$, $x_i = 1$, and $x_i = 2$, respectively. Based on the past choices of player i, the EWA model predicts the probability that the player will choose $x_i = m$ in the next period:

$$p_i^m(t+1) = \frac{e^{\lambda A_i^{x_i^m}(t)}}{\sum_{j=0}^{2} e^{\lambda A_i^{x_i^j}(t)}},$$

where $A_i^{x_i^m}(t)$ is the attractiveness of strategy choice $x_i = m$ for player i at time t. The parameter λ measures the sensitivity of players to attractions. This parameter can also be interpreted as an indicator of the level of noise in the strategy selection process. At the end of every trial, player i updates the attractiveness of a strategy based on the actual payoff and also the expected payoffs corresponding to the strategies that were not chosen. While updating the attraction of a strategy, payoffs corresponding to chosen strategies are given a weight equal to one, while expected payoffs corresponding to unchosen strategies are given a weight of δ ($0 \le \delta \le 1$). The size of parameter δ reflects the extent to which players care about foregone payoffs. Previous attractions are depreciated by ϕ ($0 \le \phi \le 1$). This depreciation is a consequence of forgetting and the degree to which players recognize that other players are adapting, and thereby place lower weight on the history of the game. If ϕ is small in size, it suggests that players are discarding old observations more quickly and becoming more responsive to recent observations. In updating the attractiveness of a strategy, the EWA model weights past attractiveness with the number of observations-equivalents of past experience, namely, $N(t)$. $N(t)$ is a weighted combination of the number of times the game has been played, and it is given by

$$N(t) = \rho N(t-1) + 1,$$

where ρ ($0 \le \rho \le 1$) is the rate of depreciation and $t \ge 1$. The attraction of playing strategy $x_i = m$, namely, $A_i^{x_i^m}(t)$, is a weighted average of the payoff for period t and the previous attraction $A_i^{x_i^m}(t-1)$ as shown below:

$$A_i^{x_i^m}(t)$$
$$= \frac{\phi N(t-1) A_i^{x_i^m}(t-1) + [\delta + (1-\delta) I(x_i^m, x_i(t))] \pi_i(x_i^m(t), x_{-i}(t))}{N(t)},$$

where $\pi_i(x_i^m(t), x_{-i}(t))$ is the payoff received by player i by selecting choice $x_i^m(t)$ when the opponent plays $x_{-i}^m(t)$. The indicator function $I(x_i^m, x_i(t))$ is defined as follows:

$$I(x_i^m, x_i(t)) = \begin{cases} 1 & \text{if } x_i(t) = x_i^m, \\ 0 & \text{otherwise.} \end{cases}$$

Hence, if player i selects strategy $x_i^m(t)$, then the resulting payoff is added to the attraction of the corresponding strategy, $A_i^{x_i^m}(t)$. But if the individual does not play $x_i^m(t)$, then

only δ fraction of the payoff is added to the attractiveness of $A_i^{x_i^m}(t)$. The initial values of $N(t)$ and $A_i^{x_i^m}(t)$ are denoted by $N(0)$ and $A_i^{x_i^m}(0)$.

If our participants followed classical reinforcement-based learning, then we should observe $N(0) = 1$, $\delta = 0$, and $\rho = 0$. On the other hand, if they were following a pure belief learning process, then we should find $\delta = 1$ and $\rho = \phi$. Thus, the parameter values provide us some insight into the underlying adaptive dynamics in the choices of our participants. In addition, the asymmetric dominance effect predicts that the Row players should be naturally attracted toward the dominating choice more than the undominated choice. If so, then we should observe that $A^{x^1}(0) > A^{x^2}(0)$. The size of $N(0)$ might indicate the strength of the predisposition.

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