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RESEARCH ARTICLE

Beyond Hawks and Doves: Can inequality ease coordination?

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Abstract
It is often argued that inequality may worsen coordination failures as it exacerbates conflicts of interests, making it difficult to achieve an efficient outcome. This paper shows that this needs not to be always the case. In a context in which two interacting populations have conflicting interests, we introduce ex-ante inequality, by making one population stronger than the other. This reduces the cost of miscoordination for the weakest population, and at the same time it makes some equilibria more equitable than others, thus more focal and attractive for inequality-averse players. Hence, both social preferences and strategic risk considerations may ease coordination. We provide experimental support for this hypothesis, by considering an extended two-population Hawk–Dove game, where ex-ante inequality, number of pure-strategy equilibria, and cost of coordination vary across treatments. We find that subjects coordinate more often on the efficient outcomes in the treatment with ex-ante inequality.

Keywords Asymmetric payoff matrix · Conditional cooperation · Equilibrium selection · Experiment · Hawk–Dove game · Inequality aversion

JEL classification C72 · C91 · D63 · D74

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1 Introduction

Coordination failures (between countries, social/interest groups, or individuals) occur everywhere, often leading to conflicts that might be very costly for involved parties.[1] The roots of coordination failures are very diverse and context-specific. This paper studies coordination failures in which a trade-off emerges between equality and efficiency, as any stable agreement allocates resources unequally among the conflicting parties. Such a framework characterizes several economically relevant situations—such as trade wars, military battles, collective bargaining, and legal disputes—of which the Hawk–Dove game is the prototypical example.

In this paper, a critical emphasis is placed on whether, before any actions, the two parties are identical—potentially leading to symmetric agreements—or if there is an initial imbalance in their relative strength. In the latter case, when the strongest party prevails, the settlement heavily favors the winner while disadvantaging the loser significantly. On the contrary, when the initially weaker party prevails, the final agreement tends to be more equitable. A typical example of such an unbalanced conflict is salary negotiation between workers and employers. This wage bargaining scenario fits well within the theoretical framework of a hawk-dove game with pre-existing payoff inequality, where the owner's profits are significantly larger than the workers' earnings. Workers can strike (hawk) or negotiate while working (dove), while the owner can refuse demands and replace workers (hawk) or negotiate and make concessions (dove). As usual, both parties choosing hawk results in high losses for both, while cooperation or one-sided aggression yields varied outcomes. However, the owner's higher profits and greater stakes-halted production, potential revenue losses, and the risk of long-term damage to the business-make them more likely to concede. Similar asymmetries between payoffs and stakes are observed in peace treaty negotiations between victors and the vanquished at war's end, as well as in industrial organization scenarios such as competition with product differentiation between an incumbent and a new entrant (Cabrales et al. 2000).

The recent experimental literature on the Hawk–Dove game focused on the evolutionary dynamics of inter- and intra-group interactions (Oprea et al. 2011; Benndorf et al. 2016, 2021). Typically, this literature considers the symmetric version of the game, where the two pure-strategy equilibria are ex-ante equally likely to emerge,[2] and on the theoretical and empirical differences in the dynamics of behavior in one- and two-population models.

Our focus here is instead on the impact that ex-ante inequality has on coordination. Inequality is a pressing issue in the economic and political sphere. It is often argued that inequality, by being an accelerator of tensions between groups, may worsen a conflictual situation, leading to coordination failures.[3] To explore whether the presence

[1] Coordination failures may also have positive externalities, for example the difficulty to collude has a positive impact on the competitive level of the market.

[2] The one exception we are aware of is the recent theoretical paper by Bilancini et al. (2021) which also considers the case of asymmetric payoff matrices.

[3] One of the reasons often mentioned is that some individuals have some strong preferences for fairness and may not accept to coordinate on an outcome considered as "unfair" (Bolton and Ockenfels 2000; Fehr and Schmidt 1999; Charness and Rabin 2002).

of inequality fosters or hinders coordination, we compare a set-up in which the payoff matrix is symmetric (no ex-ante inequality) with one in which the two conflicting players have different strengths. This links our paper to the recently expanding literature that explores the impact of inequality on coordination in different game-theoretical setups (Tavoni et al. 2011; Abbink et al. 2018; Camera et al. 2020; Feldhaus et al. 2020; Isoni et al. 2020). While the results from previous papers indicate that inequality either hinders coordination on the efficient equilibrium, or – at best – does not interfere with it, in our set-up inequality actually eases coordination and promotes efficiency.

We consider an extended version of the Hawk-Dove game to account for the fact that people do not always fight to death or fully accommodate; rather, they choose their action between these two extreme options. Subjects can choose from a set of eleven possible values (labeled from 0 to 10). The structure of the payoff matrix is such that an equitable and efficient allocation exists, but it is not sustainable in equilibrium, so there is a trade-off between equality and efficiency. Indeed, all equilibria lead to unequal payoffs between players but the degree of inequality as well as the number of pure-strategy equilibria differ across treatments. In line with the recent literature, we consider a two-population model, which is closer to the real-world environments we would like to mimic, and also allows for coordination on the pure-strategy equilibria to emerge as an evolutionary stable outcome (Oprea et al. 2011).

Our design comprises three treatments. In the BASELINE treatment, the game is perfectly symmetric and there are three pure-strategy equilibria where one player receives thrice as much as the other one, and three equilibria where the situation is reversed. In the ASYMMETRIC treatment, players are characterized by different “strengths”, and the payoff matrix is modified so that, for each combination of choices, the strongest player earns more than in the BASELINE, while the weakest player earns less. Thus, the payoff matrix becomes asymmetric. The number of pure-strategy equilibria is still six, but with a different payoffs distribution. In two of these equilibria, the strong player earns almost seven times as much as the weak one, while in the other four pure-strategy equilibria, the weak player earns almost twice as much as the strong one. The RESTRICTED treatment is similar to BASELINE but has only two pure-strategy equilibria, and has a lower cost associated to miscoordination.

The literature on outcome-based inequality aversion (Fehr and Schmidt 1999; Bolton and Ockenfels 2000; Charness and Rabin 2002) would imply that – in the ASYMMETRIC treatment – subjects coordinate on one of the least unequal Nash equilibria. Furthermore, according to the focal point literature, payoff equality is a crucial factor that drives saliency. The concept of saliency was first introduced by Schelling (1980), and later widely explored, both theoretically (Sugden 1995) and empirically, by means of controlled experiments (see Cooper and Weber (2020), for a comprehensive review). While most contributions focused on pure-matching games, where no conflict of interest emerges between players (see, e.g., Bardsley et al. (2010); Hargreaves Heap et al. (2014)), a strand of this literature also explored the case in which coordination is associated with payoff asymmetries. Within this line of research, empirical results reveal that players may be more likely to coordinate towards a more equitable outcome (Isoni et al. 2014; Luhan et al. 2017). This suggests that, when this more equitable – thus focal – outcome aligns with an equilibrium, such as in the ASYMMETRIC treatment, tacit coordination should be easier to achieve. By contrast, in the BASELINE and

Restricted treatments, although a perfectly equitable and fully efficient outcome exists, it cannot be sustained in equilibrium. Hence, payoff-focality here can impair coordination, rather than easing it.

Strategic considerations can also promote coordination on the most equitable equilibria in the Asymmetric treatment. In this treatment, playing "dove" (which is the least risky strategy) enables the strong players to secure a higher payoff, as compared to the other treatments. As a consequence, strong players may be more inclined to prefer this option over a more hawkish but riskier strategy, in the Asymmetric than in the other two treatments. In the Restricted treatment, instead, the coordination issue may seem less severe compared to the Baseline since we have only two – instead of six – pure-strategy equilibria. On the other hand, this treatment also reduces the cost of miscoordination, because the Pareto-dominated (but perfectly equitable) outcome where both players play "hawk" here is more profitable than in the Baseline. Subjects who are averse to outcome-based inequality, thus, might have a stronger incentive to play hawkish strategies in this treatment than in the Baseline. Strategic risk considerations also push in the same direction: by making the hawkish strategies less risky, and on average more profitable, the Restricted treatment reduces the strategic incentives to coordinate on the efficient, pure-strategy equilibria.

Thus, with our experiment we explore three questions related to coordination failure and inequality: (i) whether coordination on the efficient equilibrium is easier to achieve when the payoff matrix is asymmetric; (ii) whether – in the Asymmetric treatment – players coordinate on the more equitable equilibrium, and (iii) whether coordination on efficient equilibrium outcomes is easier when the cost of miscoordination is higher, or when the number of pure-strategy equilibria is lower.

There are two main results. First, making the game asymmetric seems to simplify coordination: subjects in the Asymmetric treatment are able to coordinate more often on pure-strategy NE, leading to higher efficiency. In particular, they coordinate on the least inequitable among the equilibria. To better understand the determinants of this result, we look at the individual behavior, which differs across treatments. In the Baseline and Restricted treatments, players tend to be imperfect conditional cooperators (Fischbacher et al. 2001), who play "dove" more often when they expect their opponents to do the same. In the Asymmetric treatment, instead, the players tend to best respond (play "dove" against "hawk" and vice versa), with the weak ones being more aggressive than the strong ones, overall. Thus separation between "hawks" and "doves" emerges prominently only in the Asymmetric treatment, where we observe specialization, but not in the other treatments. Our second result is that restricting the number of (pure strategy) equilibria (in absence of ex-ante inequality) does not seem to facilitate coordination. Comparing Baseline and Restricted treatments, we find no differences in terms of aggregate efficiency or individual behavior.

Our paper proceeds as follows. Section 2 describes the game and introduces our theoretical hypotheses; Sect. 3 presents the experimental design and methodology; Sect. 4 illustrates the results and Sect. 5 concludes.

2 Set-up and hypotheses

We consider a generalized version of the Hawk–Dove game, which allows for asymmetric payoffs, and for an expansion of the action set. In our setup, there are two players characterized by parameters s_1 and s_2, where $s_1 \geq s_2 > 0$, which we can interpret as their relative "strength." Each player simultaneously and independently chooses his action, $a_i \in [\underline{a}, \bar{a}]$, $i = 1, 2$, where $\underline{a}$ and $\bar{a}$ are exogenously determined and equal for both players. A player i's payoff is defined as:

$$\pi_i(a; \theta, s) = \begin{cases} a_j s_i & \text{if } a_i < a_j \\ a_i \dfrac{s_i}{s_i + s_j} \theta & \text{if } a_i = a_j \\ a_i(\theta - s_j) & \text{otherwise} \end{cases} \tag{1}$$

where $\theta \in [s_1, s_1 + s_2]$ parametrizes the size of the pie to be divided between the two players, and is exogenously determined.[4]

For the sake of simplicity, in the experiment we use a discrete choice set C with a given and fixed number n of elements: $C = \{\underline{a},\ \underline{a} + x,\ \underline{a} + 2x, \ldots, \bar{a}\}$, where $x = \frac{\bar{a} - \underline{a}}{n-1}$. In what follows, we denote the choice of player i by $c_i \in C$.

2.1 Parameters and treatments

Our first treatment variable is the minimum admissible action $\underline{a}$. By discretizing the choice set, we can manipulate the minimum admissible action without changing the number of choices available to subjects. This element is crucial to maintain the same game structure across treatments. We consider two alternatives:

(i) a *baseline* choice set C, and
(ii) a *restricted* choice set C', where $\underline{a}' > \underline{a}$.

The second treatment variable is the degree of asymmetry between players. We consider two scenarios: in the *symmetric* case, players have the same strength $s_1 = s_2 = s$; in the *asymmetric* one $s_1 > s_2$.

In total, we consider three treatments:

- BASELINE: with *baseline* set of actions, and *symmetric* strengths;
- ASYMMETRIC: with *baseline* set of actions, and *asymmetric* strengths;
- RESTRICTED: with *restricted* set of actions, and *symmetric* strengths.

Parameters. In the experiment, we set $\bar{a} = 10$, $\theta = 10$, and $n = 11$, that is: in all treatments players can select their choice from a set C of 11 possible values. In the BASELINE and RESTRICTED treatments, $s_1 = s_2 = 7.6$, while in the ASYMMETRIC treatment $s_1 = 8.7$ and $s_2 = 6.5$. In the BASELINE and ASYMMETRIC treatments, $\underline{a} = 1$, while in the RESTRICTED treatment $\underline{a}' = 3$. In all treatments, choices $c_i \in C$ are labeled from 0 to 10, and payoffs are rounded to integer numbers. The resulting payoff matrices are reported in Table 1.

[4] In our experiment, θ does not change across treatments.

Table 1 Payoff tables

	0 (hawk)	1	2	3	4	5	6	7	8	9	10 (dove)
0 (hawk)	5; 5	14; 5	21; 7	28; 9	35; 11	42; 13	49; 15	55; 18	62; 20	69; 22	**76; 24**
1	5; 14	10; 10	21; 7	28; 9	35; 11	42; 13	49; 15	55; 18	62; 20	69; 22	**76; 24**
2	7; 21	7; 21	14; 14	28; 9	35; 11	42; 13	49; 15	55; 18	62; 20	69; 22	**76; 24**
3	9; 28	9; 28	9; 28	19; 19	35; 11	42; 13	49; 15	55; 18	62; 20	69; 22	76; 24
4	11; 35	11; 35	11; 35	11; 35	23; 23	42; 13	49; 15	55; 18	62; 20	69; 22	76; 24
5	13; 42	13; 42	13; 42	13; 42	13; 42	28; 28	49; 15	55; 18	62; 20	69; 22	76; 24
6	15; 49	15; 49	15; 49	15; 49	15; 49	15; 49	32; 32	55; 18	62; 20	69; 22	76; 24
7	18; 55	18; 55	18; 55	18; 55	18; 55	18; 55	18; 55	37; 37	62; 20	69; 22	76; 24
8	20; 62	20; 62	20; 62	20; 62	20; 62	20; 62	20; 62	20; 62	41; 41	69; 22	76; 24
9	22; 69	22; 69	22; 69	22; 69	22; 69	22; 69	22; 69	22; 69	22; 69	46; 46	76; 24
10 (dove)	**24; 76**	**24; 76**	**24; 76**	24; 76	24; 76	24; 76	24; 76	24; 76	24; 76	24; 76	50; 50

(a) Baseline

	0 (hawk)	1	2	3	4	5	6	7	8	9	10 (dove)
0 (hawk)	15; 15	28; 9	33; 11	39; 12	44; 14	49; 16	55; 17	60; 19	65; 21	71; 22	**76; 24**
1	9; 28	19; 19	33; 11	39; 12	44; 14	49; 16	55; 17	60; 19	65; 21	71; 22	76; 24
2	11; 33	11; 33	22; 22	39; 12	44; 14	49; 16	55; 17	60; 19	65; 21	71; 22	76; 24
3	12; 39	12; 39	12; 39	26; 26	44; 14	49; 16	55; 17	60; 19	65; 21	71; 22	76; 24
4	14; 44	14; 44	14; 44	14; 44	29; 29	49; 16	55; 17	60; 19	65; 21	71; 22	76; 24
5	16; 49	16; 49	16; 49	16; 49	16; 49	33; 33	55; 17	60; 19	65; 21	71; 22	76; 24
6	17; 55	17; 55	17; 55	17; 55	17; 55	17; 55	36; 36	60; 19	65; 21	71; 22	76; 24
7	19; 60	19; 60	19; 60	19; 60	19; 60	19; 60	19; 60	40; 40	65; 21	71; 22	76; 24
8	21; 65	21; 65	21; 65	21; 65	21; 65	21; 65	21; 65	21; 65	43; 43	71; 22	76; 24
9	22; 71	22; 71	22; 71	22; 71	22; 71	22; 71	22; 71	22; 71	22; 71	47; 47	76; 24
10 (dove)	**24; 76**	24; 76	24; 76	24; 76	24; 76	24; 76	24; 76	24; 76	24; 76	24; 76	50; 50

(b) Restricted

	0 (hawk)	1	2	3	4	5	6	7	8	9	10 (dove)
0 (hawk)	6; 4	17; 2	24; 4	32; 5	40; 6	48; 7	56; 8	64; 9	71; 11	79; 12	**87; 13**
1	7; 12	11; 8	24; 4	32; 5	40; 6	48; 7	56; 8	64; 9	71; 11	79; 12	**87; 13**
2	10; 18	10; 18	16; 12	32; 5	40; 6	48; 7	56; 8	64; 9	71; 11	79; 12	87; 13
3	13; 24	13; 24	13; 24	21; 16	40; 6	48; 7	56; 8	64; 9	71; 11	79; 12	87; 13
4	16; 30	16; 30	16; 30	16; 30	26; 20	48; 7	56; 8	64; 9	71; 11	79; 12	87; 13
5	19; 36	19; 36	19; 36	19; 36	19; 36	31; 24	56; 8	64; 9	71; 11	79; 12	87; 13
6	22; 42	22; 42	22; 42	22; 42	22; 42	22; 42	37; 27	64; 9	71; 11	79; 12	87; 13
7	26; 47	26; 47	26; 47	26; 47	26; 47	26; 47	26; 47	42; 31	71; 11	79; 12	87; 13
8	29; 53	29; 53	29; 53	29; 53	29; 53	29; 53	29; 53	29; 53	47; 35	79; 12	87; 13
9	32; 59	32; 59	32; 59	32; 59	32; 59	32; 59	32; 59	32; 59	32; 59	52; 39	87; 13
10 (dove)	**35; 65**	**35; 65**	**35; 65**	**35; 65**	35; 65	35; 65	35; 65	35; 65	35; 65	35; 65	57; 43

(c) Asymmetric

The pure-strategy equilibrium outcomes are reported in bold, in the shaded cells. Player 1 is the row player, and Player 2 is the column player

2.2 Testable hypotheses

The game described above has a multiplicity of pure-strategy asymmetric equilibria, in which player 1 plays as a "dove" and chooses $c_1 = 10$ and player 2 plays more hawkishly, choosing $c_2 < c_1$, or vice-versa, as illustrated in the shaded cells of Table 1. All these equilibria yield the maximum possible social surplus (100).

In the Baseline treatment, we have two sets of three pure-strategy equilibria, which all yield 24 points to the "dove" player and 76 to the "hawk", hence a serious coordination issue emerges. In the Asymmetric treatment, we also have two sets of equilibria. Here, however, one set includes four equilibria in which the strong player, characterized by $s_1 = 8.7$, plays as a dove choosing $c_1 = 10$ and earning 35 while the weak player—with $s_2 = 6.5$—plays as a hawk and selects a low choice $c_2 \in [0, 3]$, thus earning 65 points. The other set contains two equilibria in which the payoff imbalance is reversed: the strong player chooses $c_1 \in [0, 1]$ and earns 87, while the weak player chooses $c_2 = 10$ and earns 13 points. The two sets of equilibria are equally efficient, but the distribution of the surplus between the two players in the first set of equilibria is much less unequal than in the second set.

The literature on outcome-based inequality aversion highlights how people may prefer more even resource distributions and may sacrifice personal gains for greater fairness (Fehr and Schmidt 1999; Bolton and Ockenfels 2000; Charness and Rabin 2002). On the other hand, the focal point literature emphasizes that some features of the payoffs (e.g. symmetry, efficiency or equality) may make certain equilibria more salient than others, thus helping players to solve coordination issues (Isoni et al. 2014; Luhan et al. 2017). Based on these considerations, we expect that subjects in the ASYMMETRIC treatment coordinate on the least unequal outcome: in other words, we hypothesize that inequality aversion and payoff-focality will work as coordination devices, preventing miscoordination and thus promoting efficiency at the social level. Another argument supporting the choice of the least unequal equilibria in the ASYMMETRIC treatment is that there are four such equilibria, while the more unequal equilibria are only two. By the lexicographic selection principle, the (higher) number of equilibria works as a signal to the players, further contributing to the focality of the more equal equilibria.[5] Coordination on the least unequal equilibrium, however, might also be driven by strategic considerations: by choosing 10 (i.e. "dove") the strong players ensure a payoff of at least 35, which may induce them to prefer this option to a more hawkish but riskier strategy.[6]

Hypothesis 1 *(a) Coordination on efficient equilibrium outcomes is more frequent in the* ASYMMETRIC *treatment than in the* BASELINE *treatment. (b) In the* ASYMMETRIC *treatment, subjects coordinate on one of the least unequal pure-strategy equilibria.*

In the RESTRICTED treatment, the coordination issue may seem less severe compared to the BASELINE since we have only two—instead of six—pure-strategy equilibria, which however yield the same outcome as in the BASELINE: one player sets $c_i = 0$ and earns 76, and the other chooses $c_j = 10$ and earns 24. On the other hand, by increasing $\underline{a}$ from 1 to 3, we also limit the cost of miscoordination, and we make the Pareto-dominated (but perfectly equitable) outcome where both players play "hawk" more profitable, as compared to the BASELINE (both players earn 15, rather than 5). Being comparatively more profitable, all other symmetric outcomes also become more focal. Subjects who are averse to outcome-based inequality, thus, might have a stronger incentive to play hawkish strategies in this treatment than in the BASELINE, because they are sure to earn at least 15, if they do so.[7] Strategic risk considerations also push

[5] We thank an anonymous referee for having suggested this additional consideration.

[6] This intuition is supported by a more formal analysis, carried out by Blázquez and Koptyug (2022), who analyze this game through the lenses of the concepts of risk-dominance proposed by Harsanyi and Selten (1992), the robustness to strategic uncertainty proposed by Andersson et al. (2014), and the quantal response equilibrium proposed by McKelvey and Palfrey (1995), to investigate whether these approaches provide a solution to the issue of equilibrium selection. Blázquez and Koptyug (2022)'s results indicate that both the tracing procedure and QRE predict convergence to the least unequal equilibrium outcome.

[7] The difference between our BASELINE and RESTRICTED treatments resembles in some sense the difference between the two dynamic games with complete information discussed by Goeree and Holt (2001), who show that a threat is more likely to be implemented when it is less costly.

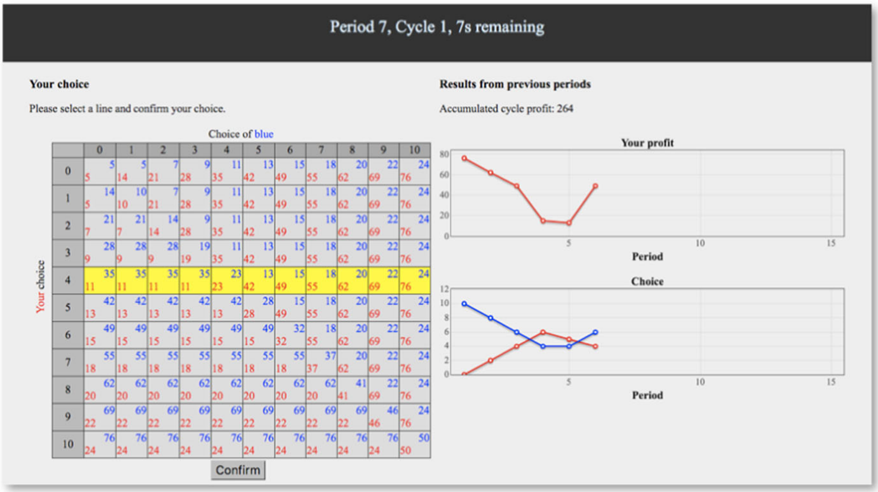

Fig. 1 Screenshot of the decision screen of a Red player, for the BASELINE treatment.
Note: in the bottom-right panel of the figure, the graph displays the choice made by the two players in the previous periods: it shows that the Blue player started playing "dove" in period 1, while the Red player started with "hawk", but then in the following periods the distance between their choices decreased

in the same direction: by making the hawkish strategies less risky, and on average more profitable, the RESTRICTED treatment reduces the strategic incentives to coordinate on the efficient, pure-strategy equilibria. We conjecture that—in the RESTRICTED treatment—strategic risk and payoff-focality considerations would prevail over the reduced complexity stemming from a smaller number of pure-strategy equilibria. We thus summarize our second hypothesis as follows:

Hypothesis 2 *Coordination on the pure-strategy equilibria is less frequent in the* RESTRICTED *than in the* BASELINE *treatment.*

3 Experimental design

Framing. We adopt a neutral framing. Player 1 and player 2 are labeled "Red" and "Blue", respectively. In the ASYMMETRIC treatment, the Red players are the "strong" ones, while the Blue players are the "weak" ones. Subjects have to make their choice by selecting one of the rows of the payoff matrix, which are displayed on their decision screen (Fig. 1).
Number of repetitions. Each experimental session includes 5 cycles of 15 periods each. In each cycle, subjects interact in "economies" comprising 4 Red and 4 Blue players each, with random matching across periods within an economy. Roles remain fixed within each cycle, but change from cycle to cycle in a predetermined way, so that some participants are Red in three cycles, and Blue in two cycles, and other participants are Red in two cycles and Blue in three cycles. At the beginning of each cycle, new

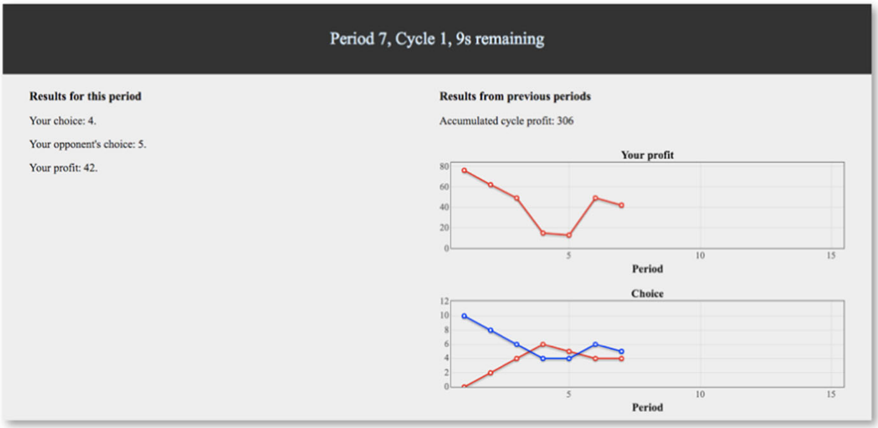

Fig. 2 Feedback screen at the end of each period (for a Red player)

economies are formed, so that no two subjects interact with each other for more than one cycle, along the lines of what was done by Camera and Casari (2014) and Bigoni et al. (2020).

Feedback at the end of each period. At the end of each period, subjects receive information on the choices made by both players, and their own profit. We do not inform subjects of the other player's profit, which however can be inferred by the payoff matrix. Results from previous periods of the current cycle are always displayed on the subjects' screens by means of two graphs, presenting the choices and the profits, respectively (Fig. 2).

Expectations on others' behavior. At the beginning of each cycle we ask subjects to guess the average choice of the other participants who had a role different from their own, in the first period of the cycle which is about to start. The procedure is incentivized by means of a quadratic scoring rule: subjects earn 250 points (€5) for a correct guess, 240 points if their guess differ from the correct answer by at most one unit, 210 if the difference is of at most 2 units, and so forth and so on (see Instructions in Appendix A). To minimize the scope for strategic hedging (Blanco et al. 2010), we ask subjects to guess the choice of subjects who are not part of their economy. Furthermore, we randomly select one of the five cycles for the payment of the guess, and another, different cycle for the payment of the profits realized in the main game.

Procedures. We ran 3 sessions per treatment, with 24 subjects per session, between April 17 and May 3, 2016. To test the robustness of our results, we replicated the experiment running 9 more sessions between September 4 and September 13, 2023.[8] Considering all treatments, the experiment involved 432 subjects randomly recruited via Orsee (Greiner 2015) from a pool of more than 4000 subjects who normally participate in experiments at the BLESS laboratory in Bologna (where all sessions took place). The experiment was programmed and conducted in English with an ad-hoc

[8] Appendix E presents all graphs and tables on the results reported in this paper, separately for each wave of data collection.

web-based platform. Instructions (a copy is in Appendix A) were read aloud at the start of the experiment and left on the subjects' desks. To verify subjects' full understanding of the instructions, we administered two "understanding checks" (one in the middle of the instructions, one at the end), asking subjects to answer a set of computerized control questions. The experimenter did not proceed to the next part of the instructions until all subjects had completed their set of questions. Control questions were incentivized: subjects earned 50 cents for each question they answered correctly. There were 10 questions in total, hence subjects could earn up to €5 for this task.[9] At the end of the session, subjects were asked to fill out a questionnaire meant to collect information on their socio-demographic characteristics, their preferences and their educational background (Appendix B).[10] Experimental points were translated into Euro at a rate of €1 per 50 points. Average earnings were €19.40 per subject (min = 7.5, max = 28.5), and sessions lasted on average less than two hours, including instructions and payments.

4 Results

In this section, we first present and discuss aggregate behavior and the main treatment effects. We then zoom in on individual behavior to get a better understanding of the determinants of the observed differences across treatments.

4.1 Aggregate behavior

In all treatments, subjects played the most extreme choices—0 (i.e. "hawk") and 10 (i.e. "dove")—in the majority of interactions. In Baseline and Restricted the distribution of choices was approximately the same for Red and Blue players, and the modal choice was 0 (Fig. 3). In Asymmetric, instead, the modal choice for the Red (i.e. "strong") players was 10. The modal choice for the Blue players was 0 as in the other treatments, but here 10 was not chosen more frequently than the other positive numbers. This suggests that coordination on one of the efficient pure-strategy equilibrium outcomes was more frequent in this treatment than in the symmetric ones. This is indeed confirmed by Fig. 4, which illustrates the frequency of coordination on pure-strategy Nash-equilibrium outcomes across treatments, by period, across cycles.

[9] Subjects earned on average €4.42 for this task; 94% of them made at most three mistakes, 70% of them made at most one. In the post-experimental questionnaire (available in the appendix), when asked whether "the instructions you have received today's activities (are) clear," almost all subjects answered positively: 70% declared that the instructions were "very clear" and 28% reported that they were "clear enough". The average payoff obtained by subjects who failed at most one control question (36.5, $N = 302$) is slightly higher than the one obtained by the others (36.1, $N = 130$), but the difference is not statistically significant (p-val. = 0.433, linear regression with one obs. per subject and standard errors clustered at the session level.). Figure D.1 in Appendix D also shows that they tended to choose extreme actions (0 or 10) more frequently, as compared to subjects who made more than one mistake.

[10] Appendix C reports a balance check of the distribution of these characteristics across treatments.

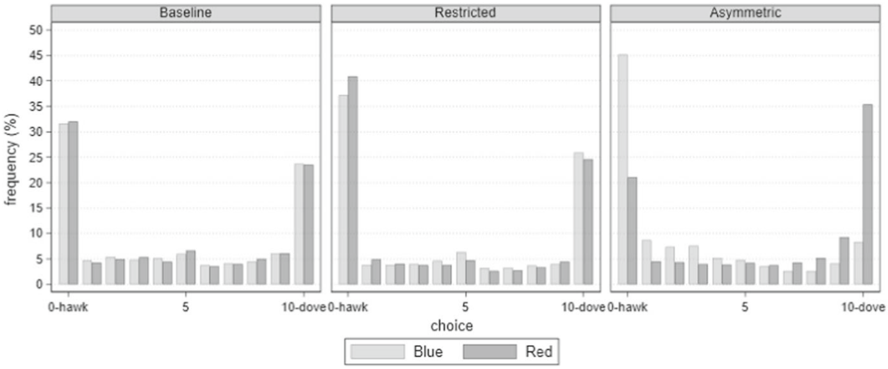

Fig. 3 Frequency distribution of choices, by role

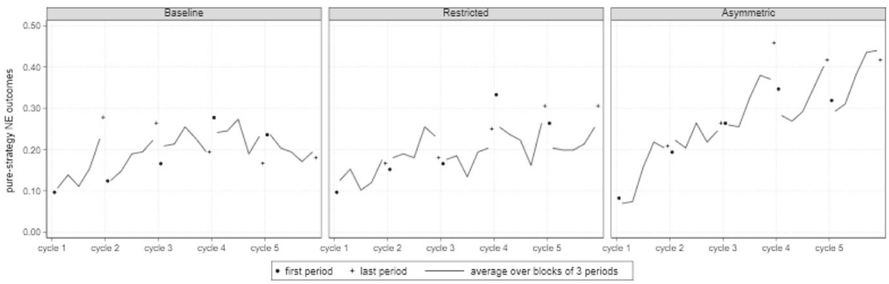

Fig. 4 Frequency of coordination on pure-strategy NE outcomes

This frequency increases across cycles in all treatments, but the increase is more pronounced in ASYMMETRIC, where a positive trend within-cycle also emerges.[11]

To assess the statistical significance of this difference, we run a linear regression where the dependent variable is the frequency ϕ_{tkz} of choices that are part of a pure-strategy Nash equilibrium, in period t of cycle k of session z. Among the regressors, we include two dummies for the RESTRICTED and ASYMMETRIC treatments, and their interactions with the variables $Period$ and $Cycle$. Results are presented in Table 2 (model 1). The regression confirms that—despite being initially lower—the estimated prevalence of coordination on NE-outcomes in the ASYMMETRIC treatment increases with experience across periods and cycles, and at the end of cycle 5 it reaches 45.8%, which is almost twice as large as in the BASELINE (24.2%) and RESTRICTED (24.5%).

Outcomes averaged at the session/period level. Standard errors clustered at the session level. Symbols ***, **, and * indicate significance at the 1%, 5% and 10% level, respectively

The increased ability to coordinate on pure-strategy Nash Equilibrium outcomes also has an impact on the realized efficiency, which we measure as the sum of the two players' payoffs, normalized by the difference between the maximum and minimum

[11] The prevalence of the equitable and efficient 10–10 outcome instead is very low and does not increase with experience.

Table 2 Linear regressions on treatment effects

	Model 1 Coordination on NE	Model 2 Efficiency	Model 3 Separation	Model 4 Inequality
Period	0.002	−0.006***	0.027	0.003***
	(0.002)	(0.002)	(0.023)	(0.001)
Cycle	0.017***	−0.012**	0.130**	0.006**
	(0.004)	(0.004)	(0.056)	(0.002)
Restricted	−0.011	−0.096**	0.416	−0.010
	(0.033)	(0.035)	(0.449)	(0.014)
Restricted × Period	0.001	−0.001	−0.039	−0.002**
	(0.002)	(0.002)	(0.027)	(0.001)
Restricted × Cycle	0.001	0.022**	−0.033	−0.008**
	(0.006)	(0.009)	(0.075)	(0.003)
Asymmetric	−0.101**	−0.136***	0.285	0.036
	(0.040)	(0.039)	(0.589)	(0.022)
Asymmetric × Period	0.009**	0.007**	0.022	−0.003**
	(0.004)	(0.003)	(0.034)	(0.001)
Asymmetric × Cycle	0.038***	0.026***	0.505***	−0.013**
	(0.007)	(0.008)	(0.097)	(0.005)
Constant	0.131***	0.769***	0.689	0.318 ***
	(0.030)	(0.023)	(0.404)	(0.012)
N	1350	1350	1350	1350
R-squared	0.237	0.083	0.353	0.207
Predicted values for Period 15 of Cycle 5, and Wald tests on their differences				
Baseline	0.242	0.615	1.751	0.392
Restricted	0.245	0.615	1.414	0.314
Asymmetric	0.458	0.723	4.897	0.323
p-value Base. vs. Restr	0.921	0.995	0.358	0.000
p-value Base. vs. Asym	0.000	0.013	0.000	0.000

possible joint payoff.[12] Figure 5 shows that efficiency tends to decrease over periods in Baseline and Restricted, but not in Asymmetric, where it even increases over the last three cycles. Results from a linear regression (Model 2 in Table 2) provide additional support to this result, showing that efficiency tends to decrease across periods and cycles in the Baseline, while the trend is reversed in the Asymmetric treatment. The downward trend across cycles also disappears in Restricted, where the negative trend across periods still persists.

[12] Formally, we define efficiency as: $\frac{\sum_i \pi_i - \underline{\Pi}_T}{\bar{\Pi} - \underline{\Pi}_T}$, where π_i denotes the payoff of player i, T identifies the treatment, $\bar{\Pi} = 100$ is the maximum surplus that can be achieved by a pair of players in a period, and $\underline{\Pi}_T$ is the minimum surplus in a pair, which is equal to 10 in treatments Baseline and Asymmetric, and equal to 30 in Restricted. Coordination on pure-strategy Nash-equilibria does not map one-to-one to efficiency, as there are efficient outcomes that are not Nash equilibria, the most prominent being the case where both players play "dove".

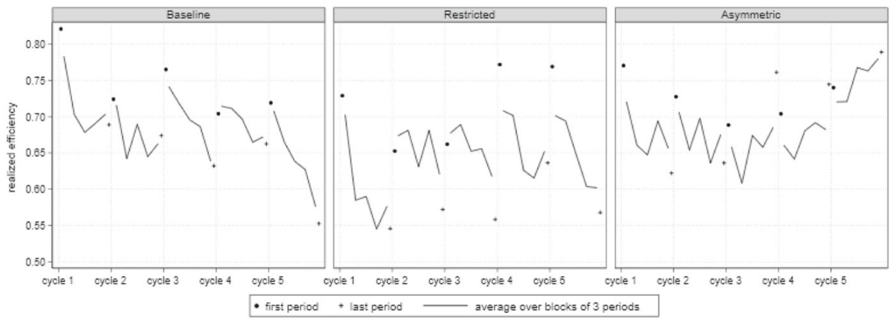

Fig. 5 Average realized efficiency

Figure 3 suggests that—in the ASYMMETRIC treatment—subjects specialize on different behaviors depending on their strength: on average, Red (strong) players play "dove" much more often than Blue players, and also than Red players in the other treatments. To investigate this aspect more closely, we follow the approach adopted by Oprea et al. (2011) and study the evolution of the average play of the Red and Blue players across periods and cycles. We identify as "hawks" the group of four (either red or blue) players that adopt the most aggressive behavior, in each economy. We identify as "doves" the other four players. Figure 6 displays the average choice made by the hawks and the doves, in each period. It confirms that in the ASYMMETRIC treatment the separation between hawks and doves is much stronger than in the other two treatments, and increases with experience. Our data also confirm that in the ASYMMETRIC treatment, the Red (strong) players take the role of doves in 96.7% of the supergames, while this percentage drops to 47.8% in the BASELINE and 42.9% in the RESTRICTED treatment.[13]

To dig deeper into this difference across treatments, we ran a linear regression where the dependent variable is the difference between the average choice taken by the hawks and the doves, in each period, and regressors include the treatment dummies and their interactions with the variables *Cycle* and *Period*. Results are reported in Model 3 of Table 2, and confirm that a net separation between hawks and doves emerges only in the ASYMMETRIC treatment, where at the end of cycle 5 the average difference between the choices of hawks and doves is 4.897, which is significantly higher than in the BASELINE (1.751, p-value <0.001).

Our results thus confirm Hypothesis 1:

Result 1 *(a) Coordination occurs more frequently in the* ASYMMETRIC *treatment than in the* BASELINE *treatment. (b) In the* ASYMMETRIC *treatment, subjects coordinate on one of the least unequal pure-strategy equilibria.*

Hypothesis 2 instead does not find support in our data.

[13] Note that there is a "restart effect" in all treatments, where subjects consistently opt for higher numbers at the beginning of a cycle. The only exception is represented by the "Hawks" in the ASYMMETRIC treatment, who consistently choose lower numbers at the beginning of a new cycle, when they are grouped with a new set of opponents.

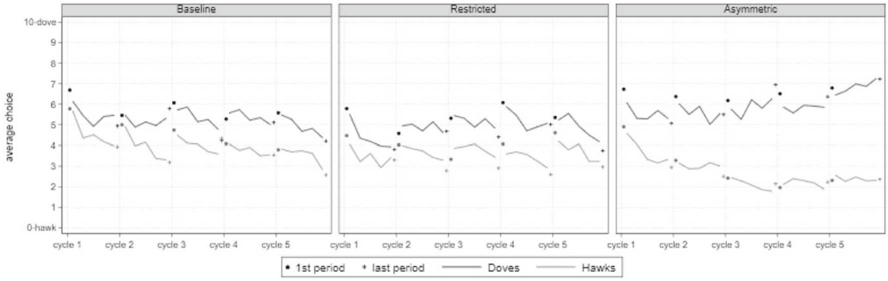

Fig. 6 Average choice played by the most ("H") and by the least ("D") hawkish group of each economy

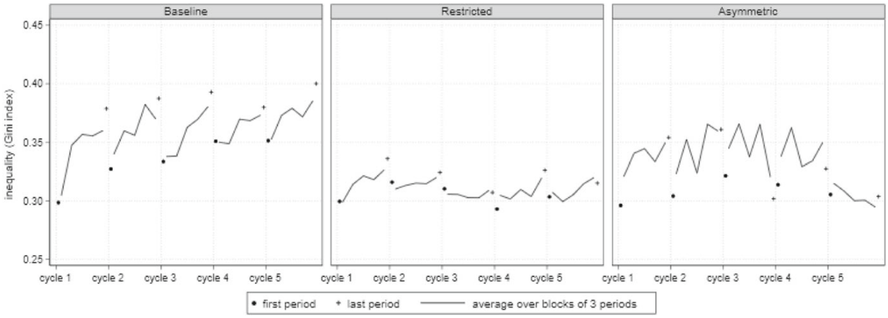

Fig. 7 Average Gini coefficient

Result 2 *Coordination occurs as frequently in the* RESTRICTED *as in the* BASELINE *treatment.*

To check whether the separation of hawks from doves we observe in the ASYMMETRIC treatment results in an increase in the level of realized inequality in payoffs, we measure the Gini coefficient at the economy-period level. Results are displayed in Fig. 7, which shows that, if anything, ex-post inequality seems to be lower in the ASYMMETRIC than in the BASELINE. Results from a linear regression (Model 4 in Table 2) suggest that the treatment differences in terms of inequality are small: a significant increasing trend across periods and across cycles emerges in the BASELINE treatment, but it is reversed both in RESTRICTED, where inequality in payoffs is lower by design (the minimum attainable payoff is substantially higher than in the BASELINE), and in ASYMMETRIC. As a consequence, in the long run the estimated Gini coefficient becomes significantly lower in ASYMMETRIC (32.3%) and in RESTRICTED (31.4%) than in the BASELINE treatment (39.2%).

4.2 Initial choices and expectations

The previous section reports evidence that the ASYMMETRIC treatment induced substantial behavioral differences, as compared to the BASELINE. In particular, the asymmetry in the payoff matrix affected the choices taken by subjects assigned the role of Red players, who progressively adopted a more dovish attitude, leading to better

Table 3 Average expectations in period 1

	Red			Blue		
	< 10		10	< 10		10
Baseline						
expectation	5.8	<***	7.5	5.4	<**	6.5
	(69.4%)		(30.6%)	(73.6%)		(26.4%)
corr.		*0.398****			*0.327****	
Restricted						
expectation	5.1	<**	6.0	5.4	<***	7.5
	(73.6%)		(26.4%)	(75.0%)		(25.0%)
corr.		*0.279***			*0.560****	
Asymmetric						
expectation	5.1	≈	5.5	6.3	≈	5.9
	(70.8%)		(29.2%)	(86.1%)		(13.9%)
corr.		*0.115*			*0.070*	

The table reports the average expectation of participants in period 1 of cycle 1, conditional on their role. It compares the average expectation of the subjects who chose 10 with those who chose a lower number. In parentheses, it reports the fraction over the total number of subjects by role and treatment. Symbols <*** and <** indicate significance at the 1% and 5%, respectively, according to pairwise Mann–Whitney-Wilcoxon tests with a total of 72 observations, per role, per treatment. In italics, we report the correlation between actions and expectations in period 1, by role. Symbols *** and ** indicate significance at the 1% and 5% level, respectively

coordination and more efficient outcomes. Here, we explore whether this change in behavior is immediately induced by the different setup and appears already in the first period of play.

As argued by Luhan et al. (2017), behavior may be influenced by "payoff-based sources of focality (payoff focality), such as equality, efficiency, and total payoff maximization." Therefore, in our framework, the highly focal 10–10 outcome should be chosen more frequently when available, as in the Baseline and Restricted treatments. This mechanism is not applicable in the Asymmetric treatment, where such a focal outcome is removed. In line with this intuition, we observe that the percentage of subjects choosing 10 in the first period of the first cycle is higher in the Baseline and Restricted treatments than under Asymmetric, but this difference is only driven by the subjects in the role of Blue players (Table 3). In the Asymmetric treatment, the fraction of players choosing 10 is 29.2% among the Red players, and it drops to 13.9% among the Blue players (p-value: 0.0257, Chi-squared test, $N_1 = N_2 = 72$). The fraction of Blue players choosing 10 is also lower than in Baseline (p-value: 0.0675, Chi-squared test, $N_1 = N_2 = 72$) and in Restricted (p-value: 0.0921, Chi-squared test, $N_1 = N_2 = 72$), but the difference is only marginally significant.

Table 3 also indicates that, in Baseline and Restricted, subjects choosing 10 are more inclined to believe that participants in the opposite role would opt for a high number, as compared to subjects who chose lower numbers as their initial action. This, however, does not hold in the Asymmetric treatment. More in general, we observe that the correlation between expectations and actions in period 1 is positive and significant in all treatments but Asymmetric. Taken together, these results indicate that in Baseline and Restricted the 10–10 outcome, which is at the same time maximally efficient and equitable, initially represents an important attractor: between 1/3 and 1/4 of the subjects choose 10, and most of them believe the opponent would also choose a large number. This is in line with the theories of team reasoning, usually deployed to explain focal points, which may suggest that players would try to achieve this solution when first faced with the game (Bardsley et al. 2010). However, since in these two games the payoff-focal outcome is not an equilibrium, coordination on 10–10 is hard to achieve and sustain, and subjects progressively become more aggressive (Fig. 6) and efficiency decreases (Fig. 5).

By contrast, in the Asymmetric treatment payoff-equality can make one of the two sets of pure-strategy equilibria more focal than the other. Here, we observe that even before having any experience with the game, this outcome becomes an attractor, at least for the Blue players. Subjects in the role of Blue adopt a more aggressive behavior, as compared to the other two treatments: while in Baseline and Restricted players display a conditionally cooperative attitude—that is, they play more dovishly when they expect the opponent to do the same in an attempt to coordinate on a mutually beneficial and equitable outcome—in the Asymmetric treatment the weak (Blue) players tend to best respond, and become more aggressive the less aggressive the Red players are. Coordination on the least inequitable equilibrium increases with experience (Fig. 6), as it takes time for subjects in the role of Red players to adjust their behavior. To conclude, our results suggest that coordination becomes more challenging in contexts characterized by high payoff-asymmetries, particularly if a conflict emerges between payoff-focality and equilibrium considerations. This is, to some extent, in line with previous findings by Crawford et al. (2008), Isoni et al. (2014), and Rojo Arjona et al. (2022), albeit in a markedly different set-up.

5 Conclusions

This paper presents an experiment on a two-population Hawk–Dove game, in which we vary the degree of asymmetry between players, the number of pure-strategy equilibria, and the cost of miscoordination.

Our study contributes to two main strands of literature: first, we relate to the literature on inequality and coordination in experimental games, which so far has never explored this issue within the context of the Hawk–Dove game. This is a framework in which agents face a coordination game with a strong conflict of interest, and captures the strategic incentives characterizing many economically relevant relations. As such, it is quite different from other frameworks already analyzed within this line of research, such as the threshold public good game, the minimum effort game and the indefinitely repeated helping game, which all allow for efficient and equitable cooperative equilibrium outcomes. Second, we expand the literature on the Hawk–Dove game, as—to our knowledge—we are the first to experimentally study the impact on coordination of introducing asymmetry in the payoff matrix. We also consider an expanded payoff matrix, which clearly complicates the game-theoretical analysis, but also makes the game more realistic, as in many situations people do not simply face a binary choice between fighting to death and accommodating completely, but also have more nuanced options. This expansion also allows us to study whether coordination becomes more difficult to achieve when we vary the number of pure-strategy equilibria, and the cost of miscoordination.

Our results indicate that making the game asymmetric seems to simplify coordination: populations characterized by ex-ante unequal strengths coordinate more often on the least inequitable pure-strategy Nash equilibria, leading to higher efficiency. Instead, with a symmetric payoff matrix, we observe no differences in terms of efficiency or individual strategies when we vary the number of pure-strategy equilibria and the cost of miscoordination.

Our main result on inequality and coordination suggests that, if one of the two conflicting populations is ex-ante disadvantaged to the point that for them the cost of miscoordination is much lower relative to the other population, members of this population can afford to be more aggressive forcing the others to accommodate. This eventually drives society to coordinate on the least unequal equilibrium outcome, which increases overall efficiency. While of course our result is limited to the artificially simple set-up implemented in our experiment, it would be interesting to study whether the same dynamics would emerge in other, more realistic, frameworks. We leave this for future research.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00199-024-01603-7.

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