

Research

Shifting strategies: exploring cooperation dynamics in fisheries co-management

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ABSTRACT. In the governance of common-pool resources (CPRs), co-management policies are a conventional approach to prevent the tragedy of the commons. Although generally efficient, the performance of these policies varies across communities. Experimental economics applied to co-management settings has widely informed this heterogeneity. However, progress made in experimental economics in understanding how cooperative strategies influence cooperation dynamics has seldom been applied to explain the diverse outcomes observed in co-management. Investigating how cooperative strategies are shaped by institutions within co-management schemes can deepen our understanding of the behavioral mechanisms and motivations driving resource users' actions to better inform co-management policies. We propose that variation in co-management performance can be explained by the distribution of strategic types within user groups and how these distributions shift in response to external enforcement, a common institution in co-management policies. Employing a repeated common pool resource game experiment, we investigated small-scale fishing communities in Chile that had been previously categorized in types of user groups based on their real-life experience with co-management (no experience, high performance, and lower performance). In the experiment, all subjects participated in two treatments: one without enforcement of a social norm and one with a non-deterrent external enforcement of the social norm (resembling the actual co-management institution faced by the experimental subjects). We then classified fishers' cooperative strategies in each treatment as either free-riders, conditional cooperators, unconditional cooperators, or negative cooperators, and assessed the distribution of strategies across types of user groups in both treatments. We found that strategic heterogeneity can explain differences in co-management outcomes only under external enforcement. These results underscore differences in how user groups develop cooperative norms to sustain common-pool resources, and suggest that external enforcement helps signaling these norms, preventing the erosion of cooperation through shifts in strategies. This process reveals underlying behavioral mechanisms and motivations that influence users involved in co-management and should be considered to foster the sustainable use of natural resources.

Key Words: *co-management; common-pool resource games; cooperative strategies; lab-in-the-field experiments*

INTRODUCTION

Small-scale societies that make use of common-pool resources (CPRs) are exposed to the depletion of the resource system in the so-called “Tragedy of the Commons” (Hardin 1968), a social dilemma in which individual interests collide with collective goals, threatening both the resource system and the communities that make use of it. This potential tragedy endangers a vast array of CPRs and, therefore, has been thoroughly investigated in cases of fisheries (Berkes 1985, Kraak 2011), other marine-coastal resources (Wilkinson and Salvat 2012), grasslands (Cole et al. 2014), irrigation systems (Podimata and Yannopoulos 2015), and forests (Brown and Harris 1992). Case studies and observational evidence have shown that CPRs can undergo processes characterized by diminishing cooperation and escalating resource exploitation under inadequate governance regimes (Ostrom 1990, Castilla and Fernandez 1998, Klooster 2000, Gautam and Shivakoti 2005, Arias Schreiber 2012, Fleischman et al. 2014, Defeo et al. 2016).

In recent decades, co-management has increasingly gained attention as a policy mechanism to address the ongoing threat of the tragedy of the commons. Co-management is a governance approach associated with CPR management that establishes a partnership between public and private actors. It ranges between a simple exchange of information between stakeholders to the

joint design and implementation of formal arrangements, combining peer and non-deterrent external enforcement (Berkes et al. 1991, Sen and Raakjaer Nielsen 1996, Plummer and Fitzgibbon 2004, Carlsson and Berkes 2005). Co-management pursues the engagement of different stakeholders, including state agencies, local inhabitants, and users of the resource system (Berkes et al. 1991, Pomeroy and Berkes 1997), while seeking to implement some of the institutional design principles identified for the sustainable management of CPRs, including collective-choice arrangements and a minimal recognition of rights to organize to promote cooperation among users (Ostrom 1990).

Overall, scientific evidence suggests mixed results of co-management policies in a diverse array of CPRs, institutional designs, and sociocultural settings (Evans et al. 2011, Cronkleton et al. 2012, d'Armengol et al. 2018). The literature in this field has primarily concentrated on outcomes that reflect cooperation at the aggregated user group level (Varughese and Ostrom 2001, Cox et al. 2010, Tole 2010, Gutiérrez et al. 2011, Wamukota et al. 2012, Zhu et al. 2014, Baggio et al. 2016, Defeo et al. 2016). Although extremely informative about the drivers of co-management variability, this approach does not allow us to delve deeper into the individual motivations and within-group behavioral mechanisms, such as norms and expectations, that affect cooperation dynamics and, consequently co-management

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outcomes. To better support co-management policies, it is crucial to understand how these groups differ in their tendencies to sustain cooperation and how co-management institutions, such as norm enforcement, interact with their social structures to shape cooperation dynamics.

Sustainability scholars have for long turned to experimental economics to grasp the erosion and stability of cooperation in CPRs (Ostrom 2006, Naar 2020, Pisor et al. 2020). To explain different levels and dynamics of cooperation, two mechanisms have been proposed: strategic heterogeneity and the enforcement of cooperative social norms. Strategies are individual plans of action in response to cooperative decisions made by others and to a certain incentive structure. Three strategies have been consistently documented in experimental economics: free-riding (a strategy involving minimal to no cooperation, irrespective of the actions of others), conditional cooperation (the act of cooperating to almost match the observed cooperation of others), and unconditional cooperation (a strategy involving extensive or complete cooperation, regardless of the behavior exhibited by others (Fischbacher et al. 2001, Kurzban and Houser 2005, Kocher et al. 2008, Rodriguez-Sickert et al. 2008, Fischbacher and Gächter 2010, Rustagi et al. 2010, Carpenter and Seki 2011, Cheung 2014, Rivera-Hechem et al. 2020, van Klingeren 2022).

Evidence suggests that the erosion of cooperation in experimental repeated social dilemmas (Ledyard 1995, Chaudhuri 2011) is explained by strategic heterogeneity, in particular by the interaction between free-riders and conditional cooperators (as free riders generate a decrease in the contributions of the conditional cooperators), and by the interaction of conditional cooperators with other conditional cooperators, given the imperfect reciprocity or self-serving bias often deployed by conditional cooperators (whose contributions, even in the absence of free-riders, would decrease in repeated interactions: (Fischbacher et al. 2001, Kocher et al. 2008, Herrmann and Thöni 2009, Fischbacher and Gächter 2010, Cheung 2014, Thöni and Volk 2018). Although a handful of studies have considered conditional cooperation to explain outcomes in real-life CPR settings (Rustagi et al. 2010, Carpenter and Seki 2011), the role of other cooperative strategies, that could provide a more nuanced understanding of why co-management varies across user groups, has not received the attention it deserves.

In contrast to the role of cooperative strategies, the role of external enforcement in CPRs has been widely studied, both in lab experiments and real-life settings, including co-management arrangements (Cardenas et al. 2000, Travers et al. 2011, Santis and Chávez 2015). In many real-world settings, CPR user groups address social dilemmas by enforcing a cooperative social norm established in a co-management plan. When enforcement is deterrent, cooperative strategies may arise because of changes in economic incentives, making cooperation dominant either because of high penalties and/or the certainty of punishment for norm deviations. In contrast, non-deterrent enforcement, which is more common in co-management arrangements, may also foster high levels of cooperation, albeit through a different mechanism. In these cases, punishment for norm deviations is either too low to fully deter non-cooperative behavior or occurs only with some probability, rather than being certain. As a result, compliance is not strictly enforced but instead relies on the

signaling of cooperative norms, group-shared standards of behavior that dictate how to act in specific situations (Fehr and Schurtenberger 2018). In such cases, cooperation can become an individually beneficial choice, even for those who do not typically adhere to the cooperative norm, provided they have high expectations that others will comply with it. In CPR games, the introduction of enforcement generally increases cooperation (Ledyard 1995, Chaudhuri 2011, Fehr and Schurtenberger 2018). However, its effects can be mixed, particularly in field settings. External enforcement has sometimes been shown to crowd out intrinsic motivations to cooperate, negatively affecting long-term collective action (Cardenas et al. 2000, Gneezy and Rustichini 2000, Volland 2008), while in other cases, it crowds in intrinsic incentives to cooperate. These crowding-in and crowding-out effects may reflect shifts in cooperative strategies. Evidence suggests that the introduction of enforcement can modify strategic dispositions toward cooperation (Rodriguez-Sickert et al. 2008, Bowles and Polania-Reyes 2012).

All this evidence suggests the distribution of cooperative strategies within a group of CPR users determines how well they can sustain cooperation and consequently could explain variability in co-management outcomes. In addition, it indicates that understanding how external enforcement affects the distribution of cooperative strategies could shed light on crowding-in and out effects and the role of norms and expectations in shaping this interaction. Here we address these two proximate mechanisms (the enforcement of social norms through external enforcement and the role of strategic heterogeneity) as a potential explanation for the varying levels and dynamics of cooperation in the co-management of CPRs. To explore these ideas, we use a lab-in-the-field CPR experiment performed with 85 small-scale fishers exploiting benthic resources along the central coast of Chile. The sample includes three types of CPR user groups with differing co-management experiences: fishers from unions participating in high-performing co-management (HP), fishers from unions participating in low-performing co-management (LP), and a group of non-unionized fishers who do not participate in co-management (NU). Published results with this subject pool show that group-level behavioral differences across these groups in the CPR game reflect real-life differences in co-management, accounting for the external validity of the experiment (Gelcich et al. 2013). Here, we assess how strategic heterogeneity across user groups relates to differences in their co-management outcomes and explain cooperation dynamics in the absence of external enforcement. We also examine how the introduction of external enforcement affects cooperation dynamics by shifting the distribution of cooperative strategies within user groups and discuss how differences in responses to enforcement across groups can be explained by their real-life co-management experiences.

This exploratory study examines how external enforcement influences the distribution of cooperative strategies among different groups of resource users in a CPR setting. The experiment is designed to uncover patterns and generate insights into complex social-ecological interactions. To enhance the transparency and credibility of our exploratory findings, we used established methods, considered an ex-ante characterization of the research setting from prior studies, provided a detailed account of our procedures, and interpreted the results in relation

to behavioral regularities in experimental literature. By analyzing the interplay between individual strategies, external enforcement, and co-management outcomes in an externally valid experiment we provide insights into group-developed cooperative mechanisms that shape behavior within co-management institutions. This understanding is relevant to uncover variability in co-management outcomes in real-world settings. Analyzing the interplay between individual strategies, external enforcement, and co-management outcomes in an externally valid experiment, provides a detailed account of how resource users' behavior is shaped by group-developed cooperative mechanisms within co-management institutions. These insights are crucial for understanding variability in co-management outcomes in real-world settings.

RESEARCH SETTING AND SUBJECT POOL

In Chile, fishers who are part of a union can collectively apply for Territorial Use Rights for Fisheries within a defined geographic area referred to as Management and Exploitation Areas for Benthic Resources (MEABRs). In this co-management system, fishing unions are required to collaborate with scientific consultants to develop a management plan that combines conservation and exploitation criteria (Gelcich et al. 2010). If approved by state agencies, the MEABR will come into effect and the fishing union will have the exclusive right to exploit benthic resources in the specified area and bear the responsibility of monitoring compliance with the management plan, which will be regularly enforced by the National Fisheries and Aquaculture Service (SERNAPESCA). On the other hand, non-unionized fishers can exploit benthic resources outside these protected areas, but they can engage in illegal poaching within MEABRs, causing harm to both the ecological and economic yields of fishing unions (Oyanedel et al. 2018, Romero et al. 2022).

Since 1997, more than seven hundred MEABRs have been designated. Regarding their effectiveness in enhancing local livelihoods, scientific assessments have thus far emphasized that the success of MEABRs depends on environmental dynamics (Aburto et al. 2013, Anguita et al. 2020), and users' social and risk preferences (Gelcich et al. 2007). Furthermore, user perceptions are intertwined with the outcomes of co-management, encompassing expectations of organizational improvements and enhanced resource management, as well as concerns about increased illegal fishing and economic performance falling short of expectations (González et al. 2006, Gelcich et al. 2007, Aburto et al. 2013, Romero et al. 2022). Although there is evidence that, overall, belonging to a union and engaging in the collective action in MEABRs increase the income of fishers, there is also evidence of significant variance on the effect of MEABRs because of differences in the capacity to control illegal fishing (Romero and Melo 2021).

Another feature that conditions the success of MEABRs is the social-ecological setting. The great extension of the country's coastline (which extends over 6000 kilometers and crosses several types of ecosystems, resources, and technologies) is inhabited by human populations with different social and cultural backgrounds. Related evidence highlights the existence of differences between large biogeographic regions along the coast of Chile, each exhibiting distinctive characteristics. Additionally, there is heterogeneity within these large regions among

neighboring fishing coves in terms of fishing effort, biomass, composition of landings, and per capita income. This intra-regional heterogeneity is likely due to socioeconomic factors such as price fluctuations, individual fishing behaviors, and historical factors (Chevallier et al. 2021). To control for the large biological and sociocultural variability, we selected a subject pool from a limited area of the central coast of Chile. This ensured a culturally similar population, sharing the same geography and ecosystem, but with organizational differences. All experimental subjects live in semi-urban settlements of the Valparaíso and O'Higgins administrative regions in the central coast of Chile. Small-scale fisheries in these regions are primarily oriented toward commerce rather than direct consumption and are characterized by a blend of traditional and modern techniques and technologies. Commercially traded marine species include hake (*Merluccius gayi gayi*), golden kinglip (*Genypterus blacodes*), jack mackerel (*Trachurus murphyi*) mollusks such as Loco (*Concholepas concholepas*) and Keyhole limpets (*Fissurella* spp.), and sea urchins (*Loxechinus albus*). Fishing activities are also complemented by gastronomy, tourism, and occasionally farming. Unlike the northern and southern regions of Chile, this section of the central coast exhibits a low engagement of the indigenous population in official fisheries management.

The CPR experiment was performed with 85 small-scale fishers, with 30 belonging to three fishing unions that exhibit high performance in MEABR management (HP, $n = 30$), 25 belonging to two fishing unions displaying relatively low performance in the management of their MEABRs (LP, $n = 25$), and 30 non-unionized fishers who do not participate in MEABR management (NU, $n = 30$). The classification of unions into high- or low-performance categories was based on an index constructed from multiple indicators related to institutional and ecological outcomes. This index, adapted from data collected by Marín et al. (2012), was estimated as the average of seven key variables: (1) internal enforcement, and (2) compliance with union norms, assessed by union presidents; (3) co-management performance, (4) quality of the institutions and social practices, and (5) overall performance in the co-management of the MEABR, assessed by the National Fisheries and Aquaculture Service; and ecological outcomes, including (6) the evolution of the total allowable catch, and (7) biodiversity levels. These variables were chosen because they are closely linked to cooperative behavior among union members and reflect the effectiveness of self-governance in MEABR management: see Appendix 1 for details on this classification.

High-performance unions (HP) can be described as efficient organizations with stable levels of cooperation and sustainable exploitation of benthic resources. They engage in livelihood diversification, which includes a wide range of targeted resources, knowledge, and technologies for complementary income sources beyond their MEABR. Additionally, they have well-defined and valued mechanisms for norm creation and enforcement, discussed in monthly meetings, such as harvesting plans and graduated sanctions for norm transgressions. These organizational-level features are associated with profitable and sustainable ecological outcomes (e.g., sustained or increased total allowable catches over the last five years). Low-performance unions (LP) lack HP attributes and exhibit deficient social and environmental results. LP unions do not have formal MEABR committees that meet

Table 1. Sociodemographic characteristics of sampled fishers, grouped by unions (HP = high-performance; LP = low-performance). Columns report union age (years), years operating under Management and Exploitation Areas for Benthic Resources (MEABR) at the time of fieldwork, number of members, MEABR surface (ha), distance from the MEABR centroid to the nearest city (km) and to the nearest cove (km), and dependency on benthic resources (category). The sample comprises six unions from the central coast of Chile.

Union	Performance	Union's age at fieldwork's date	Years of MEABR until the date of fieldwork	Number of members	MEABR surface (ha)	Nearest city (km)	Nearest cove (km)	Dependency on benthic resources
A	HP	23	13	40	108.18	43.1	0.05	High (75%)
B	HP	53	13	93	204.14	33.9	0.33	Medium (23%)
C	HP	24	9	27	21.34	100.9	1.52	Low (3%)
D	LP	8	8	39	177.93	99.2	0.17	Low (3%)
E	LP	21	8	19	193.45	41.2	0.73	High (74%)
F	LP	23	9	39	22.65	92.4	1.26	Medium (25%)

monthly, and neither possess formal or informal mechanisms for norm enforcement. Moreover, their members developed a narrative justifying overextraction. These characteristics reflect low esteem on unions and MEABRs, and resulted in unprofitable and unsustainable MEABRs (e.g., with decreasing total allowable catch over the last five years). Finally, non-unionized fishers were recruited from nearby localities of HP and LP unions. Although they understand the advantages of co-management, they decided not to participate in unions or the MEABR system. They extract benthic resources on their own in open-access areas and frequently poach into unions' MEABR. The reasons for not participating in the MEABR system include narratives against this institution, such as usurping historical open-access zones and unwillingness to bear the costs of collective action.

Fishers in Central Chile base their activities in coves near their settlements, where they land their catch, store their gear, and socialize. It is common for unions to be associated with one of these coves, which they may share with other unions or non-unionized fishers. All unions in our sample come from different coves although it is possible that members of different unions live in the same locality as well as non-unionized fishers. In Table 1 we present demographic and geographic characteristics of the six unions sampled for this study. In general terms, HP and LP unions are similar in the number of years working on their MEABR (mean 11.6 years for HP and mean 8.3 years for LP); MEABRs surface (mean 111 ha for HP and mean 131 ha for LP); nearest city from the centroid of MEABRs (mean 59 km for HP and mean 77.6 km for LP); and nearest cove from the centroid of MEABRs (mean 0.6 km for HP and mean 0.7 km for LP). There are larger differences in the number of members (mean 53.5 fishers for HP and mean 32.3 fishers for LP), and in the union's age (mean 33 years for HP and mean 17 years for LP). We attempted to balance the sample so that each type of user group (HP and LP) included unions with varying levels of dependence on benthic resources, while ensuring that the remaining characteristics were as homogeneous as possible.

EXPERIMENTAL PROCEDURE

The CPR experiment employed a within-subjects design, in which all 85 individuals were exposed to two experimental conditions: one without enforcement of a social norm regulating resource extraction quotas ("unenforced condition," rounds 1–10) and one with external enforcement of the same norm ("enforced condition," rounds 11–20). In the experiment, subjects were assembled randomly into fixed groups of five individuals from the same fishing union. In the case of non-unionized fishers, they

played with other non-unionized fishers from nearby localities. The experiment implemented anonymous protocols to reduce third-party observation effects and reputational concerns. Additionally, no communication was allowed, payments were made privately at the end of each session, and the instructions were contextually framed to resemble their real-life fishing activities (see Appendix 2 for game instructions).

Before starting the experimental procedure, subjects answered a questionnaire and played five test rounds to confirm task comprehension. After this, the real experiment began according to the following procedure: each subject $i \in \{1, \dots, 5\}$ was informed that she possessed, at the beginning of each round, an endowment of 100 units of a local benthic fishery resource known as "Loco" (*Concholepas concholepas*). We framed these 100 units as their individual quota. Then, every round, each subject privately decided whether she wanted to extract or harvest above their quota up to 50 additional units of Loco. The overharvest is then defined as $y_{it} \in \{0, \dots, 50\}$, and measures the extra units of Loco extracted by subject i in round t . Each overharvested unit increases individual payoffs but also causes that each other member of the group loses half a Loco (simulating the real collective negative externalities associated with the overexploitation and depletion of resource stocks). During the first 10 rounds of the game (the unenforced condition) there were no sanctions to $y_{it} > 0$, and players only had to choose their overextraction level per round. After each round, subjects were informed of (i) the average overharvest of their group, (ii) their individual payoff of that round, and (iii) their individual losses due to the group's overharvested Locos. No information was given about teammates' individual overharvested levels and, therefore, individual behavior was private for every player in the experiment. Each Loco earned was valued at \$10 CLP (10 Chilean pesos), resulting in individual payoffs in rounds 1 to 10 determined by:

$$\pi_{it} = \$10 \left(100 + y_{it} - \frac{1}{2} \sum_{j=1}^5 x_{jt} \right) \quad (1)$$

Where π_{it} represents the payoff of subject i in round t , y_{it} denotes the overharvest of subject i at round t , and x_{jt} is the total number of units overharvested by i 's teammates at round t . In this setup, and considering only self-interested rational individuals, the only equilibrium of the game is a tragedy of the commons where every player over-extracts 50 units per round, resulting in a Pareto-inefficient outcome.

The rules changed for rounds 11 to 20 (the enforced condition) with the introduction of an external enforcement mechanism, implemented as an economic punishment for exceeding the individual harvest quota. Under this new setup, two subjects per group were randomly selected for inspection after each round, resembling an external enforcement mechanism implemented by a state agency. If the inspected subject exceeded her individual quota (i.e., if $y_{it} > 0$), all her extraction in that round was “confiscated” and the subject lost the entire round payoff. After each round, subjects were individually informed of the average overharvest of the group, their payoff loss due to the group’s overharvest, and their payoff. Therefore, in rounds 11 to 20, the expected payoff function for subject i is determined by:

$$E[\pi_{it}] = \begin{cases} \$10(100 + y_{it} - \frac{1}{2} \sum_{j=i} x_{jt}), & \text{if } y_{it} = 0 \\ \frac{3}{5} \$10(100 + y_{it} - \frac{1}{2} \sum_{j=i} x_{jt}), & \text{if } y_{it} > 0 \end{cases} \quad (2)$$

Note that this enforcement mechanism alone is not sufficient to deter overextraction. The incentive was designed so the decision to comply with the quota depended on the subject’s expectations on others’ overharvest. For a subject to dismiss over-extracting in round t , it must expect:

$$E \sum_{j=i} x_{jt} \leq 50 \quad (3)$$

where the left side of the inequality represents subject i ’s expectation of their teammates’ overharvest in round t . Therefore, a subject will refrain from overharvesting only if she expects her teammates to overharvest 50 or fewer units of loco in round t ; if this condition is not met, she might have no incentive to restrain herself from overharvesting.

Our design integrates ecological validity, by incorporating repeated interactions, an external monetary enforcement mechanism, and framed instructions that mirror the conditions subjects face daily, with a sample that ensures external validity, achieved through the prior classification of the subject pool based on social and biological performance. This approach enhances our understanding of the phenomenon under study.

STATISTICAL ANALYSIS

To identify the strategy of each of the 85 experimental subjects in each experimental condition, we employed two procedures, similar to those already performed by Kurzban and Houser (2005) and van Klinger (2022). First, we estimated each subject’s linear conditional contribution profile (LCCP) in both experimental conditions using an econometric model. Then, we used the LCCP results to classify each subject into a cooperative type in each experimental condition. The LCCP captures the levels of unconditional and conditional cooperation for each subject by assessing how they adjust their overharvest decisions in response to others’ behavior over the rounds of the game. We define unconditional cooperation as the level of cooperation subjects display when there is no cooperation from others, and conditional cooperation as the extent to which subjects adjust their cooperation to match the cooperative behavior of their peers.

To interpret decisions in terms of cooperation, we transformed each subject’s overharvest levels into an individual normalized cooperation measure per round, defined as $(50 - y_{it}) / 50$, resulting in compliance values ranging from 0 to 1. Specifically, an overharvest of 50 units in round t corresponds to a normalized compliance of 0 for that round, whereas no overharvesting results in a normalized compliance of 1. Next, we estimated the LCCP of each subject according to:

$$y_{it} = \alpha_{i1} + \alpha_{i2}DR + \beta_{i1}\bar{x}_{-it-1} + \beta_{i2}\bar{x}_{-it-1}DR + \varepsilon_{it} \quad (4)$$

Where y_{it} is the compliance of subject i in round t , DR is a dummy variable that takes the unenforced condition as a reference level, $\bar{x}_{-it-1}$ is the average compliance of i ’s teammates in $t-1$, and ε_{it} is an error term. Rounds 1 and 11 were dropped from regressions because there is no $t-1$ in round 1 and $t-1$ in round 11 has a trend of the unenforced condition and could have distorted our results. The estimated parameters of our model can be interpreted as the following:

α_{i1} is the unconditional contribution of subject i in the unenforced condition

α_{i2} is the change in the unconditional contribution of subject i due to the introduction of the external enforcement

$\alpha_{i1} + \alpha_{i2}$ is the unconditional contribution of subject i in the enforced condition

β_{i1} measures the responsiveness of subject i to $-i$ ’s mean compliance in the unenforced condition

β_{i2} is the change in the responsiveness of subject i due to the introduction of the external enforcement

$\beta_{i1} + \beta_{i2}$ is the responsiveness of subject i to $-i$ ’s mean compliance in the enforced condition

Note that similar models have been previously employed in studies exploring strategic heterogeneity. These models employ linear regressions with individual contributions regressed against contributions from other team members, and their parameters bear a similar interpretation to ours, where the intercept represents the level of unconditional cooperation, and the slope represents the level of conditional cooperation (Kurzban and Houser 2005, Carpenter and Seki 2011, van Klinger (2022)).

We estimated these parameters using Constrained Least Squares, which imposes restrictions to the minimization of the sum of squares residual in a linear model. In our case, we defined constraints as lower bounds of 0 and upper bounds of 1 to a set of parameters, to ensure that the LCCPs were always contained in the feasible region of the model (where compliance values less than 0 or greater than 1 were not possible). These bound were finally defined for: α_{i1} ; $\alpha_{i1} + \alpha_{i2}$; $\alpha_{i1} + \beta_{i1}$; and $\alpha_{i1} + \alpha_{i2} + \beta_{i1} + \beta_{i2}$.

We then used the LCCP results to classify each subject into free riders, conditional cooperators, unconditional cooperators, or negative cooperators by adapting the methods of Kurzban and Houser (2005) and van Klinger (2022). We classified each subject in each experimental condition to examine the distribution of strategies among different user groups (high-performers, low-performers, and non-unionized), to understand how external enforcement influenced individual strategies, and to explore the

impact of these strategy changes on the erosion or stabilization of cooperation over successive rounds. In our classification scheme, a free-rider is a subject whose LCCP is always lower than half of the total possible compliance (i.e., their expected compliance is always < 0.5 at all levels of others' compliance); on the contrary, subjects classified as unconditional cooperators always display an LCCP above half of the total possible compliance (i.e., their expected compliance is always > 0.5 at all levels of others' compliance); conditional cooperators comply below 0.5 when their teammates' compliance is absent (i.e., the intercept of their LCCP is < 0.5), but the responsiveness to their teammates is above 0.5 (intercept plus slope > 0.5); and negative cooperators comply above 0.5 when there is no compliance from others (i.e., their LCCP intercept is > 0.5), but the responsiveness to their teammates is below 0.5 (intercept plus slope < 0.5 ; see Appendix 3 to a more detailed and formal description of the classification scheme).

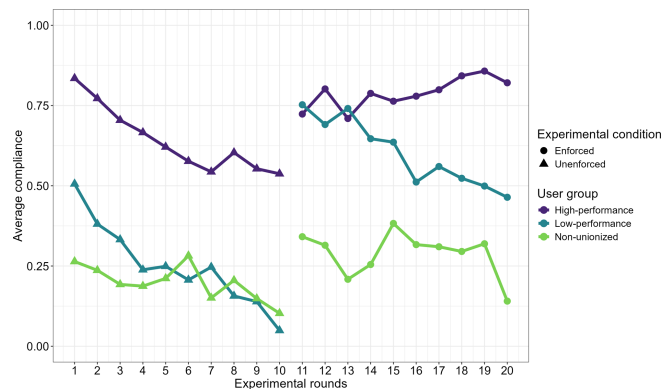
RESULTS

The dynamics of average compliance across rounds accounts for the externally valid result reported in Gelcich et al. (2013). Figure 1 shows the average compliance across user groups and experimental rounds. In the unenforced condition (rounds 1 to 10) compliance declined over rounds in all three user groups, while the introduction of the external enforcement (rounds 11 to 20) generated different effects: (i) HP unions recovered their initial levels of compliance (comparing rounds 11 and 1), and, more importantly, were the only ones capable of stabilizing cooperation until the end of the game; (ii) LP unions increased their initial compliance levels (comparing rounds 11 and 1), but were unable to stabilize it; and (iii) non-unionized fishers slightly increased their initial compliance, but were also incapable of sustaining it until the end of the game. To assess the compliance differences between the initial rounds of both experimental conditions (rounds 1 and 11), we conducted a Wilcoxon signed-rank test that suggests statistically significant differences only for the HP unions ($V = 27.5$, $p = 0.038$), while no such significance is observed for the LP unions ($V = 79.5$, $p = 0.279$) or non-unionized fishers ($V = 53.5$, $p = 0.17$). This result not only supports the external validity of the framed CPR experiment in our subject pool, but also enables us to establish HP unions in the enforced condition as a benchmark for user groups capable of stabilizing cooperation.

Because of problems in the variance of the independent variables, we were forced to drop seven individuals (five from HP and two LP unions); thus, the final sample was fixed at HP, $n = 23$, LP, $n = 24$, and NU, $n = 30$. The remaining 77 LCCPs were properly estimated and are presented, case by case, in the supplementary material (Appendix 4). In Tables 2 to 4, we present transition matrices that show changes in the distribution of strategic types between the unenforced and enforced conditions for each user group (Appendix 5 to the whole sample strategy distribution). We conducted goodness-of-fit Chi-squared tests to test the equality of strategy proportions within each user group-condition combination. All the tests yielded statistically significant outcomes, indicating that for each user group-condition combination, the strategy proportions are significantly distinct.

For HP unions, the distribution of strategies under the unenforced condition shows an almost equal proportion of conditional and unconditional cooperators (Table 2). This leads to a high initial

Fig. 1. Average compliance across user groups and experimental rounds. Groups: High-performance unions, Low-performance unions, and Non-unionized fishers. Experimental conditions: absence of enforcement (rounds 1–10) and presence of external enforcement (rounds 11–20). Lines show group averages per round; the y-axis is normalized between 0 and 1 to enable comparability. All groups exhibited declining compliance without enforcement. After its introduction, both unionized groups increased their compliance levels, but only High Performance unions sustained them through the end of the experiment.



compliance, followed by a decline across rounds. The implementation of external enforcement significantly shifts strategy proportions within HP unions, with nearly 70% of subjects adopting an unconditional cooperation strategy, less than 20% engaging in conditional cooperation, and less than 10% representing free-riders and negative cooperators. The distribution of HP unions in the enforced condition exhibits great asymmetry among strategy proportions, dominated by unconditional cooperators. For LP unions, the distribution in the unenforced condition shows a nearly equivalent proportion between conditional cooperators and free-riders, with a marginal incidence of the remaining strategies (Table 3). Consequently, within this experimental condition, there is a dominance of merely two strategies, which in combination constitute over 90% of the proportion. The impact of external enforcement leads to a significant change, primarily by halving the percentage of free-riders and augmenting the prevalence of unconditional cooperators. In this experimental condition, the distribution of strategies appears less even than under the unenforced condition. Lastly, for non-unionized fishers, the distribution of strategies under the unenforced condition exhibits two distinct characteristics: the prevalence of free-riders (with over 75% of subjects displaying this behavior) and the absence of unconditional cooperators (Table 4). This distribution is among the most unequal and its composition explains the low level of compliance between rounds 1 and 10. External enforcement impacts these proportions, reducing the incidence of free-riders by almost 20% and increasing negative cooperators by around 15%. The highest proportion of negative cooperators across user groups and conditions is observed among non-unionized fishers under external enforcement, exceeding 70% of the strategy composition when combined with free-riders.

Table 2. Effect of external enforcement on the distribution of strategic types in High-Performance unions: transition matrix. Rows indicate strategies in the unenforced condition (rounds 1–10) and columns indicate strategies in the enforced condition (rounds 11–20). Cells show the percentage of subjects, with counts in parentheses. The rightmost “Unenforced distribution” column and the bottom “Enforced distribution” row report marginal distributions. Strategy codes: CC = conditional cooperators; FR = free-riders; NC = negative cooperators; UC = unconditional cooperators.

Strategies	CC	FR	NC	UC	Unenforced distribution
CC	8.70% (2)	0.00% (0)	4.35% (1)	26.09% (6)	39.13% (9)
FR	4.35% (1)	4.35% (1)	0.00% (0)	0.00% (0)	8.70% (2)
NC	4.35% (1)	4.35% (1)	0.00% (0)	0.00% (0)	8.70% (2)
UC	0.00% (0)	0.00% (0)	0.00% (0)	43.48% (10)	43.48% (10)
Enforced distribution	17.39% (4)	8.70% (2)	4.35% (1)	69.57% (16)	100.00% (23)

To assess whether the observed distribution of strategies within each user group departed from a uniform distribution, we conducted Chi-squared goodness-of-fit tests separately for the unenforced and enforced conditions. Table 5 reports the results for each group and experimental condition, showing that empirical strategy distributions differ significantly from uniformity. This indicates that participants’ behavior clustered around specific strategic types rather than being evenly distributed across categories.

Figure 2 presents the distribution of strategies across user groups and experimental conditions, before and after the introduction of external enforcement. The figure illustrates how enforcement shifted the balance between strategies, with percentages calculated relative to each group and condition (summarizing results presented in Tables 2, 3, and 4).

Figure 3 illustrates individual-level changes in estimated LCCP parameters between the unenforced and enforced conditions across user groups. Each point represents a participant’s change. The x-axis shows shifts in the unconditional cooperation level (intercept) between enforced and unenforced conditions, while the y-axis shows changes in responsiveness to peers’ compliance (slope) between those same conditions. Colors and shapes indicate the strategy classification of each individual in the unenforced condition. The figure shows that, within HP user groups, individuals classified as unconditional cooperators in the unenforced condition hardly alter their strategies once enforcement is introduced. On the other hand, many conditional cooperators increase their levels of unconditional cooperation (on the right side in the x-axis) and decrease their responsiveness (down along the y-axis). This small cluster of subjects is the group that succeeds in altering the average behavior of HP user groups in the enforced condition and manages to stabilize compliance across rounds. In the case of LP user groups, there is a greater tendency for free-riders to increase their levels of responsiveness (moving up along the y-axis) as a response to the enforced condition, while conditional cooperators show a decrease in their levels of conditionality (moving down along the same y-axis). On

Table 3. Effect of external enforcement on the distribution of strategic types in Low-Performance unions: transition matrix. Rows indicate strategies in the unenforced condition (rounds 1–10) and columns indicate strategies in the enforced condition (rounds 11–20). Cells show the percentage of subjects, with counts in parentheses. The rightmost “Unenforced distribution” column and the bottom “Enforced distribution” row report marginal distributions. Strategy codes: CC = conditional cooperators; FR = free-riders; NC = negative cooperators; UC = unconditional cooperators.

Strategies	CC	FR	NC	UC	Unenforced distribution
CC	16.67% (4)	8.33% (2)	4.17% (1)	12.50% (3)	41.67% (10)
FR	25.00% (6)	16.67% (4)	0.00% (0)	8.33% (2)	50.00% (12)
NC	4.17% (1)	0.00% (0)	0.00% (0)	0.00% (0)	4.17% (1)
UC	0.00% (0)	0.00% (0)	0.00% (0)	4.17% (1)	4.17% (1)
Enforced distribution	45.83% (11)	25.00% (6)	4.17% (1)	25.00% (6)	100.00% (24)

Table 4. Effect of external enforcement on the distribution of strategic types in non-unionized fishers: transition matrix. Rows indicate strategies in the unenforced condition (rounds 1–10) and columns indicate strategies in the enforced condition (rounds 11–20). Cells show the percentage of subjects, with counts in parentheses. The rightmost “Unenforced distribution” column and the bottom “Enforced distribution” row report marginal distributions. Strategy codes: CC = conditional cooperators; FR = free-riders; NC = negative cooperators; UC = unconditional cooperators.

Strategies	CC	FR	NC	UC	Unenforced distribution
CC	3.33% (1)	10.00% (3)	3.33% (1)	0.00% (0)	16.67% (5)
FR	16.67% (5)	43.33% (13)	13.33% (4)	3.33% (1)	76.67% (23)
NC	3.33% (1)	0.00% (0)	3.33% (1)	0.00% (0)	6.67% (2)
UC	0.00% (0)	0.00% (0)	0.00% (0)	0.00% (0)	0.00% (0)
Enforced distribution	23.33% (7)	53.33% (16)	20.00% (6)	3.33% (1)	100.00% (30)

the other hand, NU fishers have several subjects clustered near the origin of the plot, demonstrating the limited impact of enforcement on these individuals.

DISCUSSION

In this study, we analyze the results of an ecologically valid common pool resource experiment involving artisanal fishers who exploit benthic resources along the coast of Chile, aiming to determine whether cooperative strategies and external enforcement could account for differences in co-management outcomes across user groups. Our findings reveal that the cooperation dynamics observed in the experiment, which reflect co-management outcomes of different user groups, can be attributed to the distribution of cooperative strategies and their interaction with external enforcement. When viewed through the lens of experimental games, differences in the strategic composition of user groups and their responsiveness to external enforcement are likely shaped by variations on how groups have

Table 5. Goodness-of-fit Chi-squared tests by common-pool resource (CPR) user groups and conditions. For each user group (High-performance unions, Low-performance unions, Non-unionized), the test evaluates whether strategy proportions within a condition differ significantly from equality. Entries report X^2 (df, N) and p-values for the unenforced (rounds 1–10) and enforced (rounds 11–20) conditions.

CPR user groups	Unenforced condition	Enforced condition
High-performance	$X^2(3, N = 23) = 9.86$, p = 0.019	$X^2(3, N = 23) = 25.17$, p = 1.42e-05
Low-performance	$X^2(3, N = 24) = 17$, p = 0.000	$X^2(3, N = 24) = 8.33$, p = 0.039
Non-unionized	$X^2(2, N = 30) = 25.8$, p = 2.498e-06	$X^2(3, N = 30) = 15.6$, p = 0.001

developed cooperative norms within co-management. Our results shed light on how norm enforcement affects individuals' strategy-switching behavior, which is crucial for understanding the dynamics of cooperation in commons problems, such as those faced by fishers in co-management regimes.

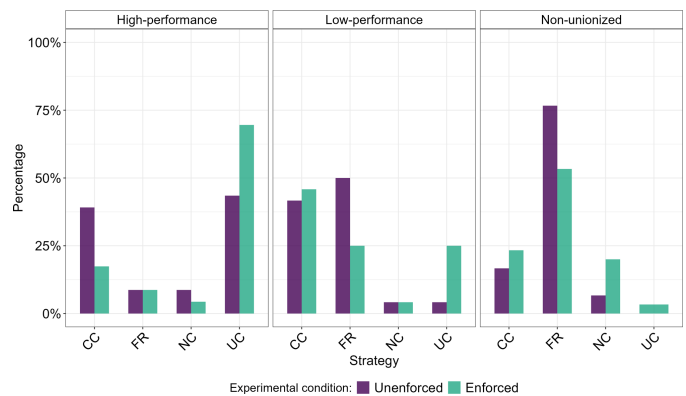
Aggregated experimental findings reveal cooperation dynamics in the game, reflecting differences in user groups' ability to sustain cooperation in real-life co-management. Specifically, (a) unions engaged in high-performing co-management experiences displayed elevated cooperation at the beginning of an unenforced condition, which subsequently attenuates to moderate levels. However, upon the introduction of enforcement, cooperation reverts to its initial level and remains consistently high; (b) unions engaged in low-performing co-management start the unenforced condition with moderate cooperation, which erodes over repeated interactions. In the enforced condition, their initial cooperation mirrors that of high-performing unions in round 11 but erodes over time; (c) non-unionized fishers, who have no co-management experience, exhibit minimal cooperation in the unenforced condition, which marginally rises after the introduction of external enforcement. Although all behavioral decisions in our experiment were made at the individual level, the classification of participants into user groups, high-performing, low-performing, and non-unionized, was based on union-level attributes assessed independently prior to the study. These attributes, including internal enforcement mechanisms, organizational structure, and ecological performance, served as contextual variables to define the composition of experimental groups (Cárdenas and Ostrom 2004). Our analysis and interpretation of behavioral outcomes remain at the individual level, but the variation observed across groups is contextualized using these union-level features. We do not draw inferences at the union level; rather, we use the institutional setting to interpret aggregate patterns in strategy adoption and responsiveness to enforcement, consistent with our exploratory approach.

Considering these cooperation dynamics, four fundamental questions arise. The response to each of these questions is based on the strategic distribution of fishers' behaviors induced by the enforced condition.

1. What causes the diminishing cooperation in both high and low-performing unions under the unenforced condition? In this condition, both HP and LP unions predominantly

consist of conditional cooperators, which makes cooperation unstable. The difference in initial cooperation levels between HP and LP unions is attributable to the higher proportion of free-riders in low-performing unions.

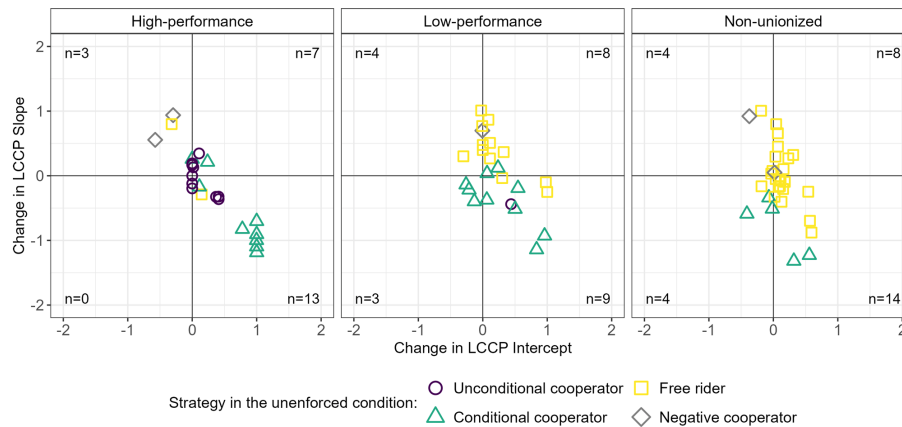
Fig. 2. Distribution of strategies by experimental condition across user groups. We estimated the distribution of behavioral types prior to enforcement (rounds 1–10) and after the introduction of external enforcement (rounds 11–20) for each group. Four types were considered: unconditional cooperators (UC) and free riders (FR), who do not condition their behavior on others' compliance levels, and conditional cooperators (CC) and negative cooperators (NC), who adjust their behavior in response to observed group compliance: CCs increase compliance when others do, whereas NCs do the opposite. Distributions were estimated as percentages (with a base of 100) within each user group (facet) and experimental condition (color). The most pronounced changes after enforcement took place among the unionized groups. In Low-Performance unions, enforcement reduced the proportion of free riders and increased the share of cooperators, particularly conditional ones. In High-Performance unions, where free riding was already low, cooperation shifted in form: conditional cooperation declined while unconditional cooperation rose. These shifts in type distributions help explain the compliance dynamics in Fig. 1. In Low-Performance unions, the rise in conditional cooperators led to an initial compliance boost that could not be sustained. In contrast, High-Performance unions displayed a shift toward unconditional cooperation, which supports both the increase and stability of compliance over time.



consist of conditional cooperators, which makes cooperation unstable. The difference in initial cooperation levels between HP and LP unions is attributable to the higher proportion of free-riders in low-performing unions.

2. What causes the resurgence of cooperation to peak levels in both union types when unenforced changes to enforced? The answer to this question is related to the norm signaling caused by the introduction of external enforcement (McAdams 2000, Fehr and Schurtenberger 2018). This allows HP unions to revert to initial cooperation levels and LP unions to increase the percentage of cooperators (from around 50% to over 70%), because of a reduction in the number of free-riders and an increase in the number of unconditional and conditional cooperators.
3. Why does the enforced condition not affect average cooperation among non-unionized fishers? In this case, the unconditional and conditional cooperators percentage for non-unionized fishers stabilizes below 25%, preventing a cooperative equilibrium.

Fig. 3. Effects of enforcement on unconditional and conditional Linear Conditional Contribution Profile (LCCP) parameters by user groups. Each point represents a participant's change in their estimated LCCP between the unenforced and enforced conditions. The x-axis shows the change in the intercept, capturing shifts in the unconditional cooperation level; the y-axis represents the change in slope relative to the unenforced condition, indicating shifts in responsiveness to peers' compliance. Colors and shapes indicate the strategy classification of each individual in the unenforced condition: conditional cooperator (CC), negative cooperator (NC), free rider (FR), and unconditional cooperator (UC). Numbers shown in each quadrant ($n=$) of the panels indicate how many individuals from the corresponding user group experienced shifts in intercept and/or slope that placed them in that specific quadrant. Changes in the distribution of strategies shown in Fig. 2 result from the aggregation of these individual-level shifts.



- Why does cooperation only stabilize in groups from high-performing unions? These results are caused by the redistribution of strategic types within the different user groups. LP unions witnessed a decline in free-riders by half. However, most of these free-riders transitioned to conditional cooperators, increasing the level of conditional cooperators from ~40% to ~50%. In stark contrast, HP union not only increased the number of cooperators to almost 90% but also underwent a change in the predominant strategy. Under the enforced condition, conditional and unconditional cooperators, previously present in similar proportions, now constitute around 80% of all cooperators. This suggests a widespread internalization of norms, thereby stabilizing cooperation at elevated levels.

Previous literature on strategic heterogeneity has suggested that greater shares of conditional cooperators in game experiments (compared to free-riders) is associated with greater extents of overall cooperation or productivity in real-life CPRs (Rustagi et al. 2010, Carpenter and Seki 2011). We propose a more nuanced interpretation of the association between the percentage of conditional cooperation and successful CPR management or, more generally, of sustaining cooperation in social dilemmas. In our results, only fishers belonging to HP unions in the enforced condition were capable of stabilizing compliance, while fishers from LP unions and nonunionized fishers failed to do so. HP unions in the unenforced condition and LP unions in the enforced condition are characterized by a larger share of conditional cooperators and face the decline of cooperation over time.

External enforcement played a crucial role in shaping the strategic composition that led to cooperation dynamics in the game that mirror real-life co-management outcomes. Our individual level regressions show that external enforcement mostly led to switches from conditional cooperators to unconditional cooperation

strategies in HP unions, similarly to what was found by Rodriguez-Sickert and colleagues (2008). In our sample, the differential effects of external enforcement on strategic composition across groups can be explained by differences in the internalization of norms and expectations across user groups with varying institutional experiences. HP unions are the most responsive to enforcement, resulting in a higher percentage of unconditional cooperators compared to other strategies and even reducing the proportion of free-riders to less than 10%. We can interpret the responsiveness of HP user groups through a normative effect. The introduction of external enforcement signals a standard of behavior, and for subjects that have internalized cooperation in co-management no matter what others are doing, this can lead them to switch into unconditional cooperators (Fehr and Schurtenberger 2018). Subjects that remain conditional cooperators under external enforcement will also increase their cooperation if they anticipate a higher share of unconditional cooperators under norm enforcement, stabilizing cooperation. Through their daily interaction groups of users develop norms, expectations, and other behavioral heuristics that they apply in similar contexts (Ostrom 1990, Rivera-Hechem et al. 2021). Real-life interactions of HP unions under functioning co-management that often involve sanctioning and social pressure, has likely led to norm internalization and high cooperation expectations in contexts that resemble co-management interactions.

Although enforcement led to switches in strategies in LP unions increasing unconditional cooperators and decreasing the proportion of free-riders, it fails to sustain the levels of compliance between rounds 11 and 20. This erosion of cooperation in the enforced condition, distinguishing it from high-performing groups, can be attributed to the repeated interaction between highly represented strategies within LP unions, where 46% are conditional cooperators and 25% are free-riders. The low cooperation levels among free-riders undermine

enforcement, leading conditional cooperators to reduce or withdraw their compliance (de Oliveira et al. 2015). A necessary condition for some conditional cooperators to shift to unconditional cooperation is the belief that external enforcement is sufficient, as the fines imposed on defectors would relieve them of the need to retaliate by withholding their own cooperation (Andreoni 1995). One plausible interpretation for the persistence of a subset of individuals as conditional cooperators is that they maintained this strategy because they perceived the enforcement mechanism as inadequate or ineffective in punishing free-riders, reflecting a potential lack of confidence in external regulators in real-life contexts. In LP communities, these expectations are likely shaped by their real-world experiences of interacting within unions that have low peer accountability, which leads to weak norm internalization.

The situation of non-unionized fishers also embodies individuals who have conducted their activities independently, lacking collective fishing experience or familiarity with institutions such as MEABRs or quota compliance. For this reason, their behavior in the enforced condition reflects the potential response of a human group to their first experience of collective action regulation, and, in this regard, their low compliance and declining behavior over time make sense if they lack confidence in this type of regulation. Differences in how groups develop norms and expectations around natural resource use are influenced by the costs and benefits each group faces. Although the unions in our sample share similar ecological and cultural backgrounds, other factors known to affect collective action in common-pool resource use may explain why developing cooperation mechanisms in co-management is more cost-effective for some groups than for others. These factors include union-level variables such as leadership, social capital and cohesion, and local knowledge (Ostrom 2009, Gutiérrez et al. 2011, Cinner et al. 2019, Gelcich et al. 2019). A potential limitation of our interpretation is that the observed differences in behavior across user groups may not solely reflect the effects of institutional experience. It is also possible that individuals with more prosocial or intrinsically cooperative dispositions are more likely to self-select into unions that offer stronger collective arrangements. Likewise, some unions may emerge and persist in communities where cooperative norms are already more robust because of historical, social, or ecological factors. These selection dynamics could shape both institutional structures and individual behaviors, making it difficult to isolate their respective effects. Although our findings are consistent with an interpretation of institutional influence on strategy adaptation, we caution against strong causal claims and emphasize the need for future research to more precisely disentangle these overlapping mechanisms.

Having controlled for ecological and cultural variability (i.e., by working with a sample within one of the major areas identified by Romero and Melo 2021), we can conjecture an association between the distribution of strategies and the informal institutions that have emerged within each type of user group. The path dependence of each community and the historical context of these groups are reflected in aspects that have molded their unions, particularly through local informal norms. The interaction of these norms with the regulatory framework prompts varying propensities for individuals to responses to the MEABR regulation. For example, in HP user groups, this

manifests as greater confidence in the effects of enforcement on other group members, which transforms individual strategies into those of highly cooperative actors by increasing trust and expectations regarding the prosocial commitment of the entire group. The findings of this study can provide insights into the processes that influence the prospect of success or failure of co-management institutions. We observed that in this sample of fishers, the heterogeneity of strategies plays a significant role in the probabilities of success and the stability of cooperation, a conclusion that aligns with previous experimental research.

The primary objective of this study was to examine how imperfect external enforcement, common in co-management settings, influences the distribution of cooperative strategies across groups of resource users with differing institutional experience. We found that enforcement affects the distribution of cooperative types in all three groups. This result provides evidence of the role of enforcement in shaping the distribution of cooperative types. We also observed that enforcement affected the distribution of cooperative types differently across groups of users in ways that align with real-world co-management outcomes. Although we designed the sampling to minimize ecological and cultural differences across groups, we cannot completely rule out the influence of other factors unrelated to co-management experience that may have shaped behavioral responses. Thus, we cannot attribute the observed patterns solely to co-management experience. This limits the generalizability of our findings regarding the extent to which differences in co-management relate to differences in the distributions of strategies. Nonetheless, the patterns observed are consistent with well-established behavioral regularities in the literature, suggesting differences in underlying social norms. Future research could apply these methods to further investigate whether differences in cooperative type distributions are norm driven to further unpacking heterogeneity in co-management outcomes. In the experiment, participants were not given the option to under-harvest. Therefore, we were unable to identify cooperative strategies manifesting voluntary under-extraction. We do not expect this feature to interfere with our primary objective of assessing changes in the distribution of strategies between enforcement conditions. However, it could have biased the prevalence of strategic types. Consequently, direct comparisons of the distribution of cooperative strategies in our experiments with previous research should be made with caution. Future research could explore the effects of alternative designs that allow participants to under-harvest, assessing whether the observed differences between high-performance (HP) and low-performance (LP) unionized fishers and their non-unionized counterparts hold across different institutional and decision-making contexts.

In this paper, we focus on understanding the dynamics of cooperation, whether cooperation erodes or stabilizes, as an emergent phenomenon resulting from the interaction of individual strategies within groups. By identifying these underlying mechanisms, we aim to provide insights into how different user groups sustain cooperation (or not) in their real-life CPR experiences. This helps to comprehend the social challenges that user groups face in maintaining cooperation, and propose potential solutions, thereby shedding light on ways to support local communities in engaging more effectively in co-management. Furthermore, results show external enforcement

drive strategic shifts in individuals who are more inclined to trust its impact on others' behavior. Future research on the role of heterogeneous strategy distribution and its interaction with the institutional environment can delve more deeply into the effects of various strategy configurations on group outcomes, as well as explore the marginal effects of increasing proportions of each strategy.

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Data Availability:

All the anonymized experimental data and statistical codes that support these findings are currently available at <https://osf.io/2kvp3/>.

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Appendix 1. Classification of CPR user groups

The following table shows the seven variables of the co-management performance index, all of which are closely related to cooperation and compliance among union members. The index, measured on a 0 to 1 scale, is simply the average of all variables identify below:

Performance domain	Variable	Survey question or statistical indicator	Scale	Justification for inclusion	Source
Internal enforcement and compliance with the union norms, as assessed by the president of the union	Internal enforcement of the union norms	Is there internal enforcement of the union norms?	1=24 hours a day enforcement; 0.66=day or night enforcement; 0.33=enforcement only in good sea conditions; 0=no enforcement	Enforcement incentivizes compliance with norms, including those that deal with cooperative behavior	Adapted from Gelcich et al. (2009).
	Compliance with the union norms	Do the union members comply with the norms?	5-point Likert scale: Highly agree=1; Highly disagree=0.	Many norms mandate cooperative behaviors, such as not overharvesting.	Adapted from Gelcich et al. (2009) and Marin et al. (2012).
Co-management performance as assessed by the National Fisheries Service	Compliance with the MEABR norms.	How closely does the union follow the rules and procedures to exploit and maintain its MEABR?	5-point Likert scale: 1=To the letter; 0=Not at all.	Compliance is largely a result of cooperation between union members.	Adapted from Marin et al. (2012).
	Quality of the institutions and social practices.	Is the union a model case of co-management?	1=Yes; 0=No.	Better institutions and practices promote cooperation.	Adapted from Marin et al. (2012).
	Overall performance in the co-management of the MEABR.	Which of these words best describes the overall performance of the MEABR?	1=Success; 0.75=Stability; 0.5=Improvement; 0.25=Stagnation; 0=Failure.	Performance depends largely on the cooperation between union members.	Adapted from Marin et al. (2012).
Ecological performance	Trend in the annual Total Allowable Catch (TAC).	Official annual TAC.	1=Increased; 0.5=Maintained; 0=decreased.	TAC falls if the community overexploits the resource.	SUBPESCA 2012.
	Biodiversity response as compared to adjacent open-access areas.	Biodiversity measured as overall species richness.	Log response ratios between adjacent open-access areas and MEABR. 0=0; >0.1=1.	Preservation of biodiversity is a cooperative endeavor.	Adapted from Gelcich et al. (2009), Marin et al. (2012), and Center for Marine Conservation surveys (available from authors).

Appendix 2. Common-pool resource game instructions

The experimental instructions were originally drafted in Spanish, which is the official language of Chile. These instructions were orally presented to the participants by a designated monitor at the outset of each session. Participants had the autonomy to interrupt the reading at any juncture for the purpose of seeking clarifications or ask questions. Below, we offer an English translation of these instructions, and the text enclosed within parentheses delineates actions carried out by either the monitor or the subjects.

(Five subjects enter the room and sit in front of the computers. They are greeted by the monitor)

“Welcome and thank you for being here. You are about to participate in an experiment. You have been randomly chosen from the list of union members provided by the union president. This experiment is part of a research project carried out by Pontificia Universidad Católica about the co-management of benthic resources. This project is not related whatsoever to the Undersecretary of Fisheries or the National Fisheries Service.”

“We will spend about an hour playing a game. By participating in the game, you will earn between 10 and 20 thousand pesos. You will be paid privately at the end of the game. I will read the instructions now. If you have any question, please raise your hand and I will answer. Let's begin:”

“First, the game is played using computers. Do not worry if you have never used a computer before. You will only have to use the number keys like on a calculator or a phone.”

“The game recreates a situation where you go fishing for loco, and you must decide how many loco to harvest. The game is divided in 20 rounds. Each one is assigned an individual quota of 100 locos per round. The computer will assume that you always harvest the whole quota, but you can overharvest up to 50 extra locos per round. Overharvest benefits you but harms other members of the group. For every loco you overharvest, the others lose half a loco unit. Similarly, for every 2 loco you overharvest, the others lose 1 loco each.”

“In each round the computer will ask you the same question: how many extra locos do you want to overharvest? (from 0 to 50). If you want to comply with your individual quota, your answer should be 0. You must answer using the key numbers, and the press enter (Monitor shows fishers on the computer). Your answers will be stored anonymously in the computer. The researcher and the other players will never know how many locos you overharvested. Your identity will be hidden from them and us. To maintain anonymity, it is very important that you remain silent during the game. Talking is forbidden.”

“I will now show you the screens that you will see on your computers while playing the game.”

(The monitor projects the user interface onto the wall)

“In each round, the following screen will appear. You must decide how many units to overharvest. Please enter your decision inside the box, and then press enter. Remember, you can overharvest between 0 and 50 units per round. Once you and the other four players have entered your decisions, the following screen will appear.”

(The monitor shows the next screen)

“This screen summarizes the results of the round. As you can see, the first box shows your harvest and the second box shows your group’s average harvest. The third box shows how many loco you lost due to the other fishers’ overharvest, and the fourth box shows the amount of money that will be added to your account. Remember that your gains will accumulate during the game. Once you see your results for the round, you can press any button and the new round will begin.”

“Now you will play five rounds for practice that will not count towards your earnings. Please raise your hand if you have any difficulties using the computer or if you do not understand what boxes mean. I will immediately answer any question. Remember that talking is not allowed.”

(Subjects play five rounds of practice)

“The trial rounds have finished. Now, the actual game will start. From now on, you will be playing for real money. Good luck.”

(After round 10, a screen appears on the computers, which the monitor reads aloud)

“From now on, the rules of the game will change. The computer will play the role of the National Fisheries Service. After each of the remaining rounds, the computer will inspect two subjects selected at random. If the computer finds that a subject exceeded his or her quota, it will confiscate the subject’s entire harvest of that round. You will know if you were inspected because a message will appear on your screen. You will not know who of the other members was inspected or whether if he was sanctioned or not.”

(At the end of the game, an assistant leads the subjects out of the room. He gives them a brief survey, and then pays them in sealed envelopes. In parallel, the monitor leads the next group in. There is no communication between groups)

Appendix 3. Strategy classification

We adapted the methods of Kurzban and Houser (2005) and van Klinger (2022), in order to classify subjects as either Free-riders, Conditional Cooperators, Unconditional Cooperators or Negative Cooperators. We use the individual LCCPs to classify each subject in both conditions, according to the following model:

$$y_{it} = \alpha_{i1} + \alpha_{i2}DR + \beta_{i1}\bar{x}_{jt-1} + \beta_{i2}\bar{x}_{jt-1}DR + \varepsilon_{it}$$

Where y_{it} is the compliance of subject i in round t ; $\bar{x}_{jt-1}$ is the average compliance of i 's teammates in $t-1$; DR is a dummy variable that takes unenforced condition as a reference level; and ε_{it} is an error term.

According to this model, the parameters of the LCP model can be interpreted as:

$\hat{\alpha}_{i1}$ is the unconditional contribution of subject i in the unenforced condition

$\hat{\alpha}_{i2}$ is the change in the unconditional contribution of subject i due to the introduction of the enforced condition

$\hat{\alpha}_{i1} + \hat{\alpha}_{i2}$ is the unconditional contribution of subject i in the enforced condition

$\hat{\beta}_{i1}$ measures the responsiveness of subject i to j 's compliance in the unenforced condition

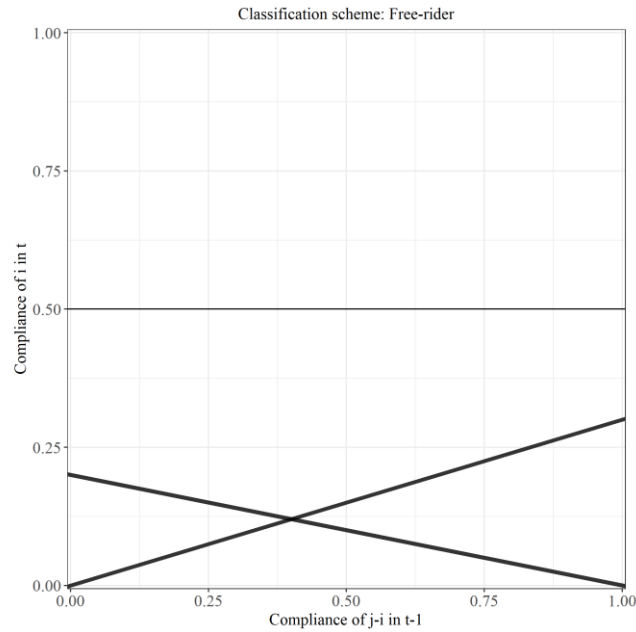
$\hat{\beta}_{i2}$ is the change in the responsiveness of subject i due to the introduction of the enforced condition

$\hat{\beta}_{i1} + \hat{\beta}_{i2}$ is the responsiveness of subject i to j 's compliance in the enforced condition

According to our definition, a Free-Rider is a subject whose LCP is always lower than half of the total possible compliance (i.e., their expected compliance is always <50% at all levels of others' contributions). This means that a subject is classified as Free-rider if:

- In the unenforced condition: $\hat{\alpha}_{i1} < 0.5$ and $\hat{\alpha}_{i1} + \hat{\beta}_{i1} < 0.5$
- In the enforced condition: $\hat{\alpha}_{i1} + \hat{\alpha}_{i2} < 0.5$ and $\hat{\alpha}_{i1} + \hat{\alpha}_{i2} + \hat{\beta}_{i1} + \hat{\beta}_{i2} < 0.5$

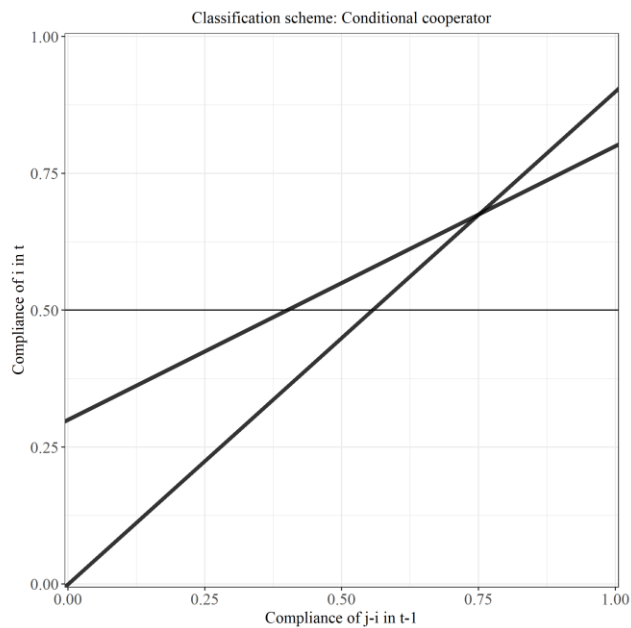
In the following plot we present two hypothetical examples of LCPs that would be classified as free-riders:



According to the classification scheme, Conditional Cooperators comply below 0.5 when their teammates' compliance is set to zero (i.e, the intercept of their LCCP is < 0.5), but the responsiveness to their teammates is above 0.5 (intercept plus slope > 0.5). This means that a subject is classified as Conditional-cooperator if:

- In the unenforced condition: $\hat{\alpha}_{i1} < 0.5$ and $\hat{\alpha}_{i1} + \hat{\beta}_{i1} > 0.5$
- In the enforced condition: $\hat{\alpha}_{i1} + \hat{\alpha}_{i2} < 0.5$ and $\hat{\alpha}_{i1} + \hat{\alpha}_{i2} + \hat{\beta}_{i1} + \hat{\beta}_{i2} > 0.5$

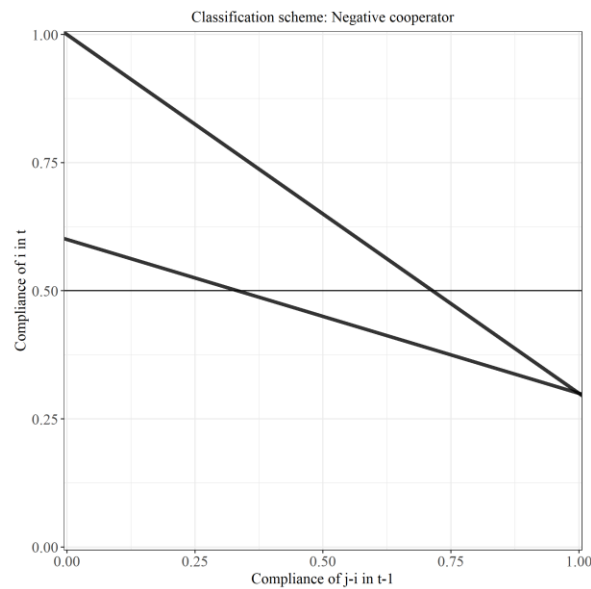
In the following plot we present two hypothetical examples of LCPs that would be classified as Conditional-cooperators:



In our classification, Negative Cooperators comply above 0.5 when their teammates' compliance is set to zero (i.e, their LCCP intercept is > 0.5), but the responsiveness to their teammates is below 0.5 (intercept plus slope < 0.5). This means that a subject is classified as Negative-cooperator if:

- In the unenforced condition: $\hat{\alpha}_{i1} > 0.5$ and $\hat{\alpha}_{i1} + \hat{\beta}_{i1} < 0.5$
- In the enforced condition: $\hat{\alpha}_{i1} + \hat{\alpha}_{i2} > 0.5$ and $\hat{\alpha}_{i1} + \hat{\alpha}_{i2} + \hat{\beta}_{i1} + \hat{\beta}_{i2} < 0.5$

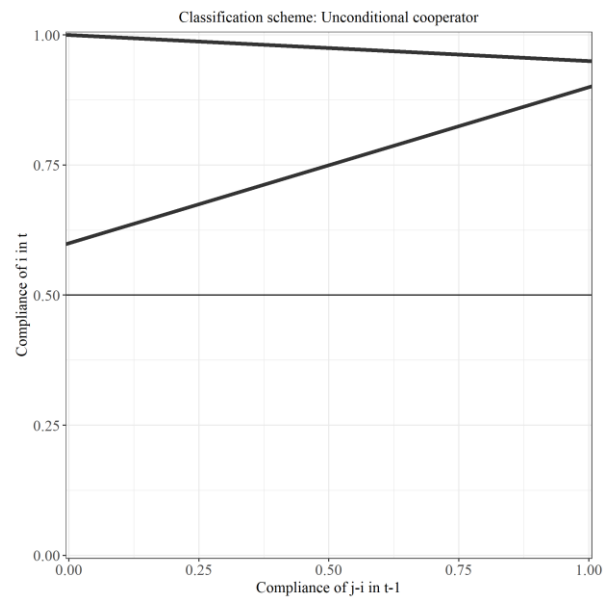
In the following plot we present two hypothetical examples of LCPs that would be classified as Negative-cooperators:



We defined Unconditional Cooperators as subjects who always display an LCP above half of the total possible compliance (i.e., their expected compliance is always $> 50\%$ at all levels of others' contributions). This means that a subject is classified as Unconditional -cooperator if:

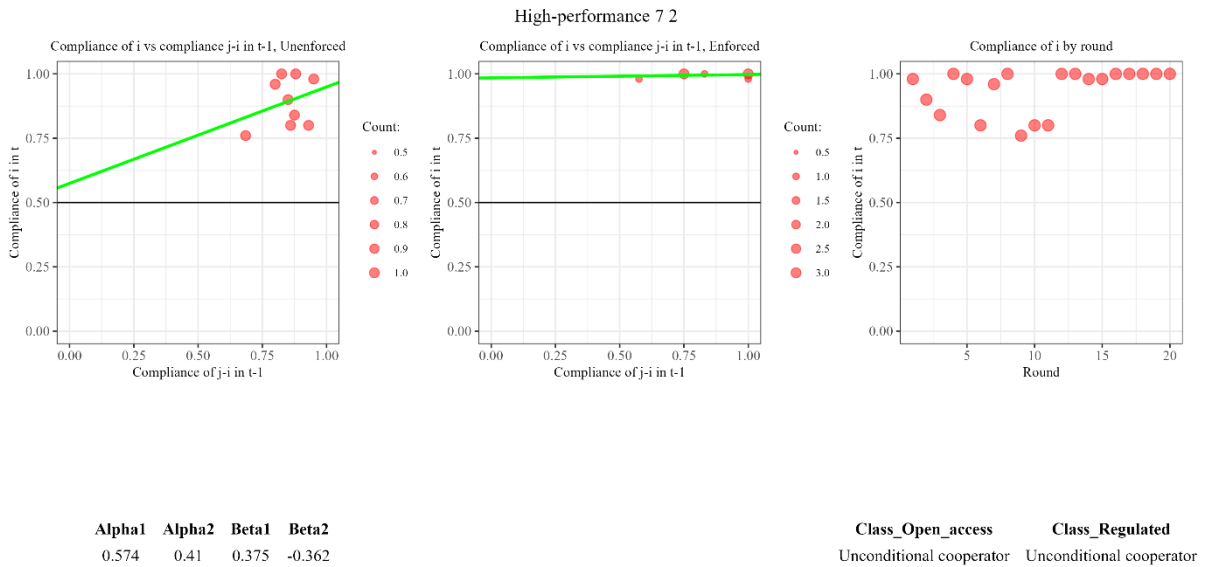
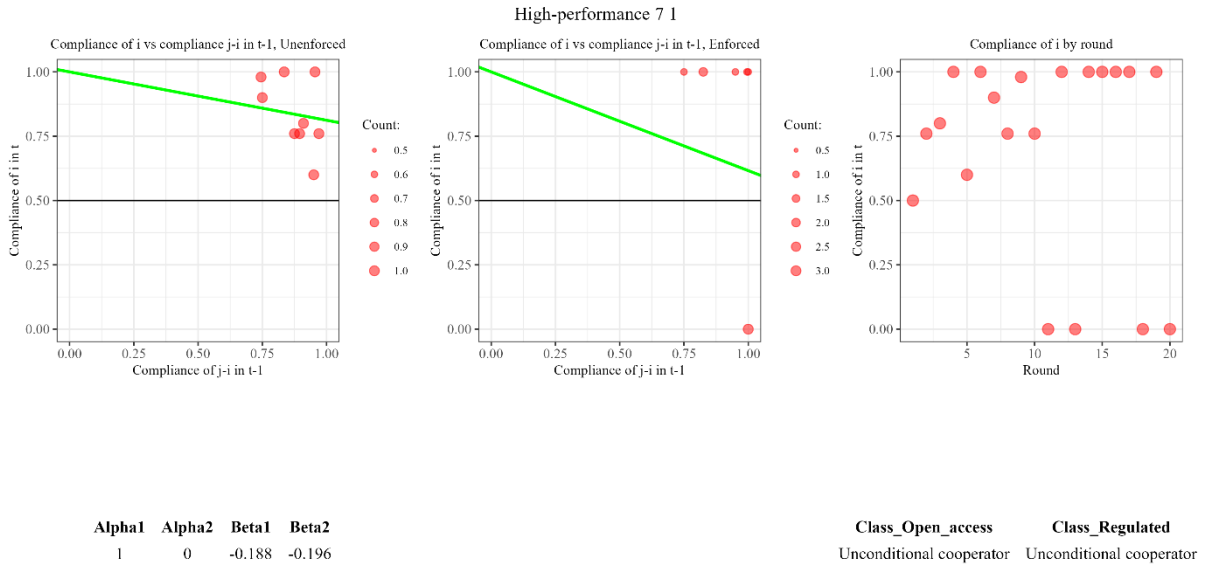
- In the unenforced condition: $\hat{\alpha}_{i1} > 0.5$ and $\hat{\alpha}_{i1} + \hat{\beta}_{i1} > 0.5$
- In the enforced condition: $\hat{\alpha}_{i1} + \hat{\alpha}_{i2} > 0.5$ and $\hat{\alpha}_{i1} + \hat{\alpha}_{i2} + \hat{\beta}_{i1} + \hat{\beta}_{i2} > 0.5$

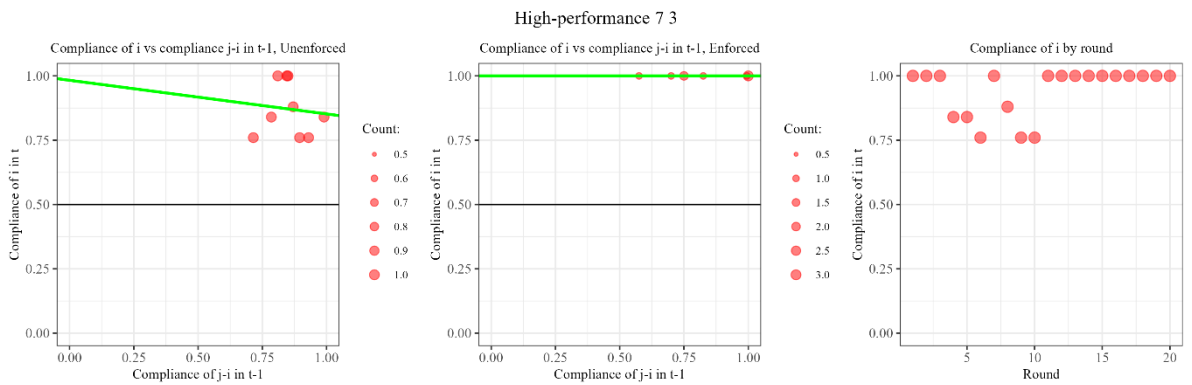
In the following plot we present two hypothetical examples of LCPs that would be classified as Unconditional-cooperators:



Appendix 4. Classification of individual strategies

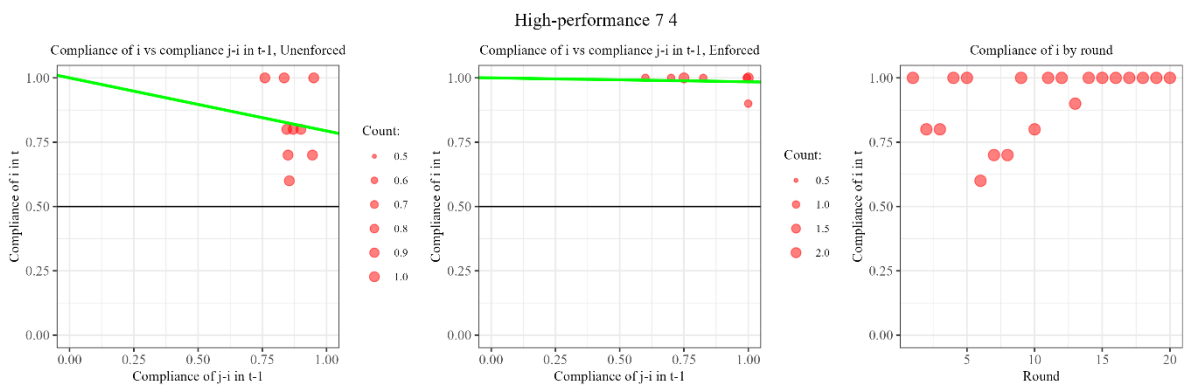
We present, case-by-case, the individual classification of strategies in both experimental conditions as a separate file, including 77 figures (one per subject). In each figure we present three plots: the LCCP in the unenforced condition, the LCCP in the enforced condition, and the compliance of the subject across rounds. We also provide information of the LCCP parameters and their classification in both conditions.





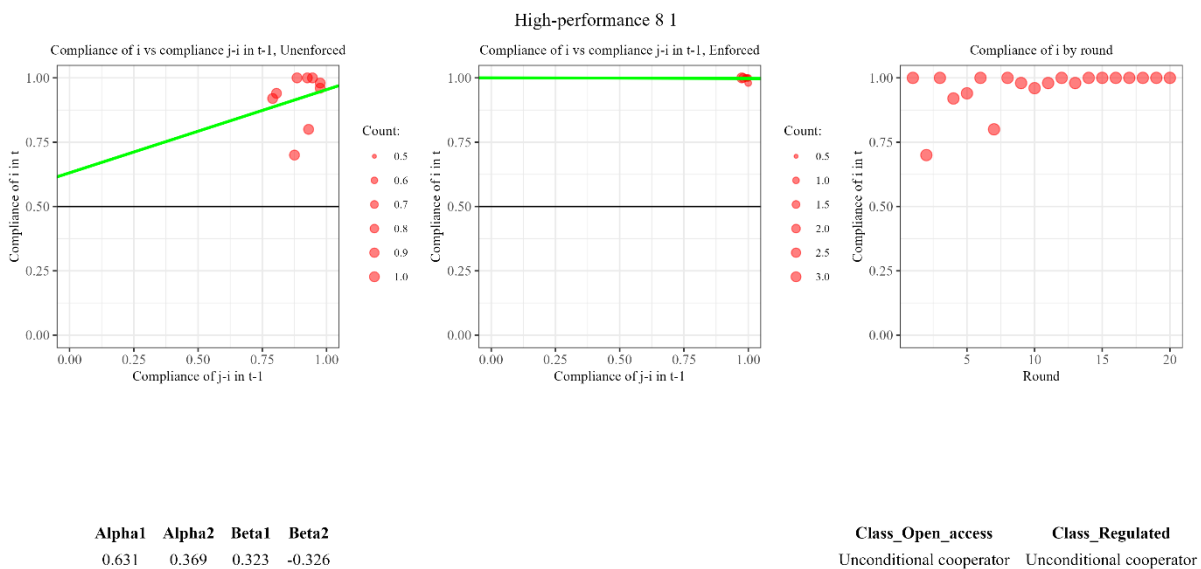
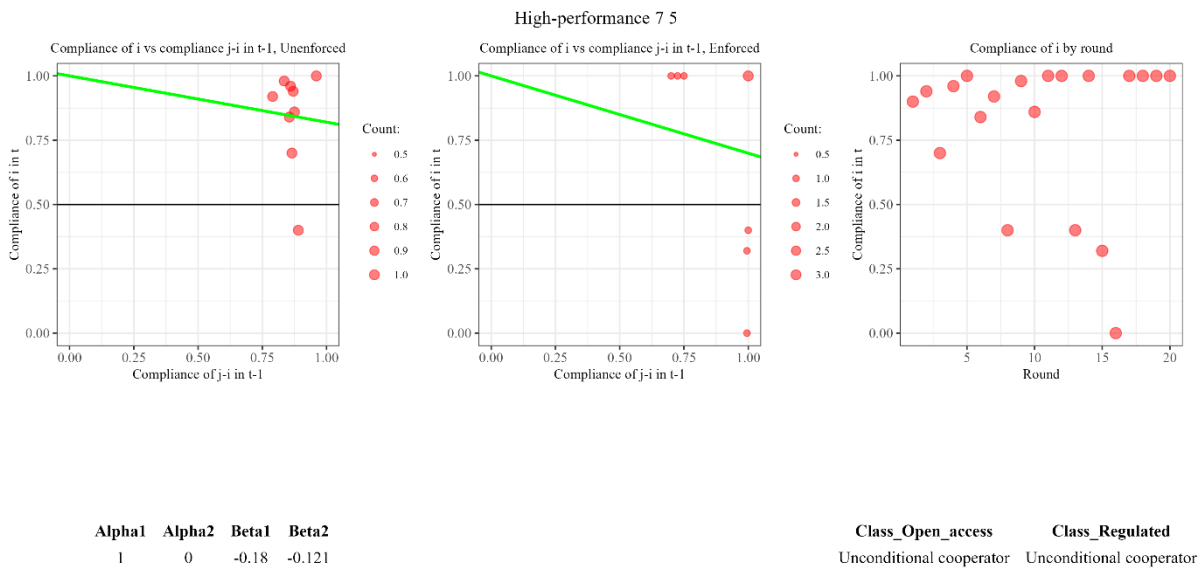
Alpha1	Alpha2	Beta1	Beta2
0.983	0.017	-0.131	0.131

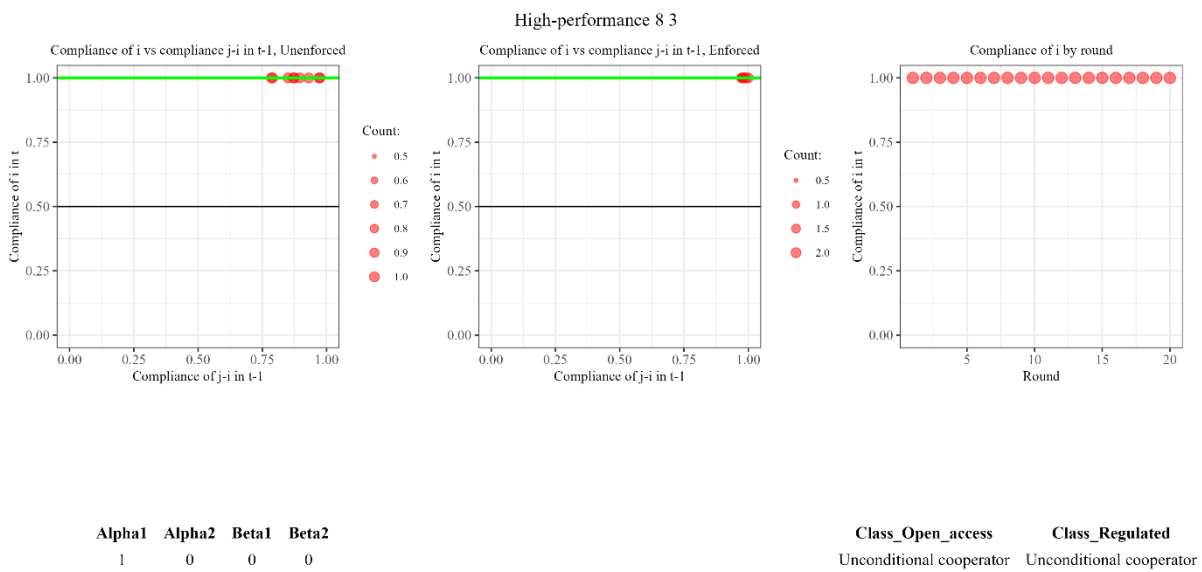
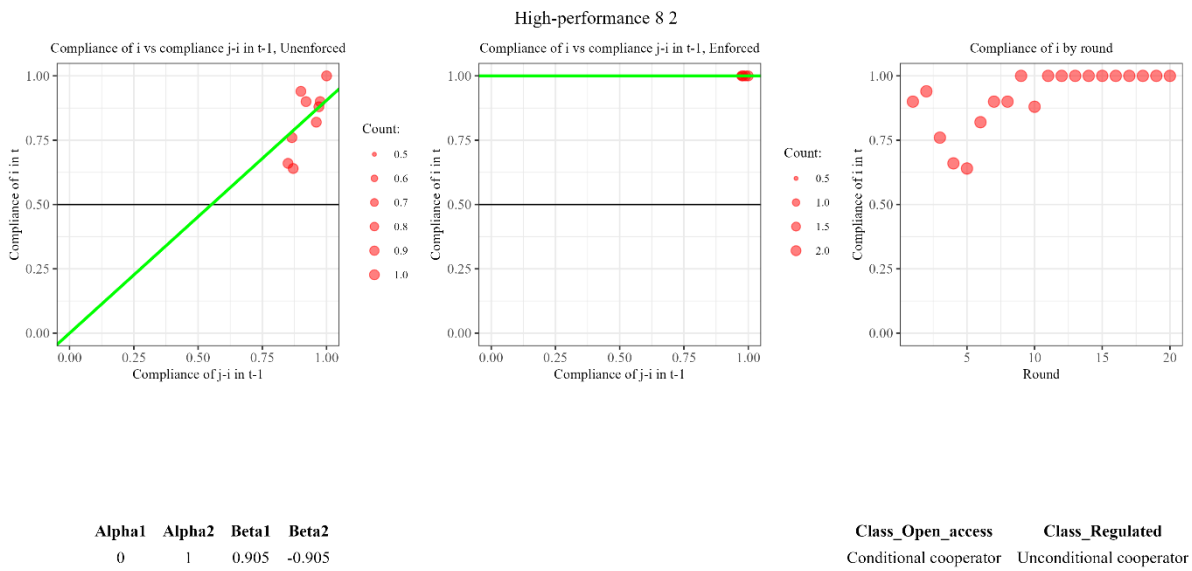
Class_Open_access	Class_Regulated
Unconditional cooperator	Unconditional cooperator

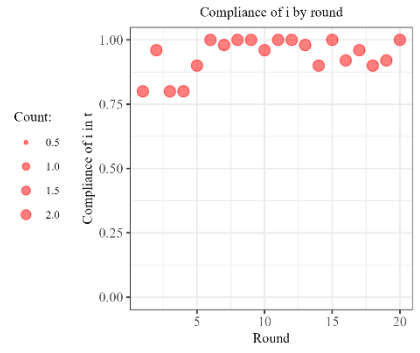
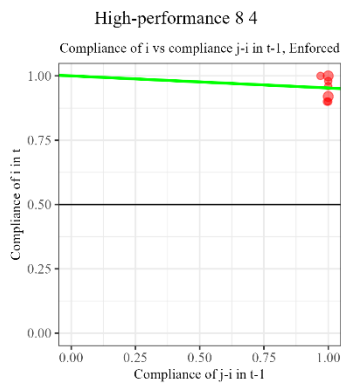
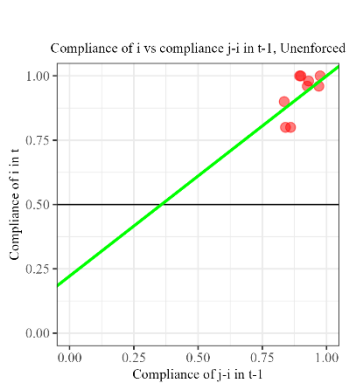


Alpha1	Alpha2	Beta1	Beta2
1	0	-0.206	0.191

Class_Open_access	Class_Regulated
Unconditional cooperator	Unconditional cooperator

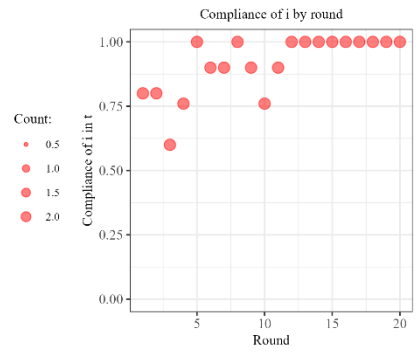
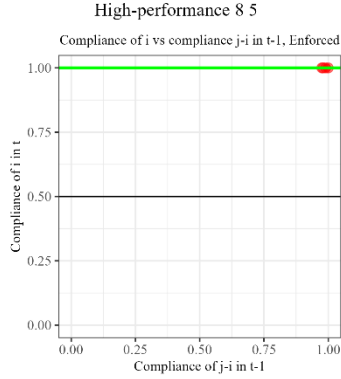
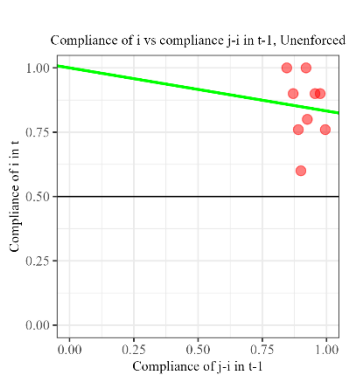






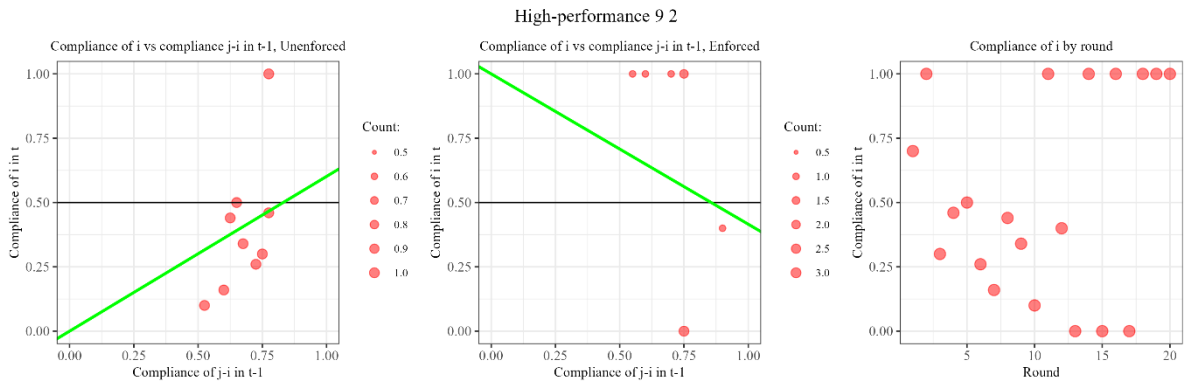
Alpha1	Alpha2	Beta1	Beta2
0.222	0.778	0.778	-0.825

Class_Open_access	Class_Regulated
Conditional cooperator	Unconditional cooperator



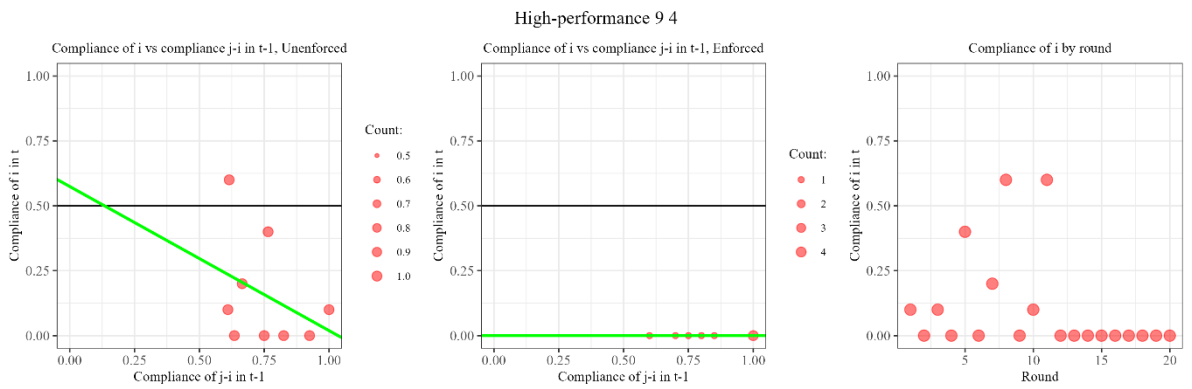
Alpha1	Alpha2	Beta1	Beta2
1	0	-0.167	0.167

Class_Open_access	Class_Regulated
Unconditional cooperator	Unconditional cooperator



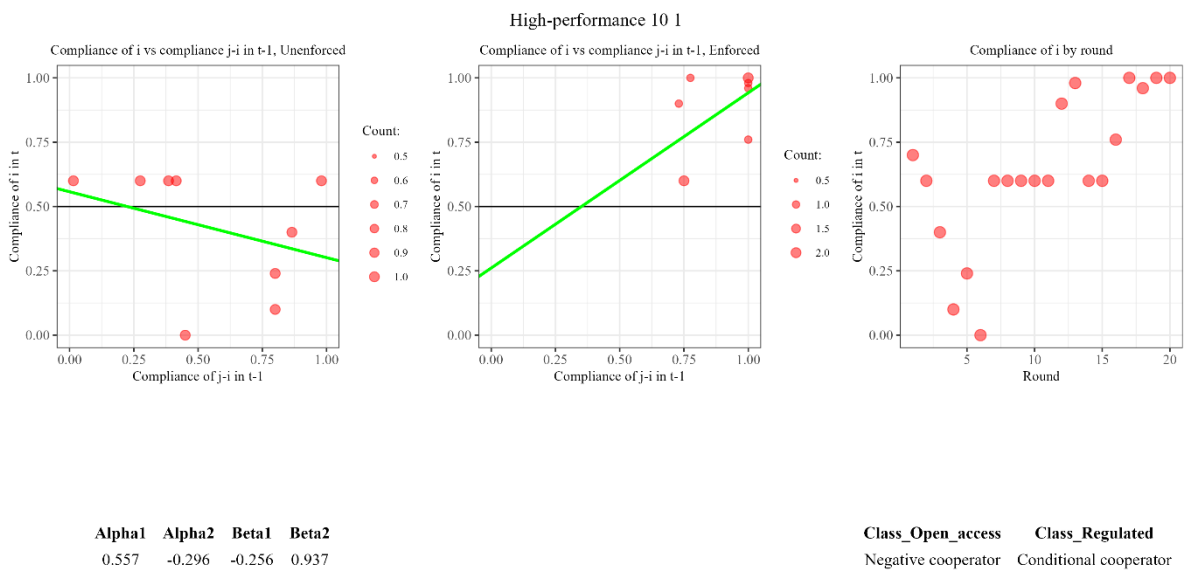
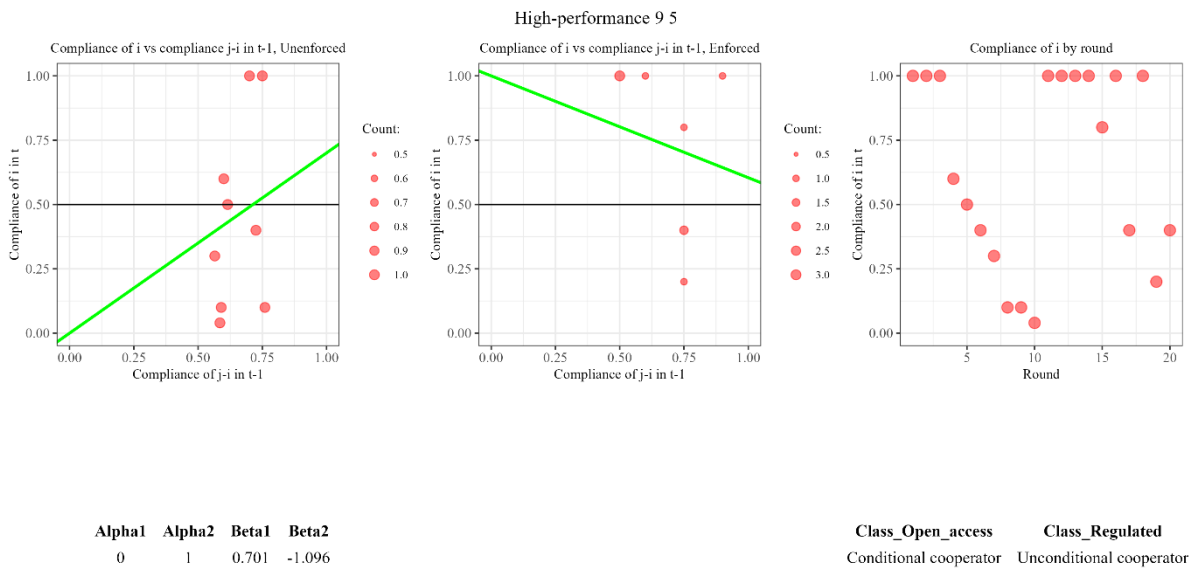
Alpha1	Alpha2	Beta1	Beta2
0	1	0.602	-1.186

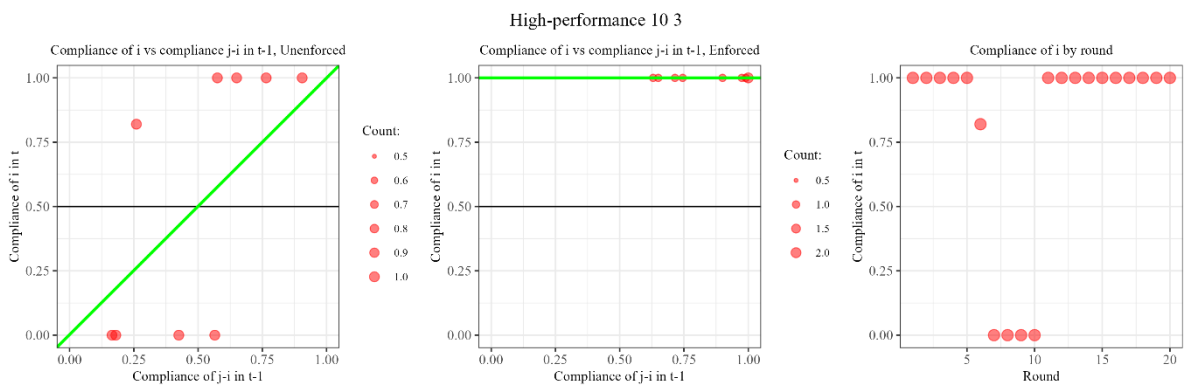
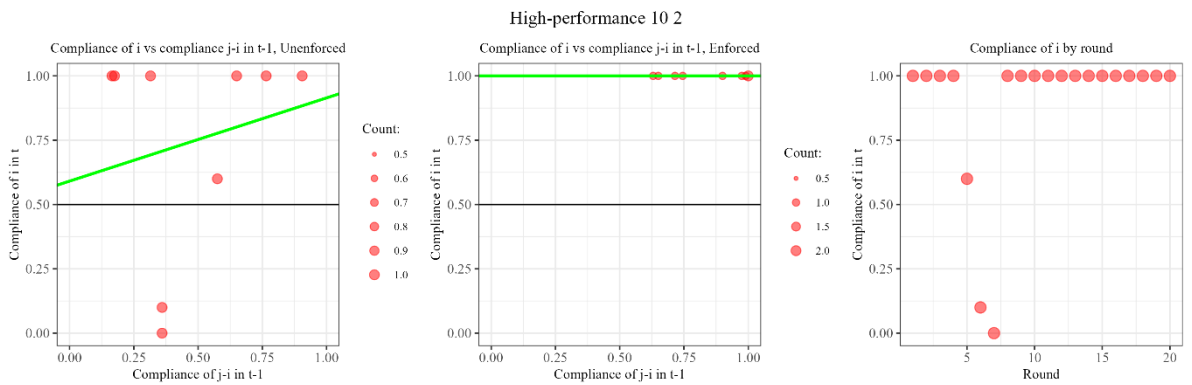
Class_Open_access	Class_Regulated
Conditional cooperator	Negative cooperator

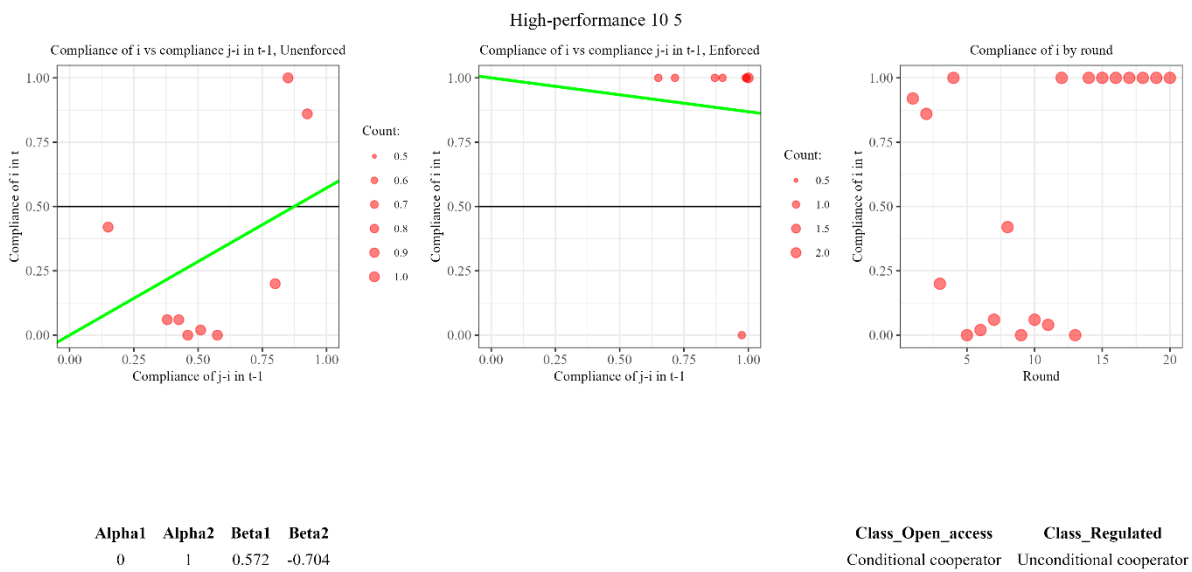
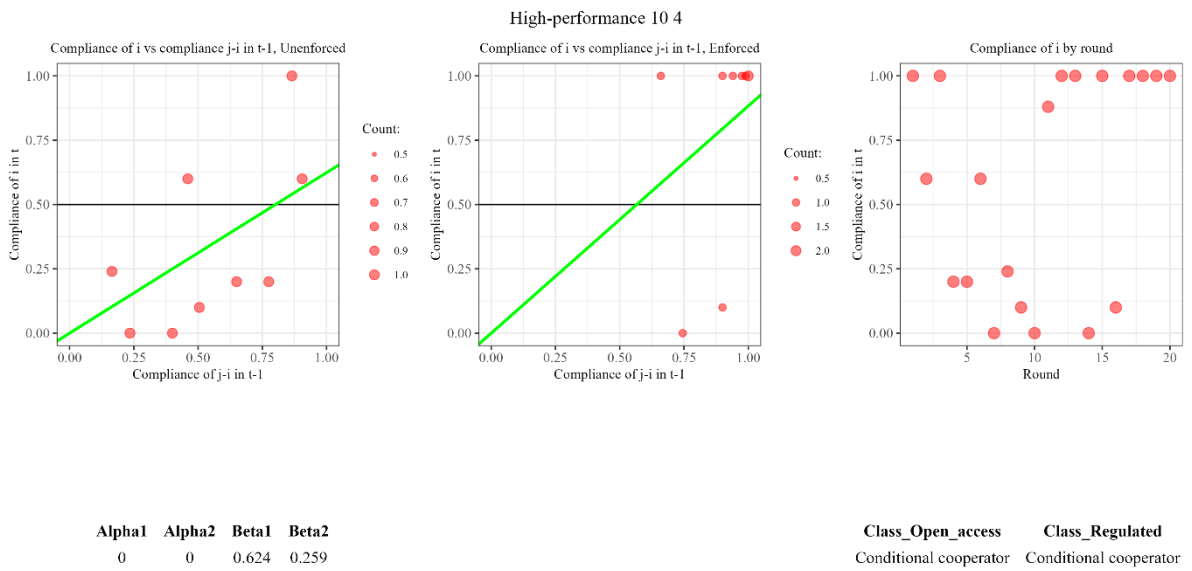


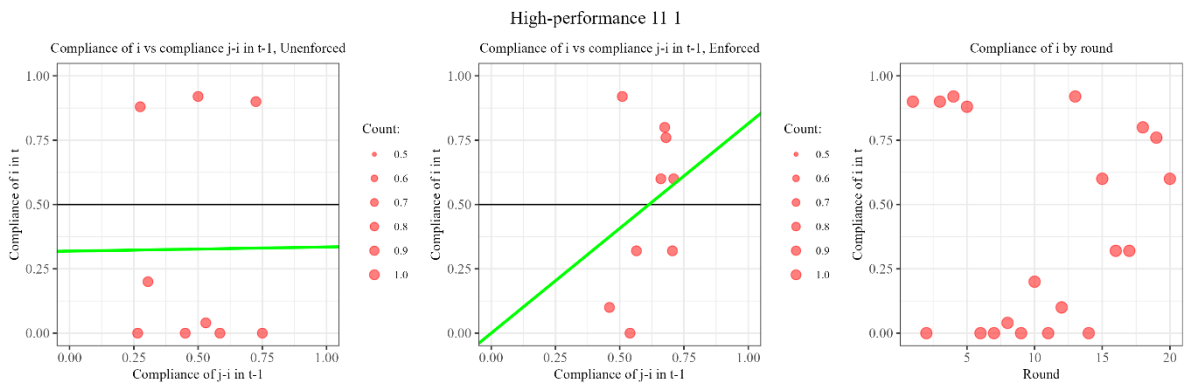
Alpha1	Alpha2	Beta1	Beta2
0.574	-0.574	-0.555	0.555

Class_Open_access	Class_Regulated
Negative cooperator	Free-rider



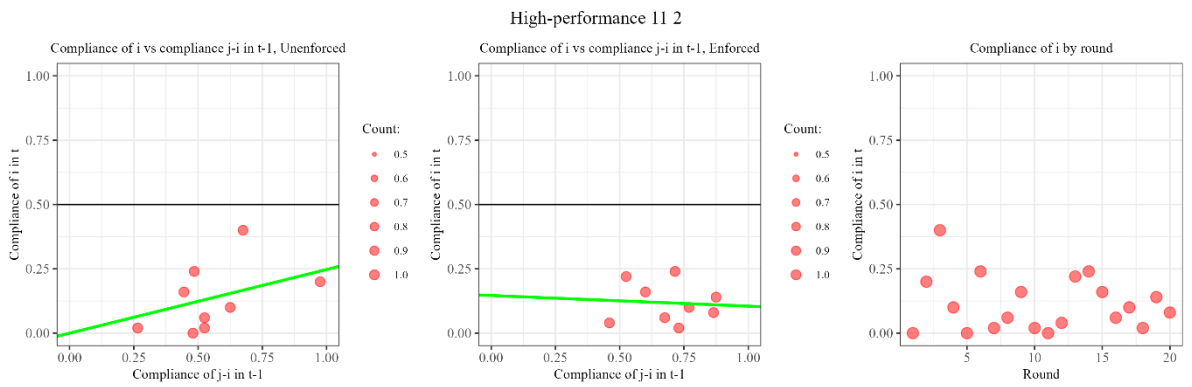






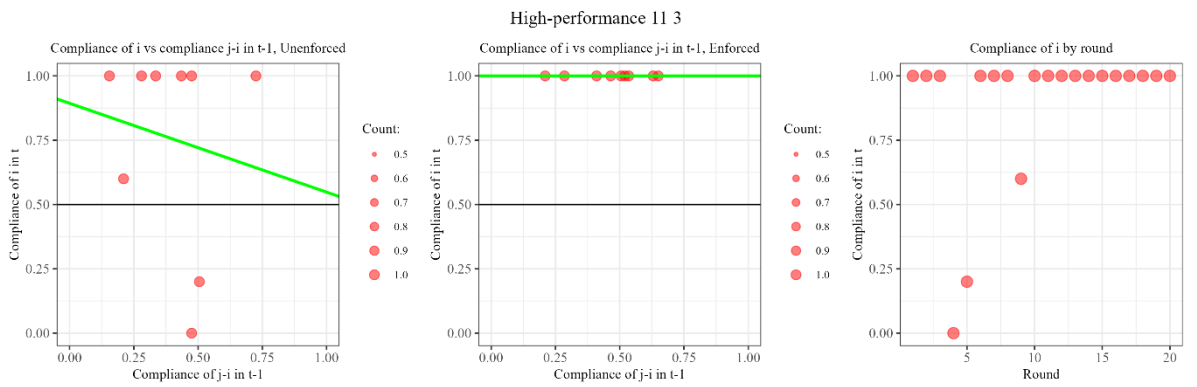
Alpha1	Alpha2	Beta1	Beta2
0.319	-0.319	0.016	0.799

Class_Open_access	Class_Regulated
Free-rider	Conditional cooperator



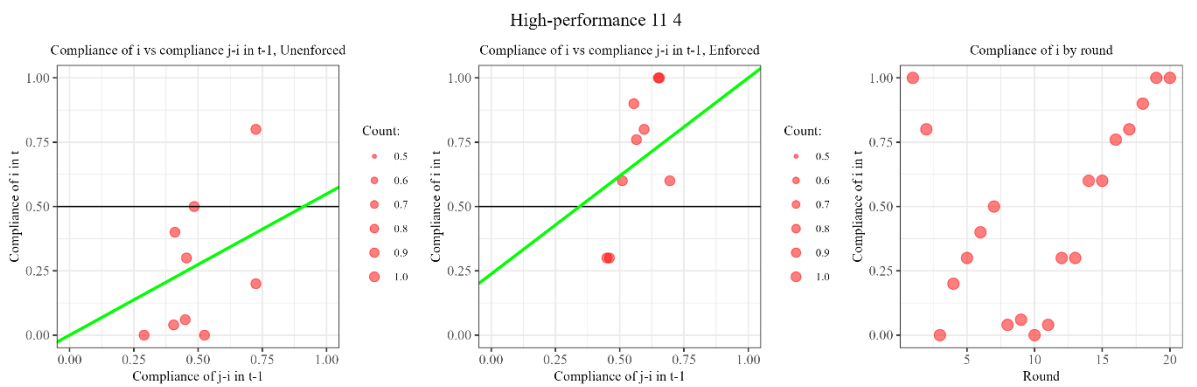
Alpha1	Alpha2	Beta1	Beta2
0	0.146	0.247	-0.289

Class_Open_access	Class_Regulated
Free-rider	Free-rider



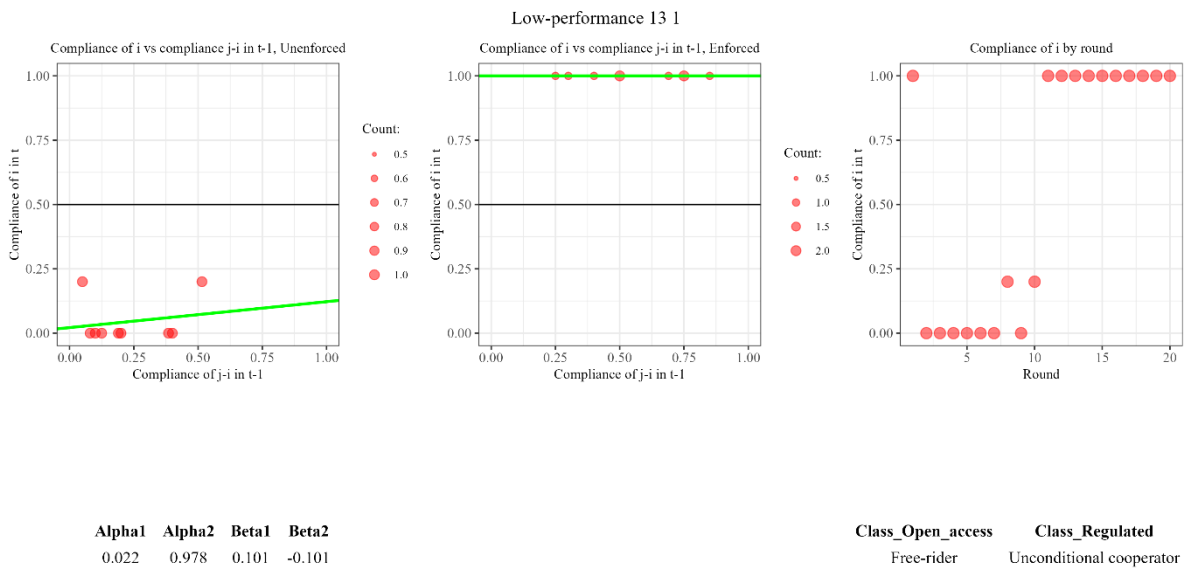
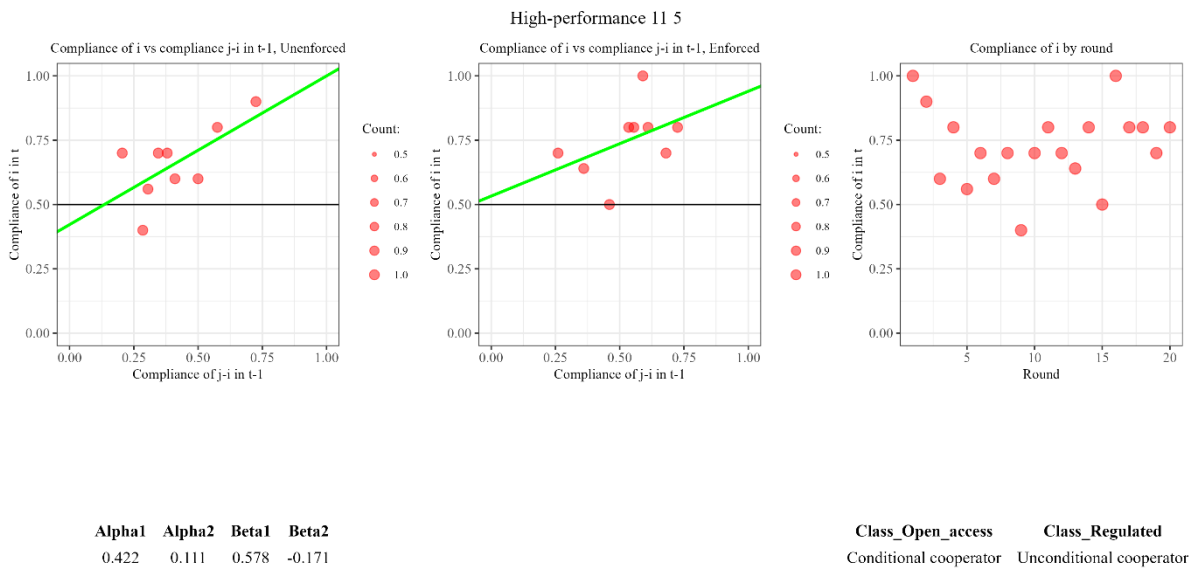
Alpha1	Alpha2	Beta1	Beta2
0.894	0.106	-0.345	0.345

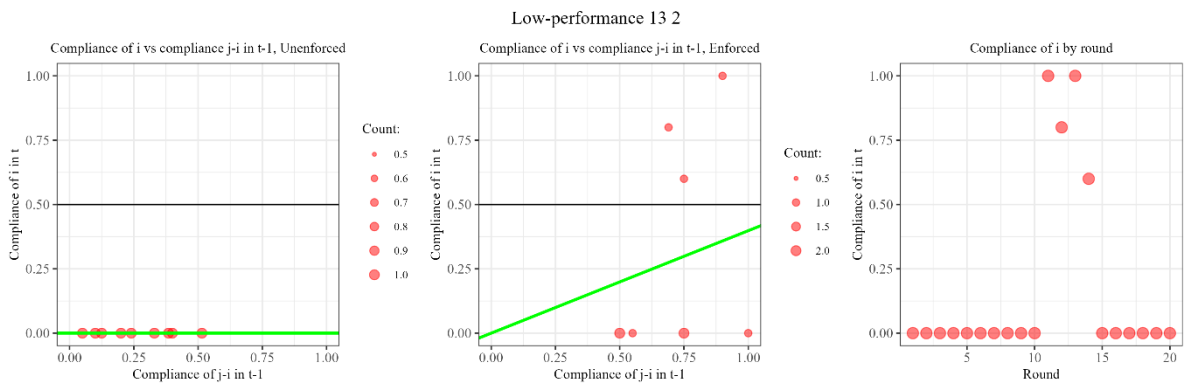
Class_Open_access	Class_Regulated
Unconditional cooperator	Unconditional cooperator



Alpha1	Alpha2	Beta1	Beta2
0	0.238	0.549	0.213

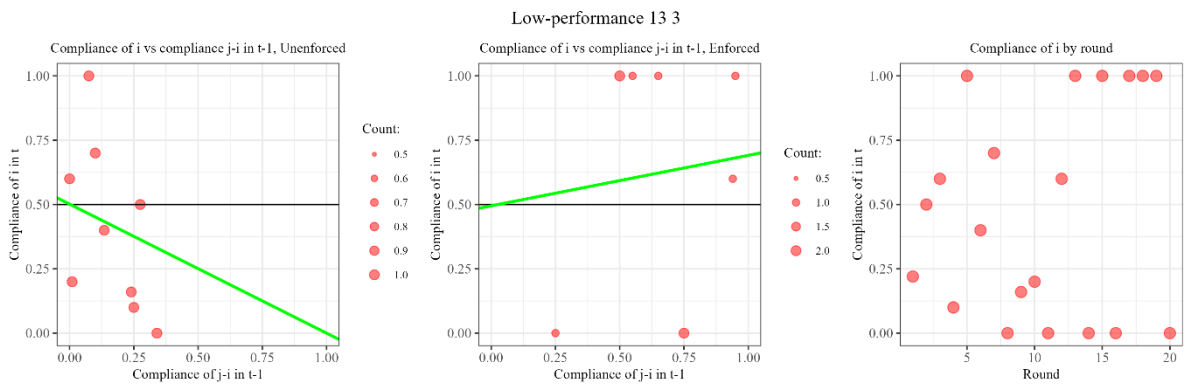
Class_Open_access	Class_Regulated
Conditional cooperator	Conditional cooperator





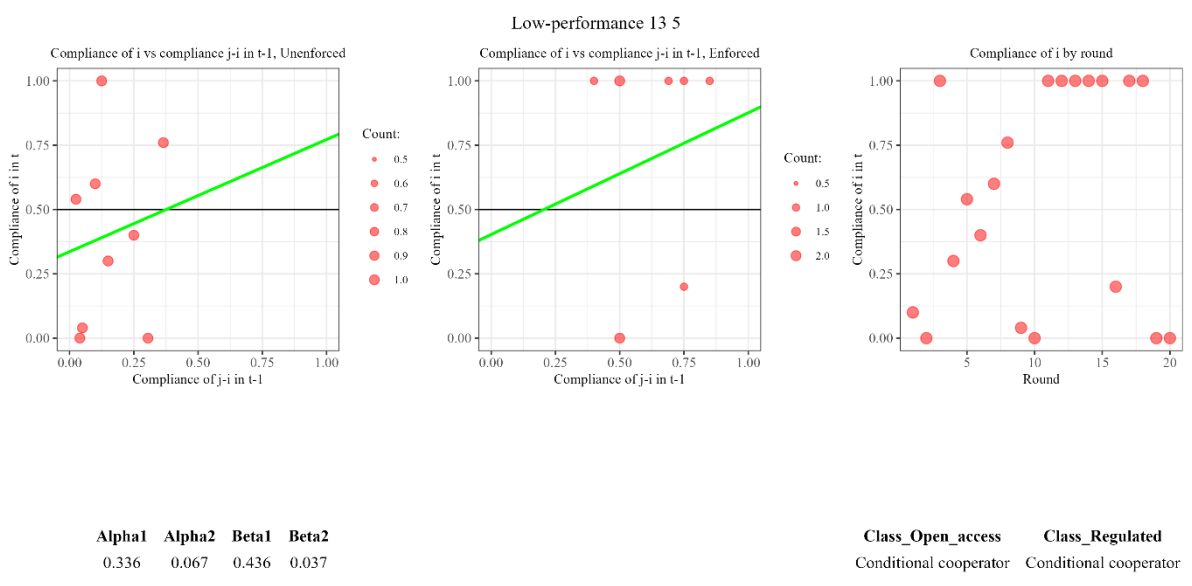
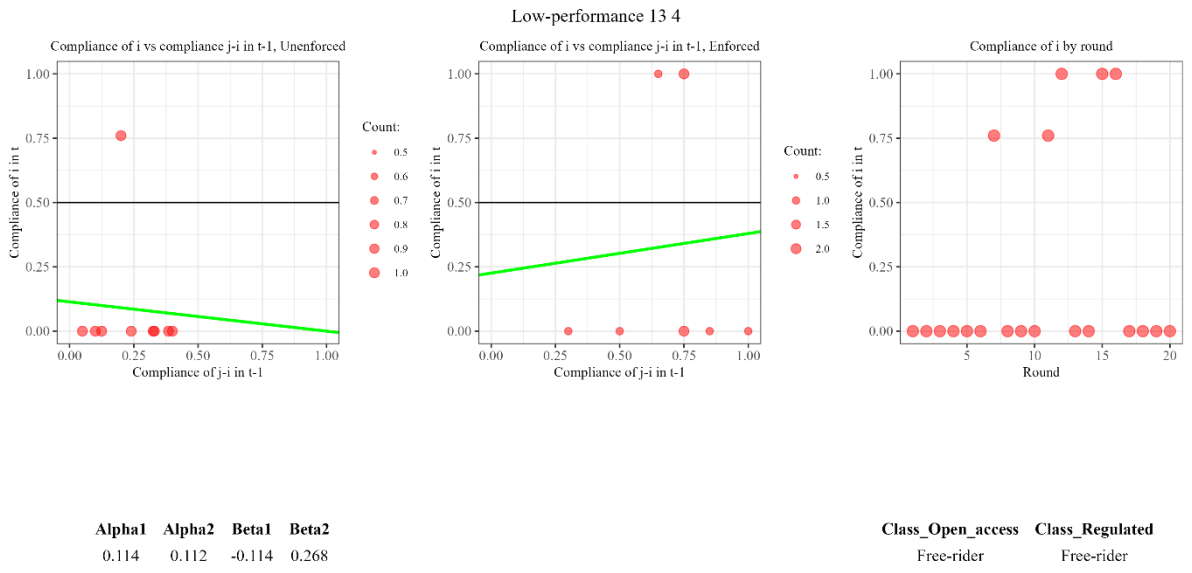
Alpha1	Alpha2	Beta1	Beta2
0	0	0	0.398

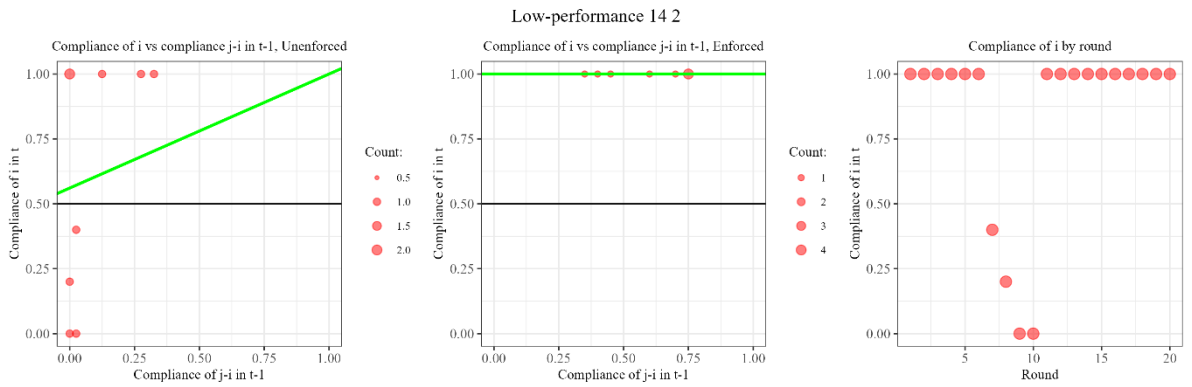
Class_Open_access	Class_Regulated
Free-rider	Free-rider



Alpha1	Alpha2	Beta1	Beta2
0.502	-0.007	-0.502	0.698

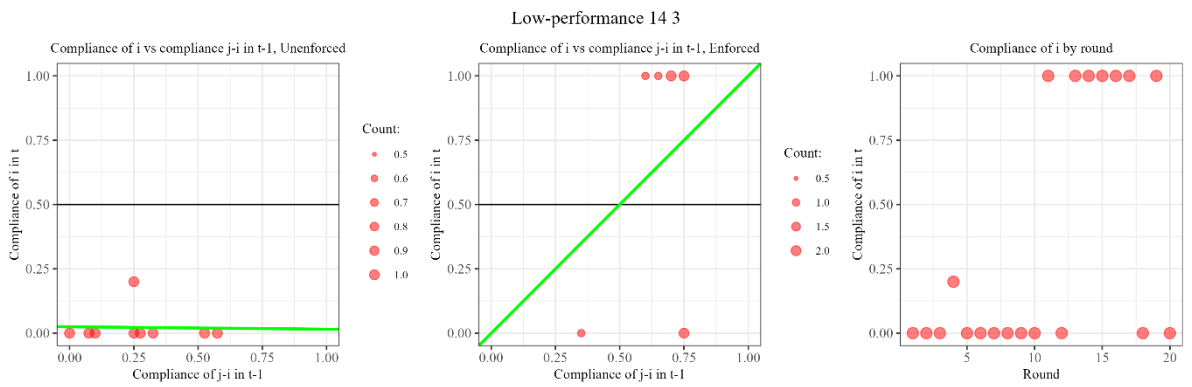
Class_Open_access	Class_Regulated
Negative cooperator	Conditional cooperator





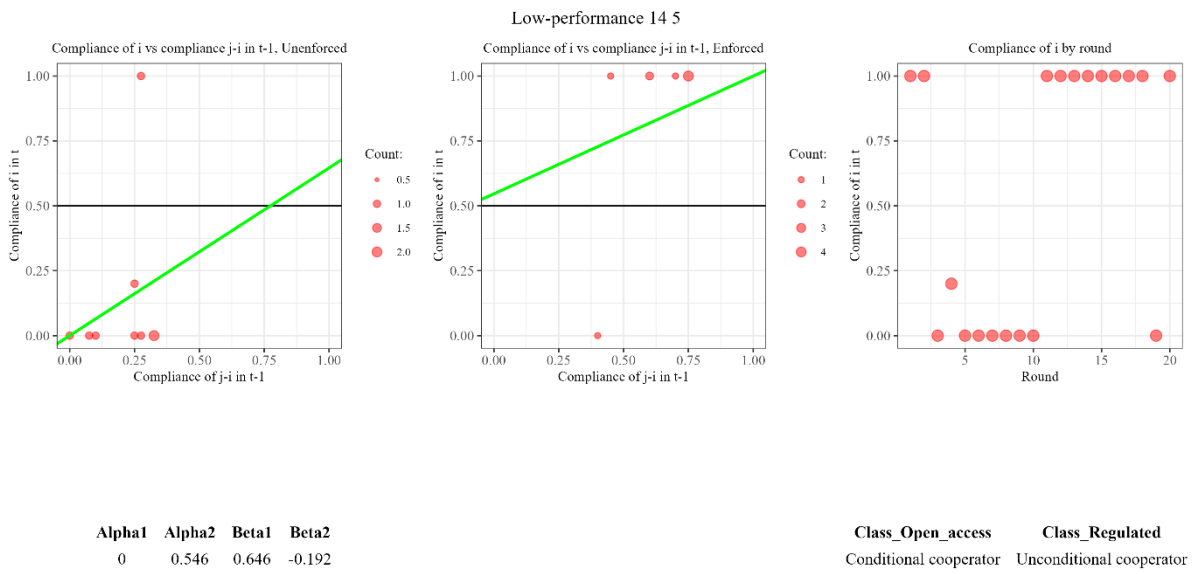
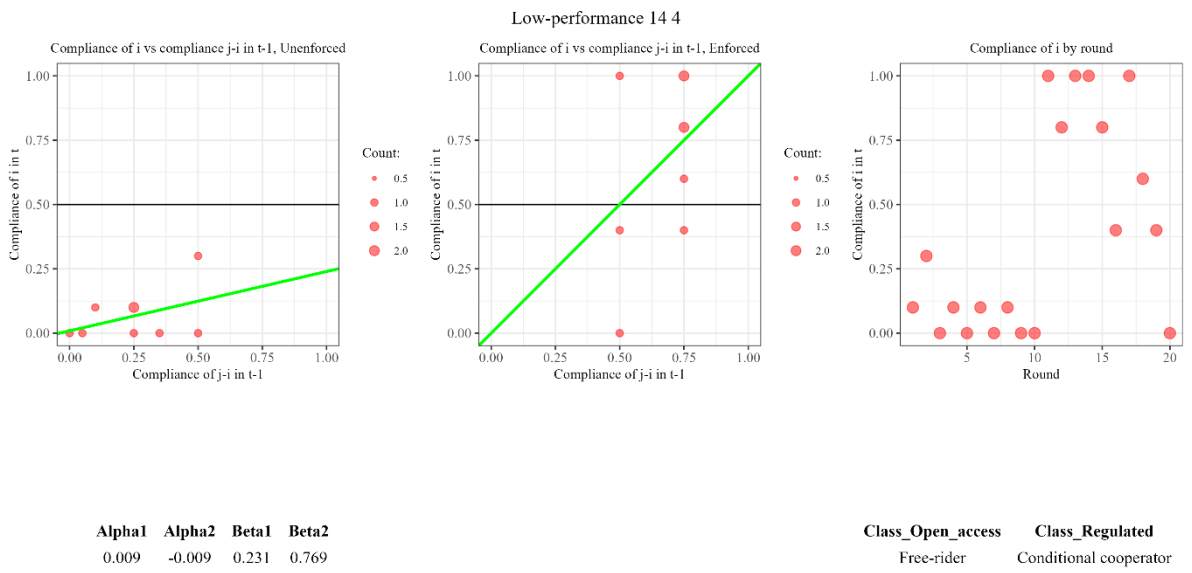
Alpha1	Alpha2	Beta1	Beta2
0.561	0.439	0.439	-0.439

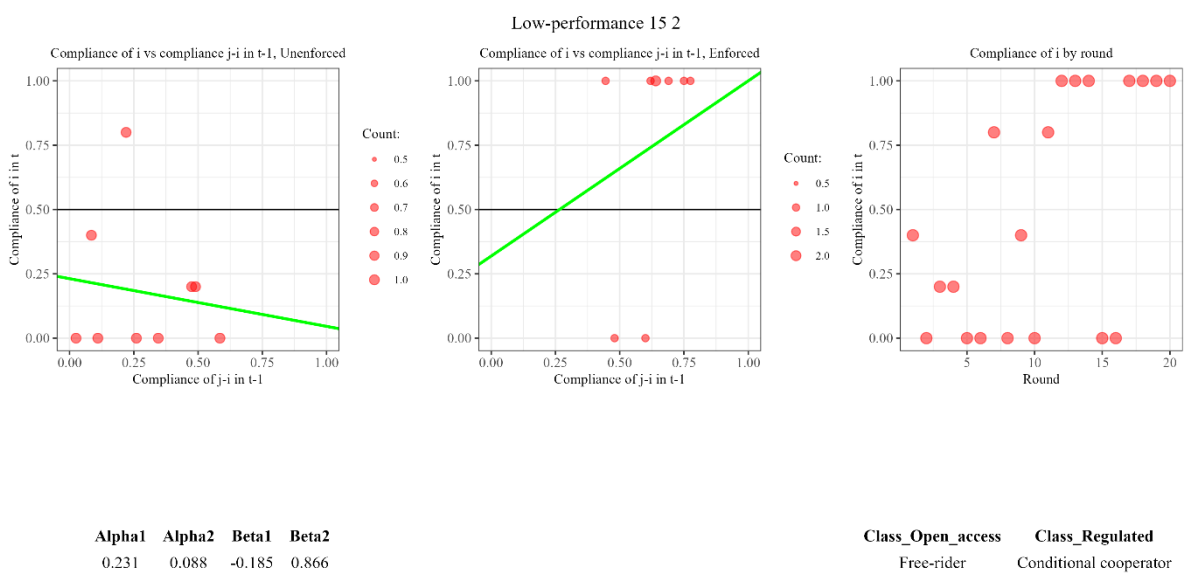
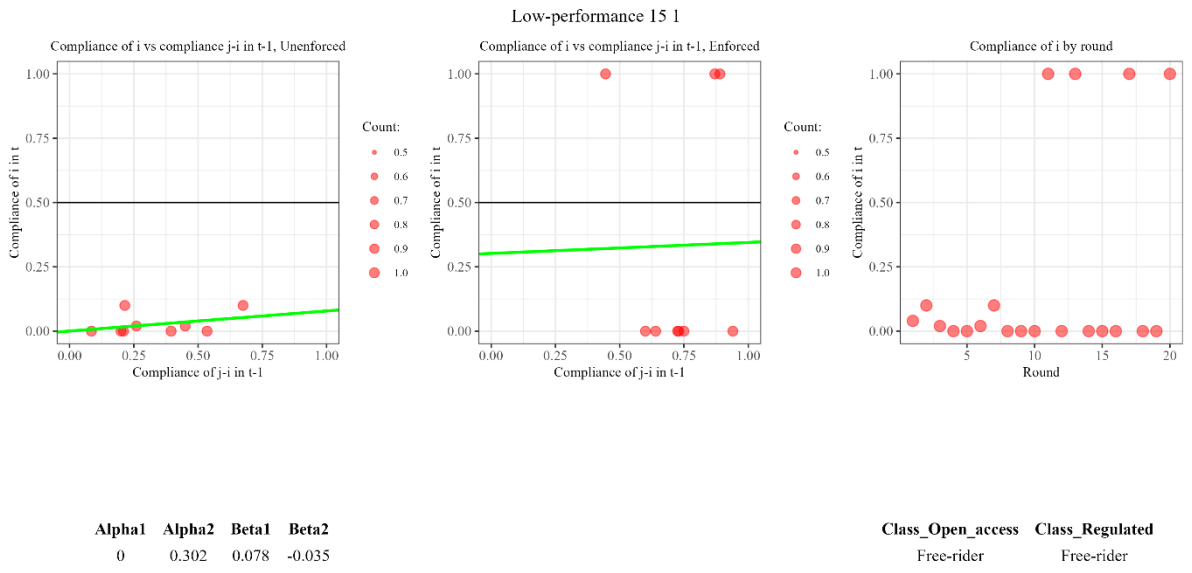
Class_Open_access	Class_Regulated
Unconditional cooperator	Unconditional cooperator

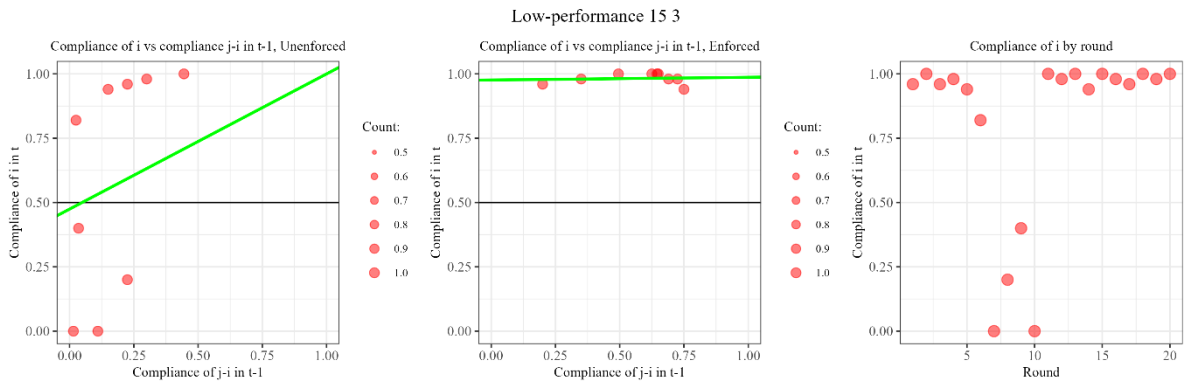


Alpha1	Alpha2	Beta1	Beta2
0.025	-0.025	-0.009	1.009

Class_Open_access	Class_Regulated
Free-rider	Conditional cooperator

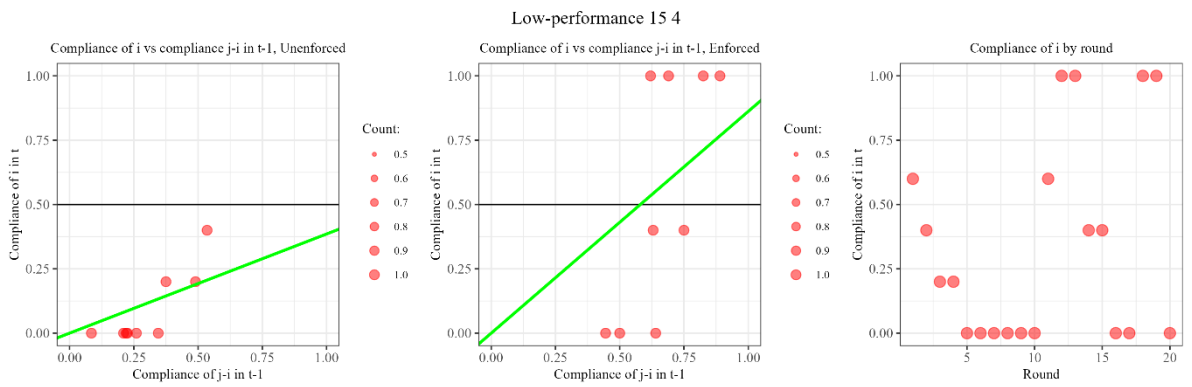






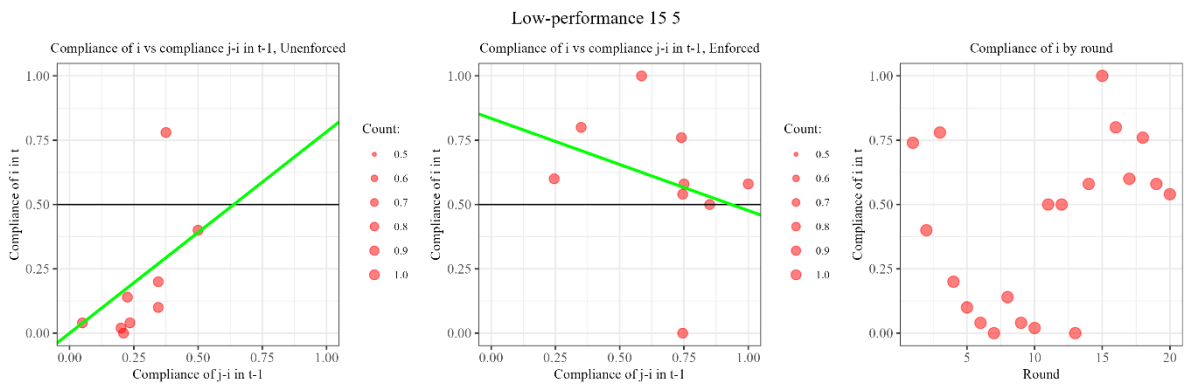
Alpha1	Alpha2	Beta1	Beta2
0.474	0.502	0.526	-0.515

Class_Open_access	Class_Regulated
Conditional cooperator	Unconditional cooperator



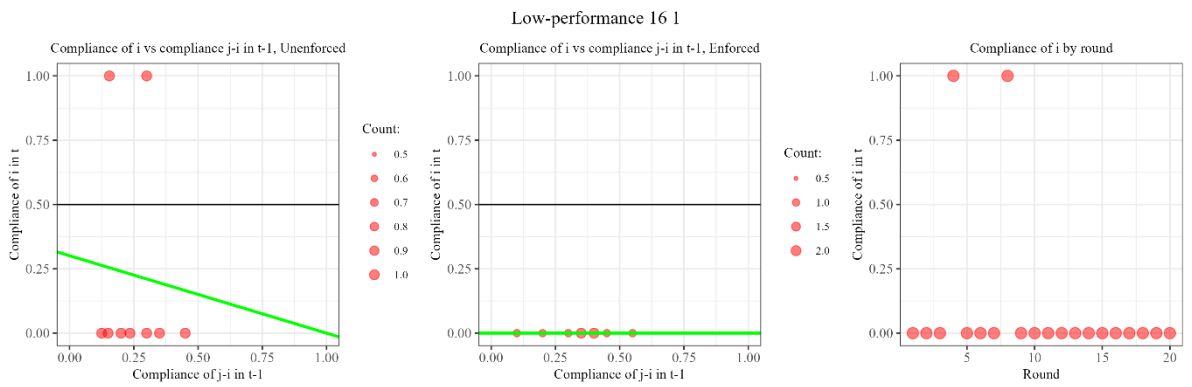
Alpha1	Alpha2	Beta1	Beta2
0	0	0.385	0.476

Class_Open_access	Class_Regulated
Free-rider	Conditional cooperator



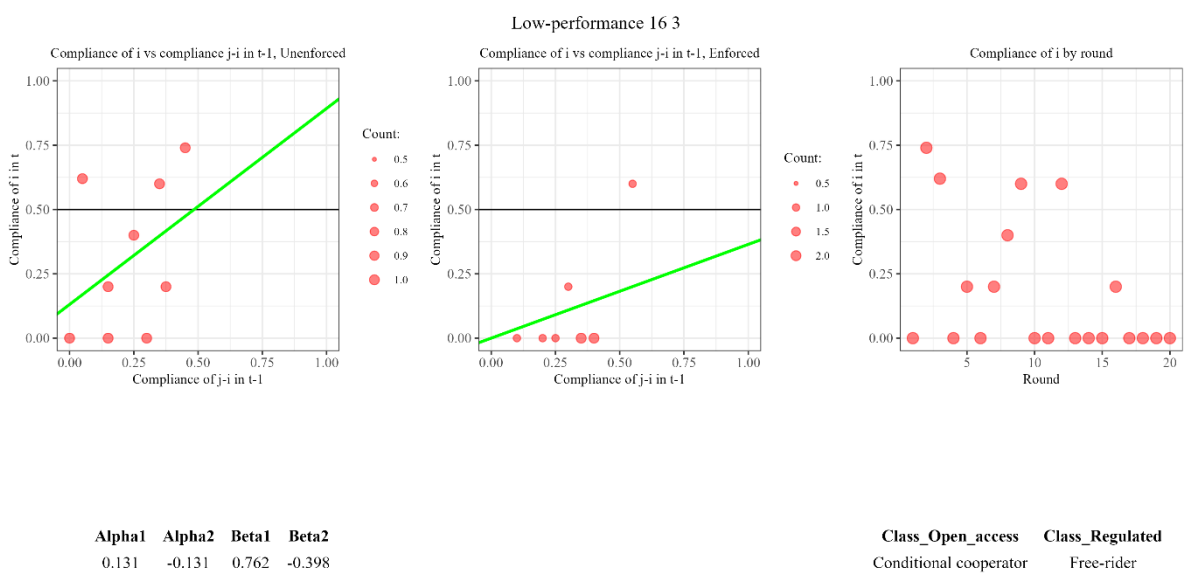
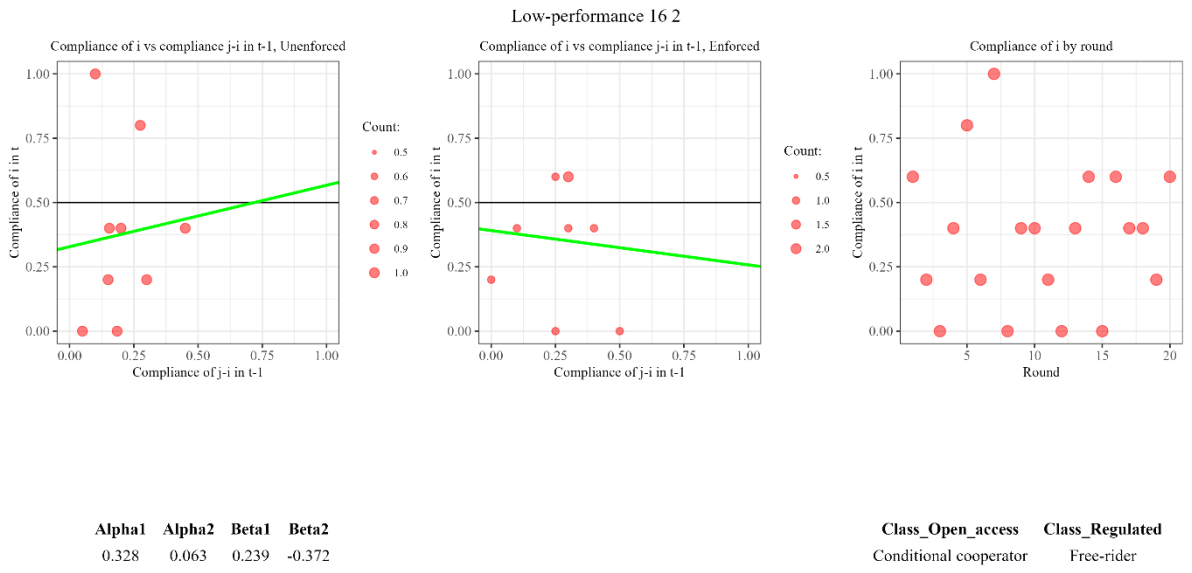
Alpha1	Alpha2	Beta1	Beta2
0	0.835	0.783	-1.141

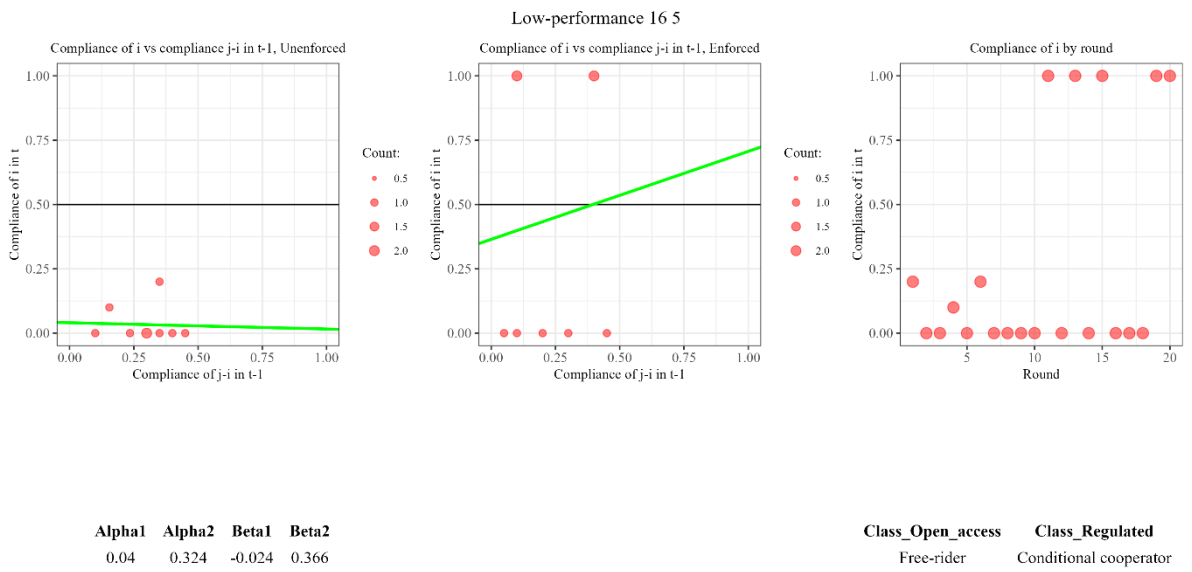
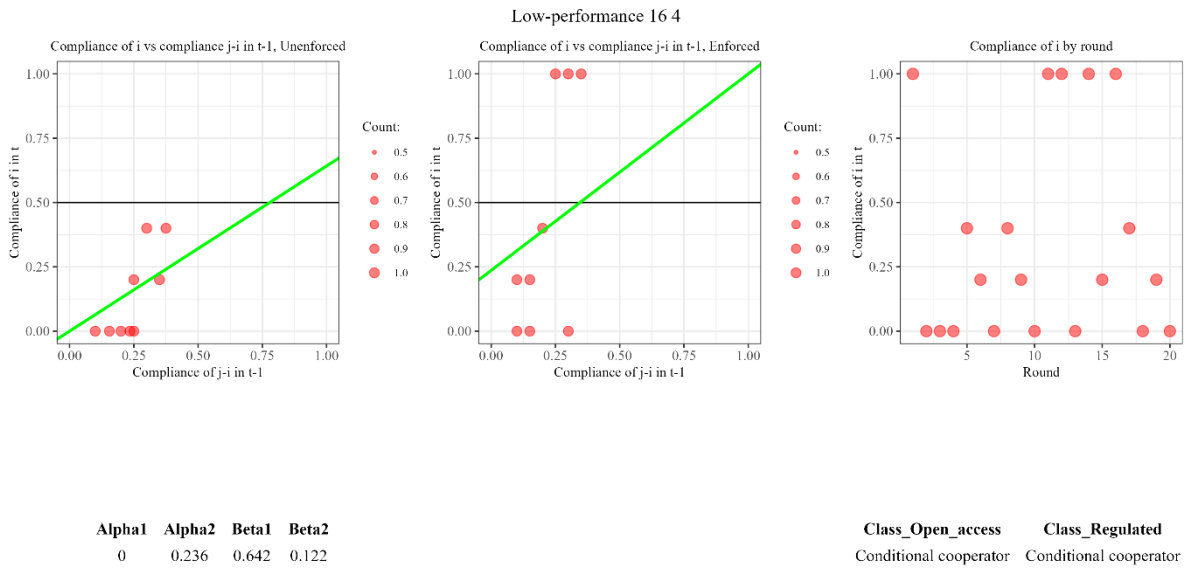
Class_Open_access	Class_Regulated
Conditional cooperator	Negative cooperator

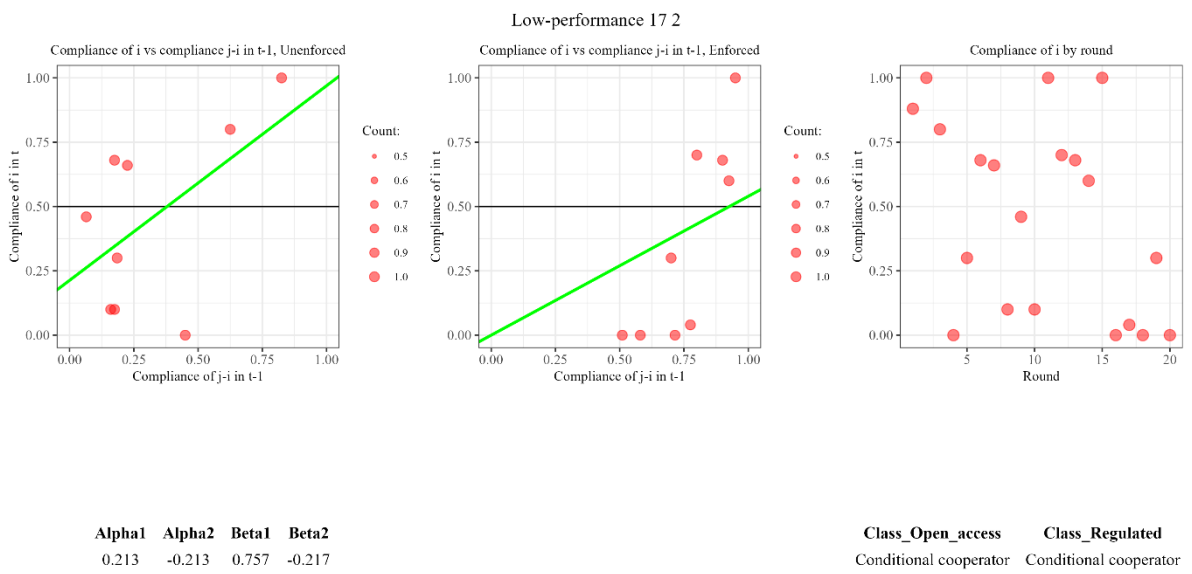
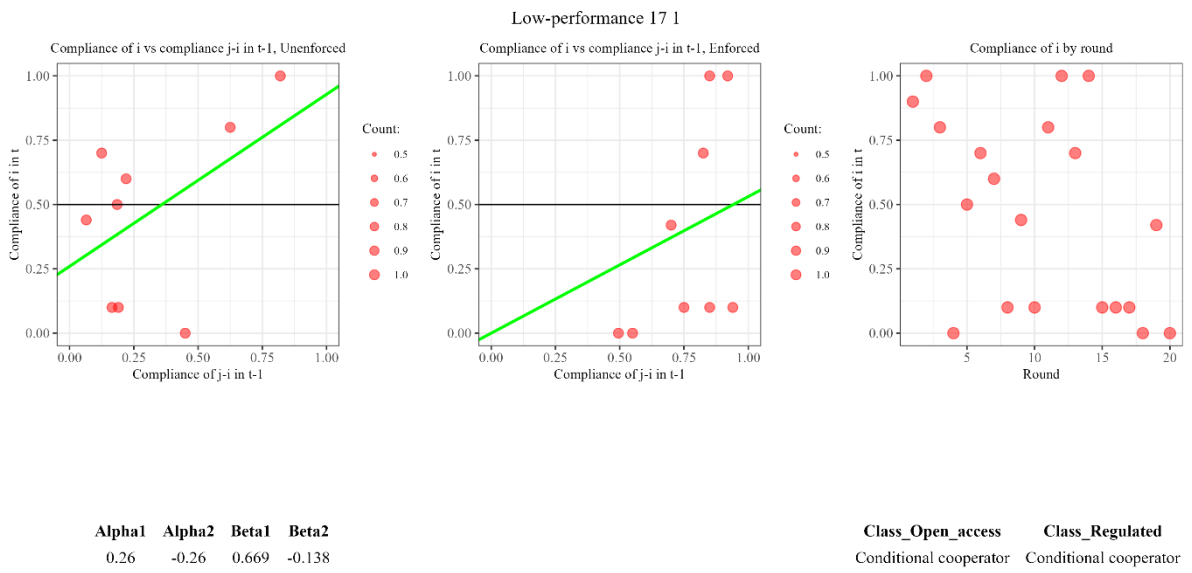


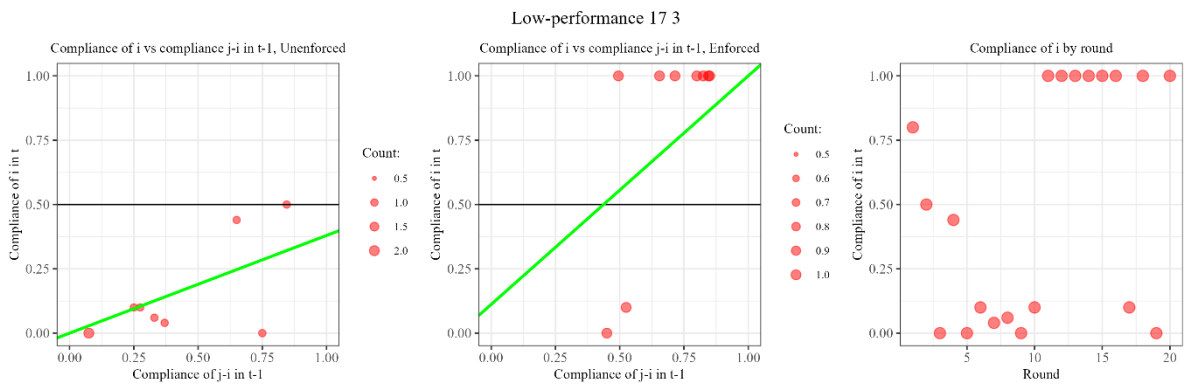
Alpha1	Alpha2	Beta1	Beta2
0.301	-0.301	-0.301	0.301

Class_Open_access	Class_Regulated
Free-rider	Free-rider



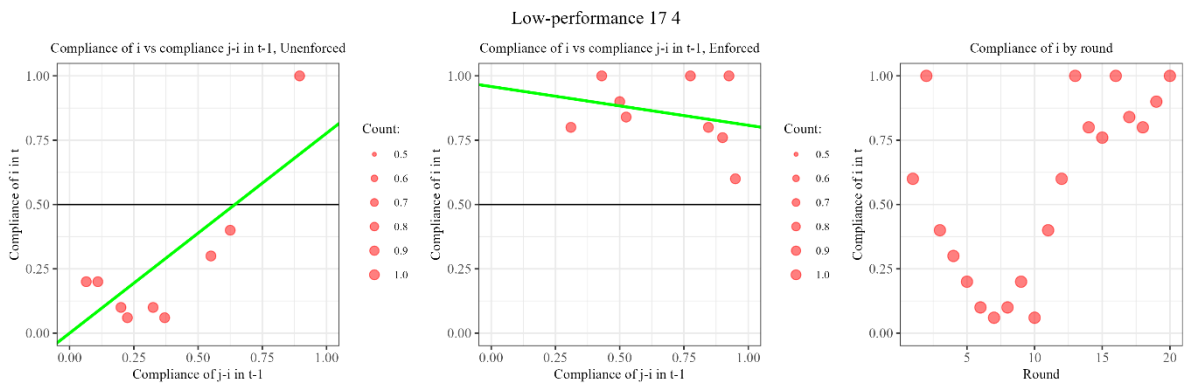






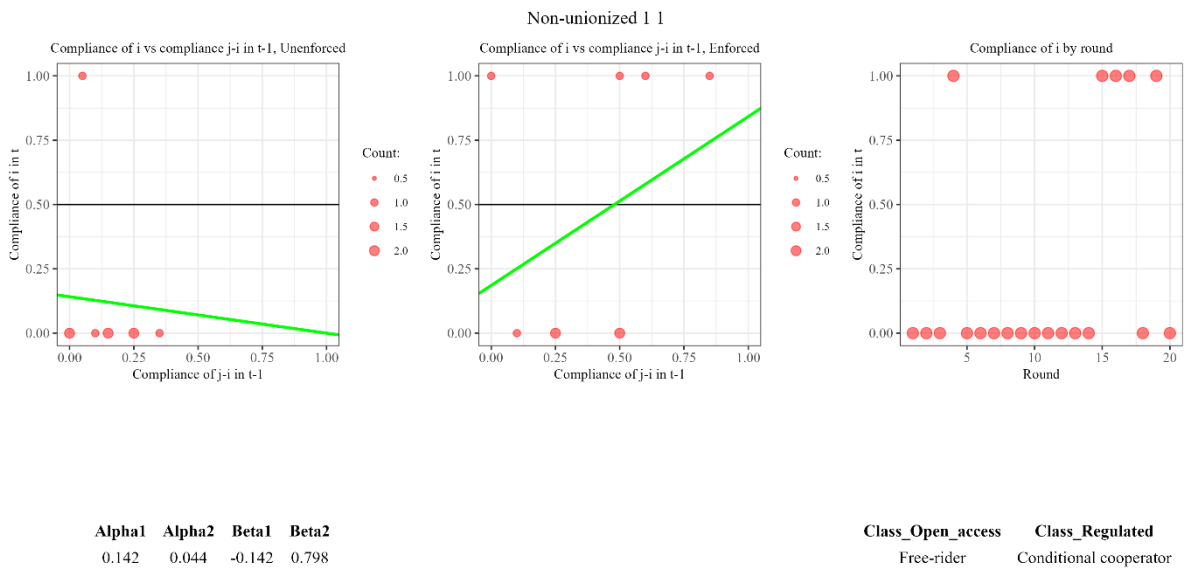
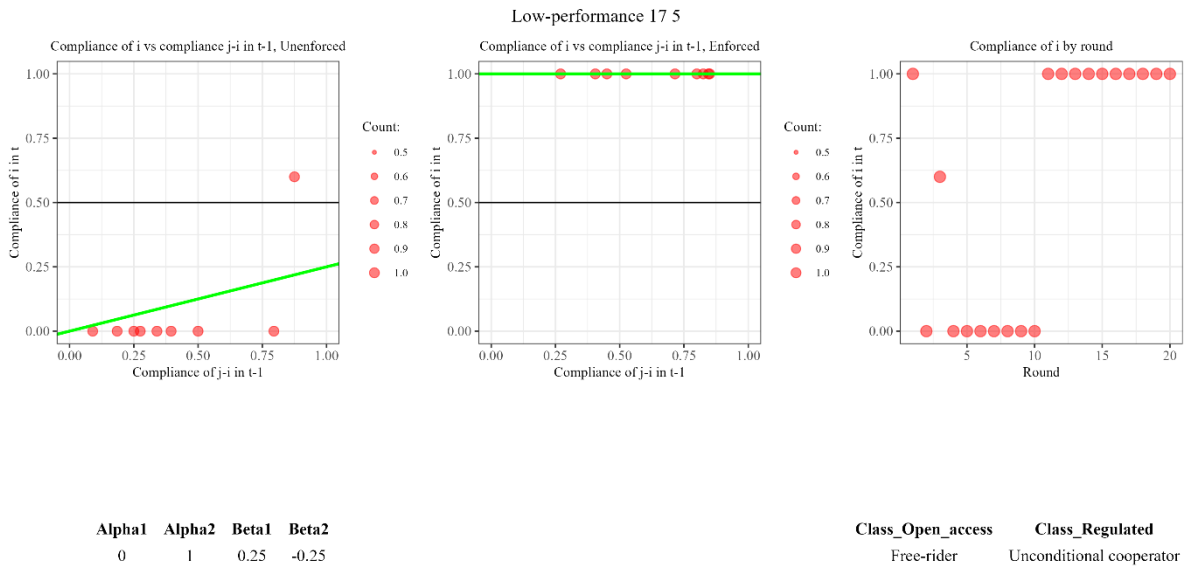
Alpha1	Alpha2	Beta1	Beta2
0	0.112	0.38	0.508

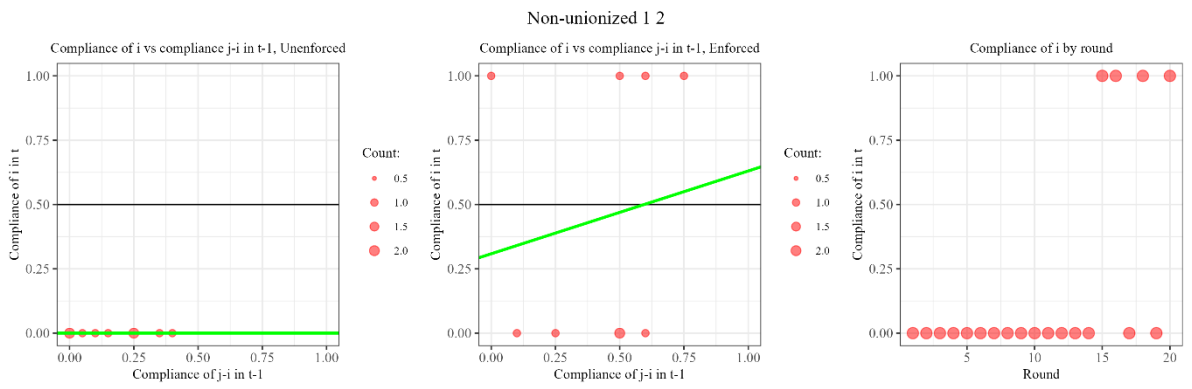
Class_Open_access	Class_Regulated
Free-rider	Conditional cooperator



Alpha1	Alpha2	Beta1	Beta2
0	0.959	0.777	-0.928

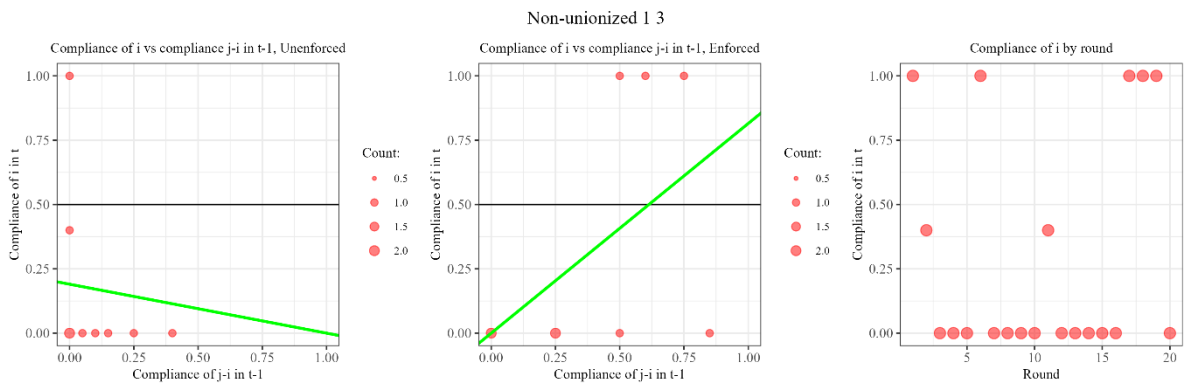
Class_Open_access	Class_Regulated
Conditional cooperator	Unconditional cooperator





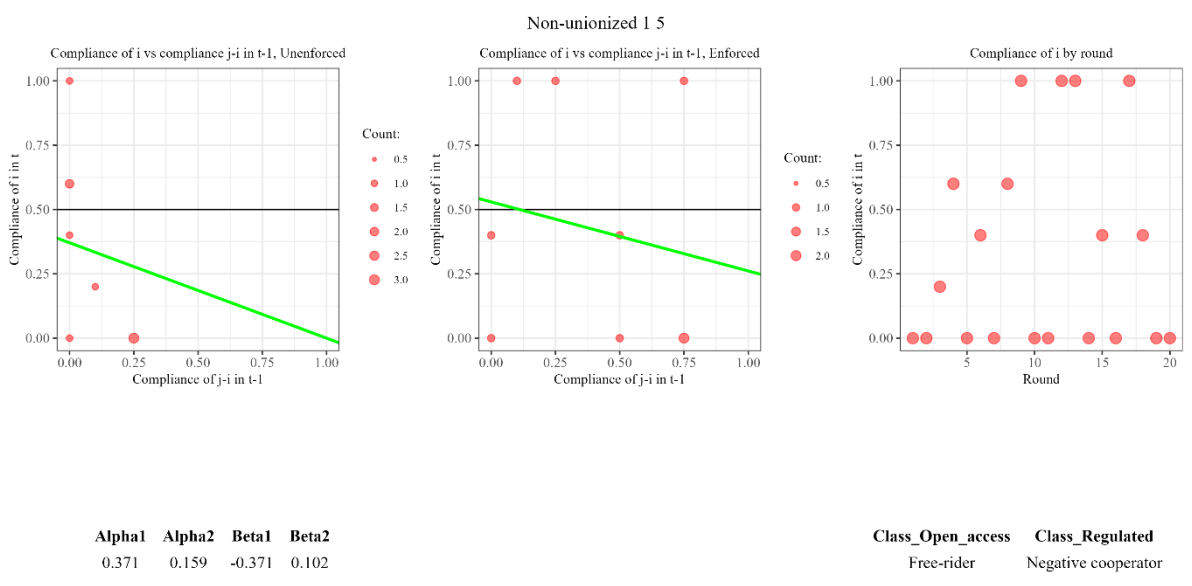
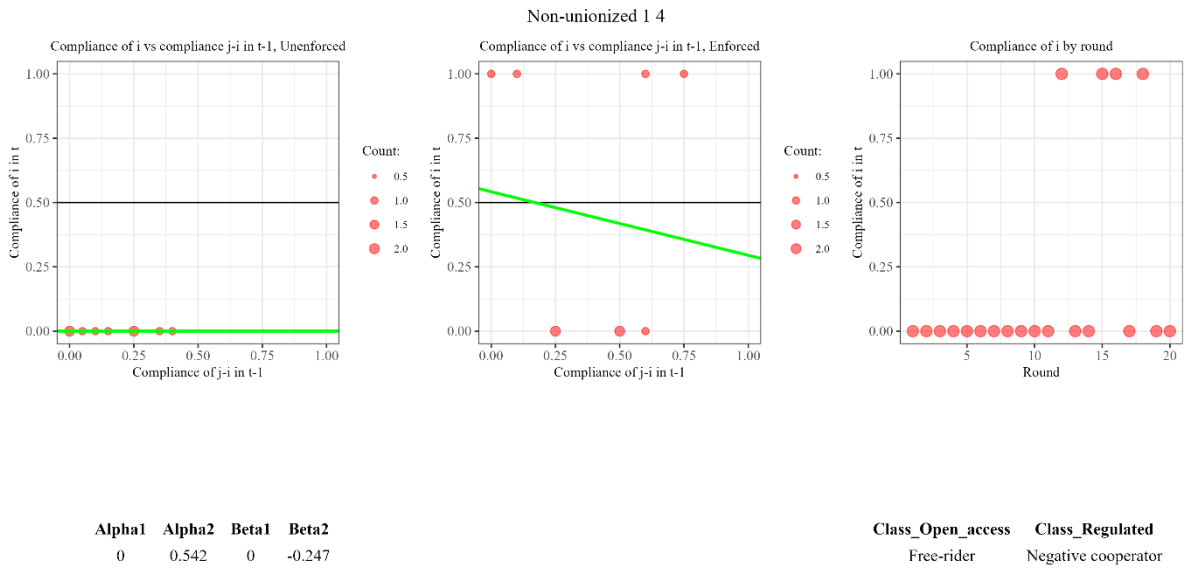
Alpha1	Alpha2	Beta1	Beta2
0	0.309	0	0.322

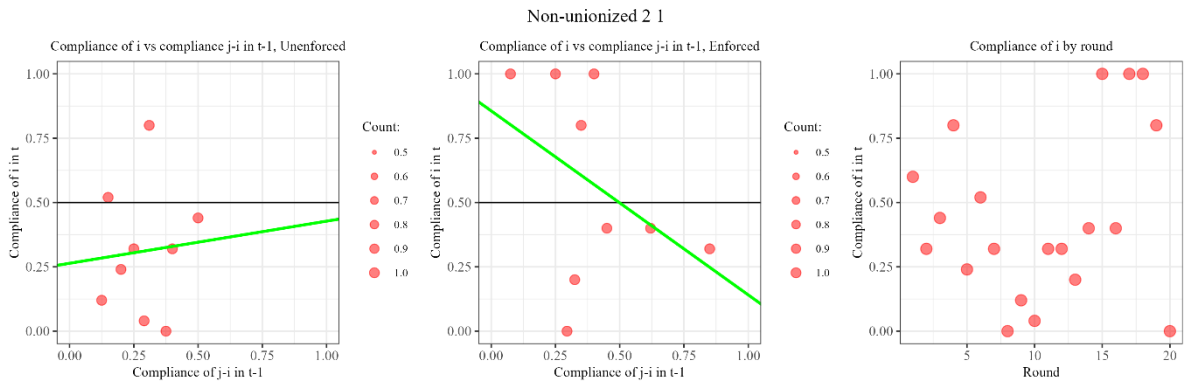
Class_Open_access	Class_Regulated
Free-rider	Conditional cooperator



Alpha1	Alpha2	Beta1	Beta2
0.19	-0.19	-0.19	1.005

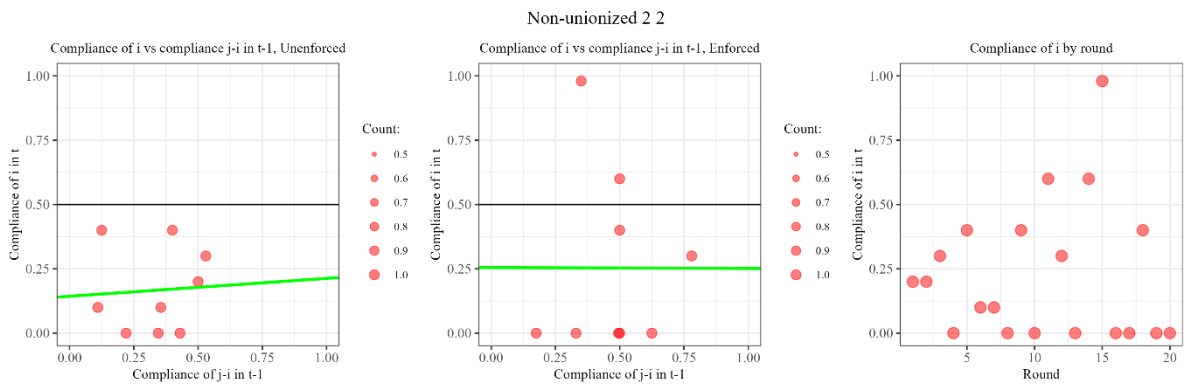
Class_Open_access	Class_Regulated
Free-rider	Conditional cooperator





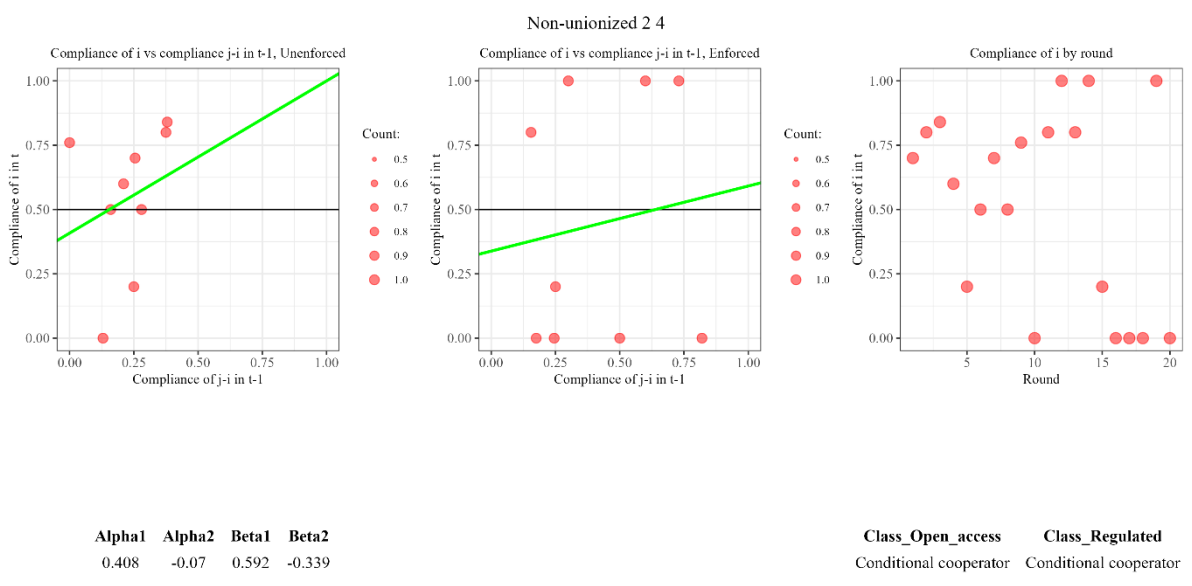
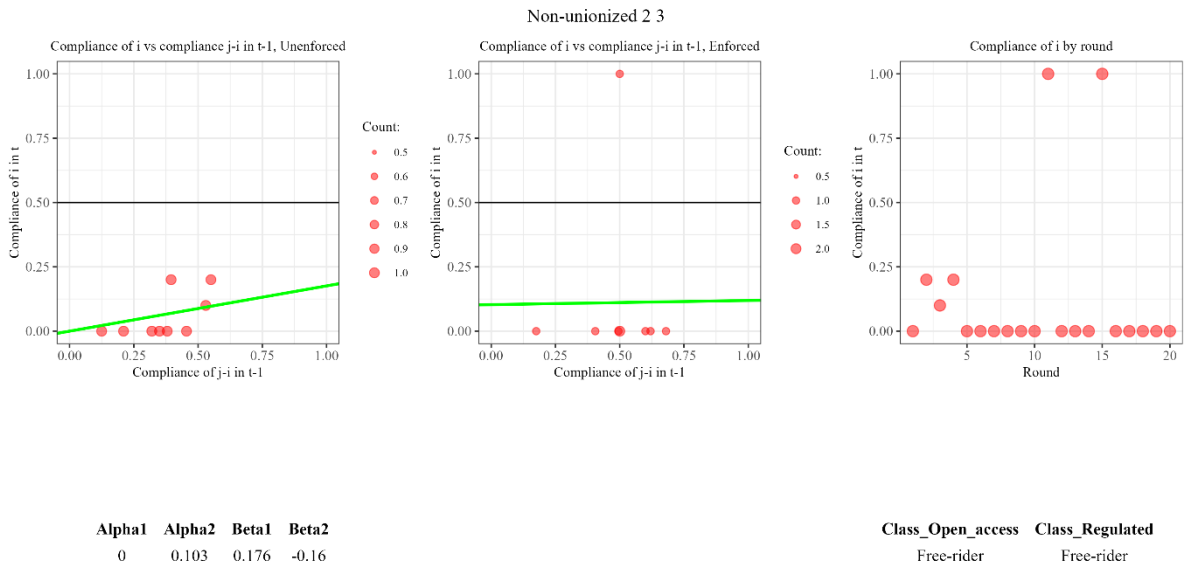
Alpha1	Alpha2	Beta1	Beta2
0.264	0.592	0.164	-0.879

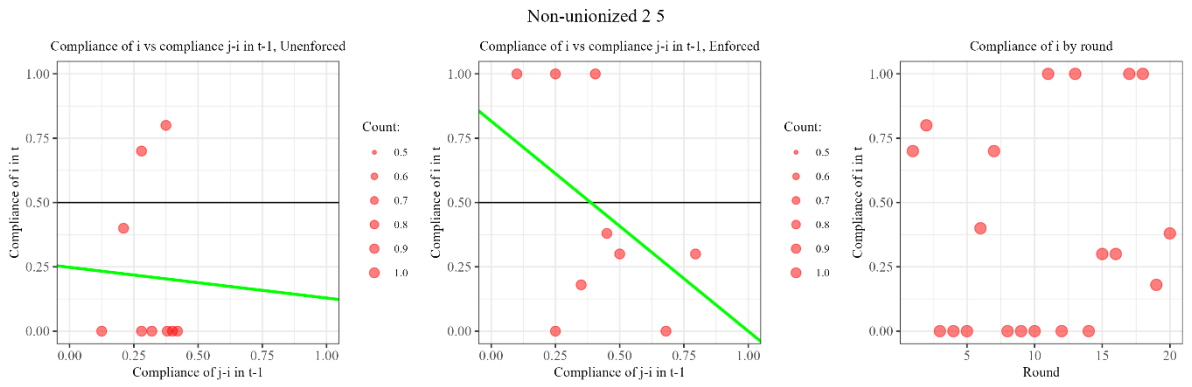
Class_Open_access	Class_Regulated
Free-rider	Negative cooperator



Alpha1	Alpha2	Beta1	Beta2
0.143	0.112	0.07	-0.073

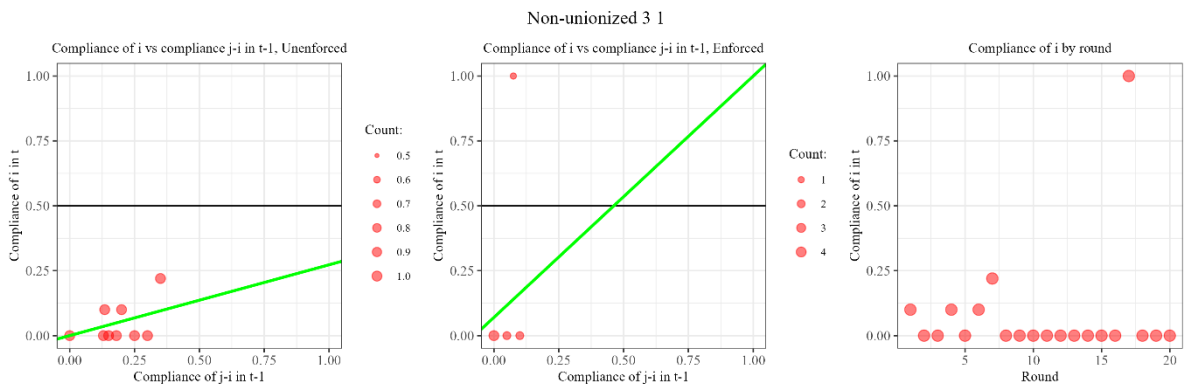
Class_Open_access	Class_Regulated
Free-rider	Free-rider





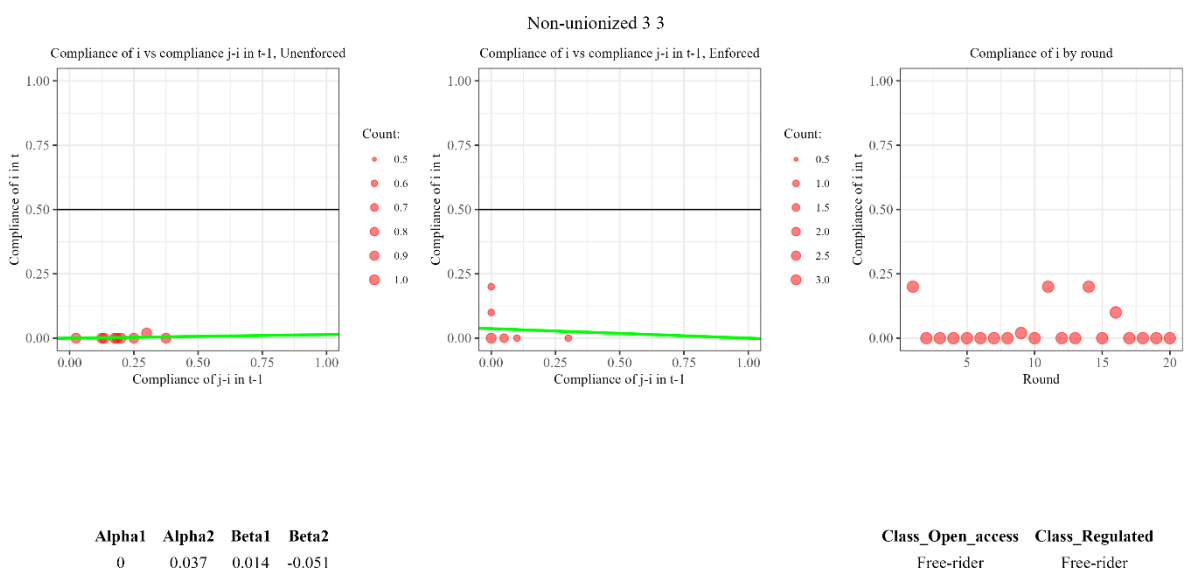
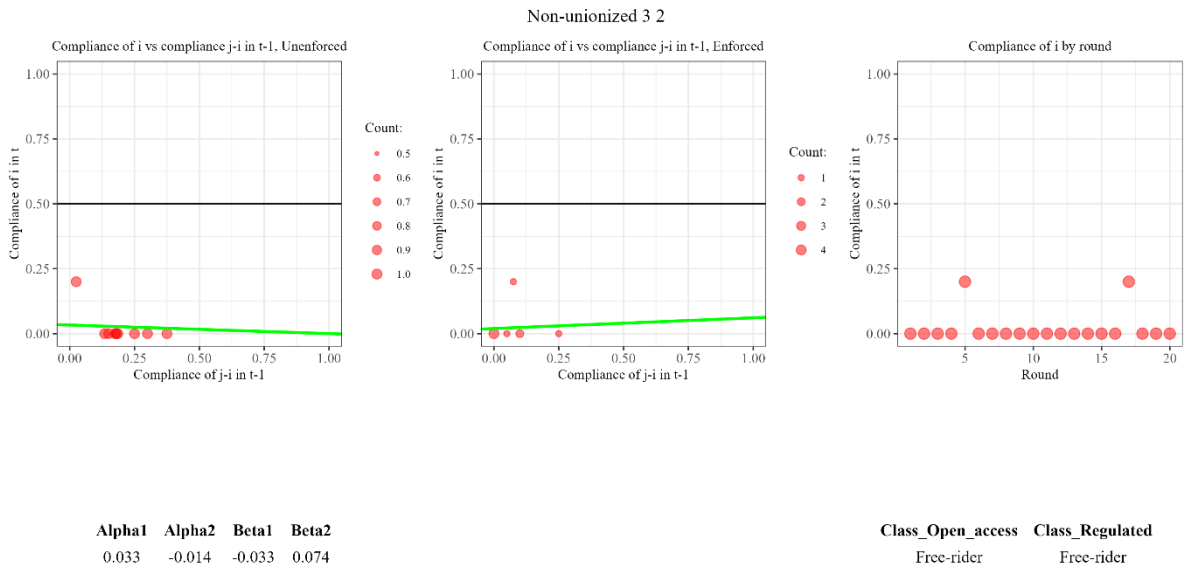
Alpha1	Alpha2	Beta1	Beta2
0.248	0.568	-0.119	-0.697

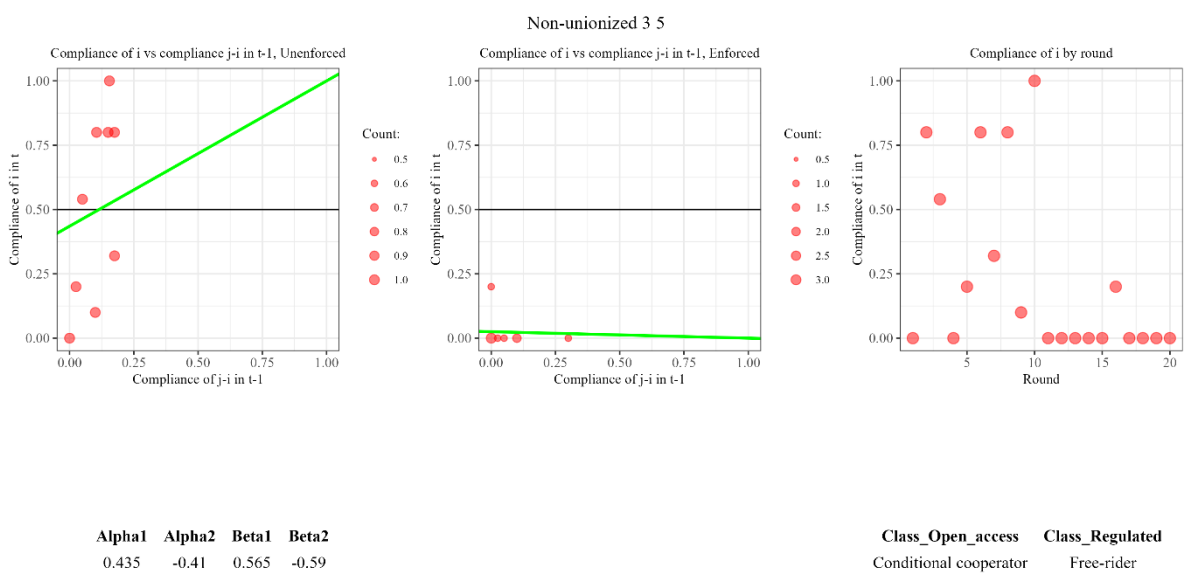
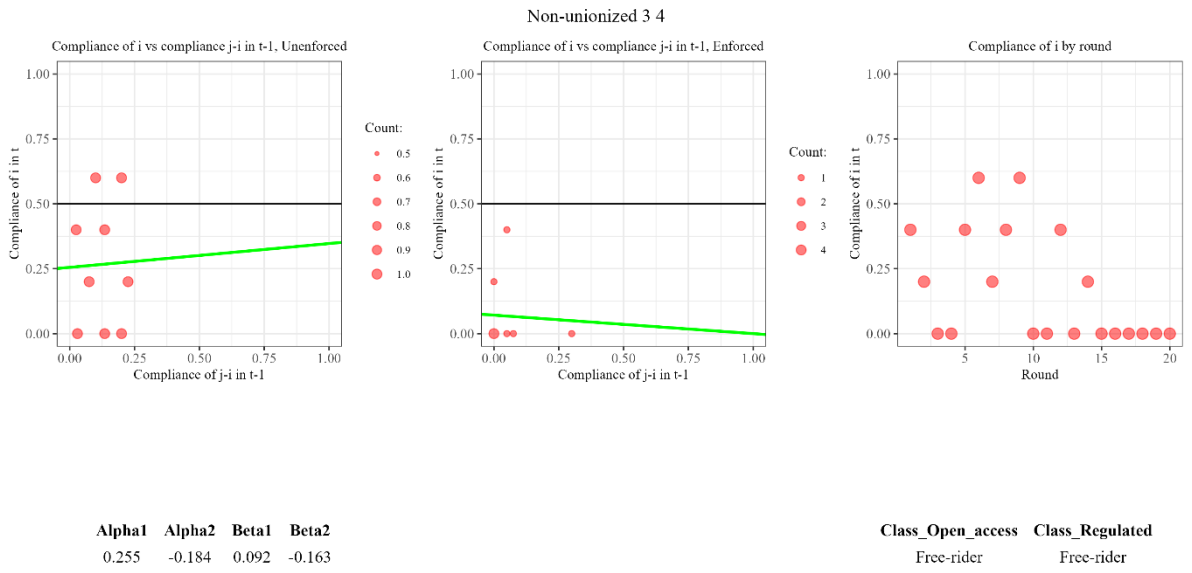
Class_Open_access	Class_Regulated
Free-rider	Negative cooperator

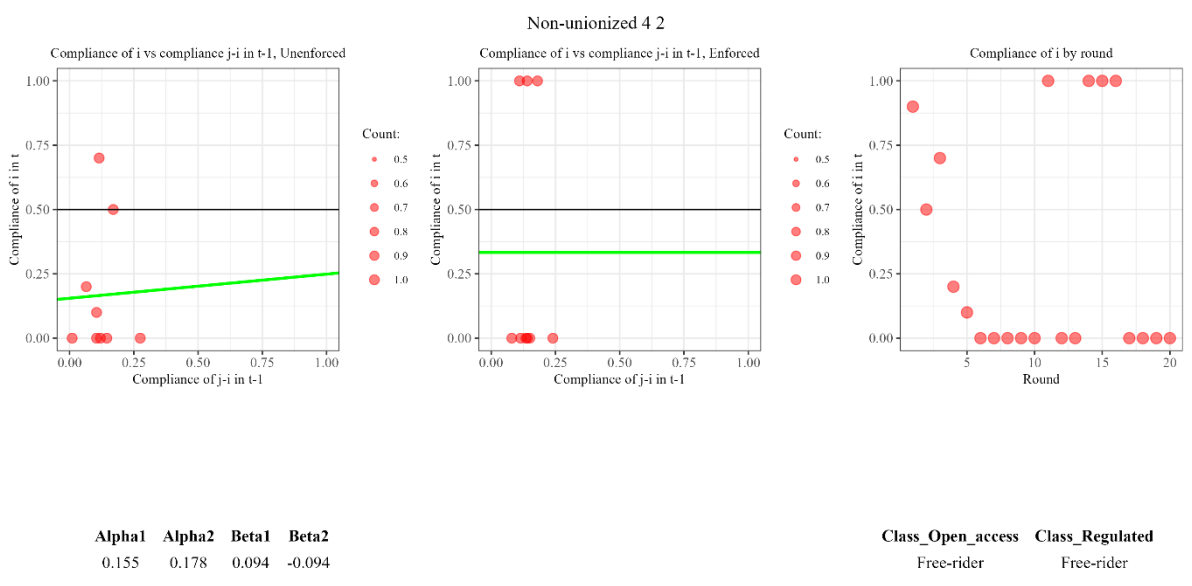
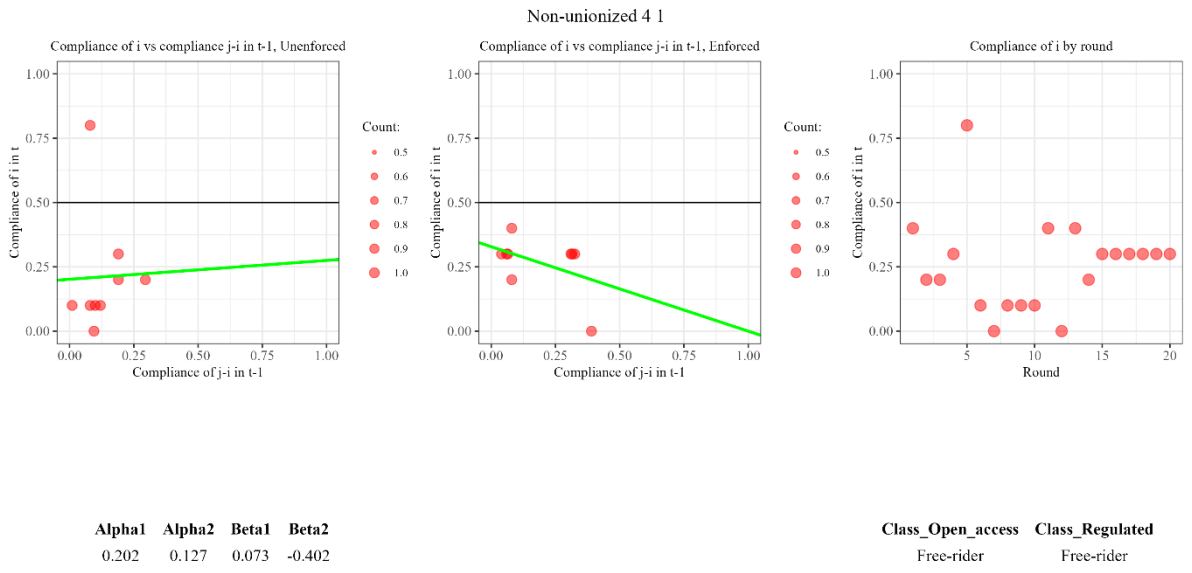


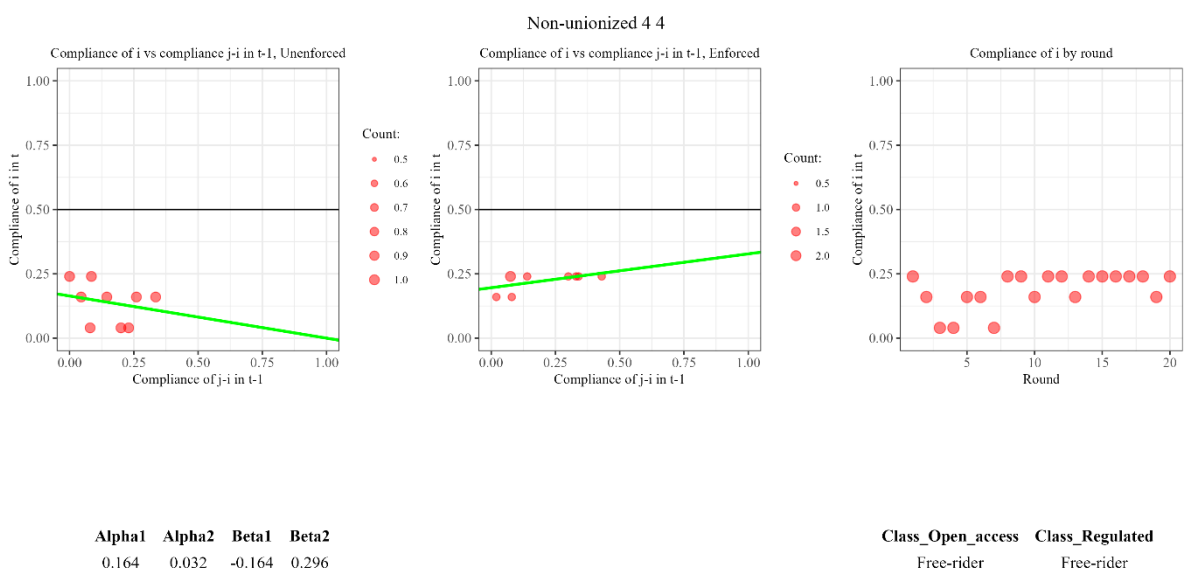
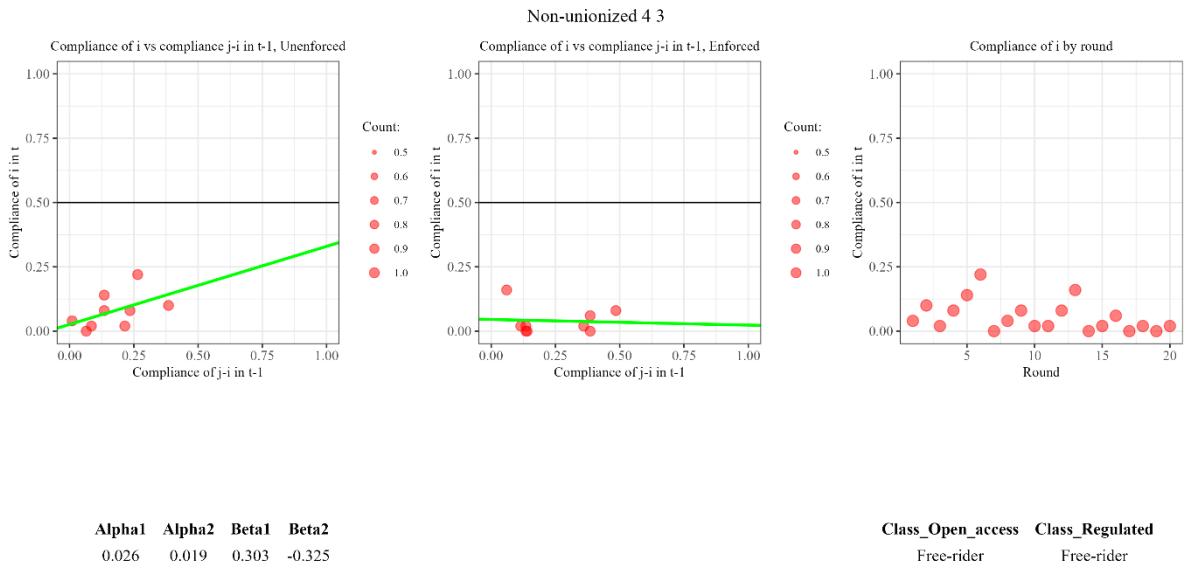
Alpha1	Alpha2	Beta1	Beta2
0	0.07	0.273	0.657

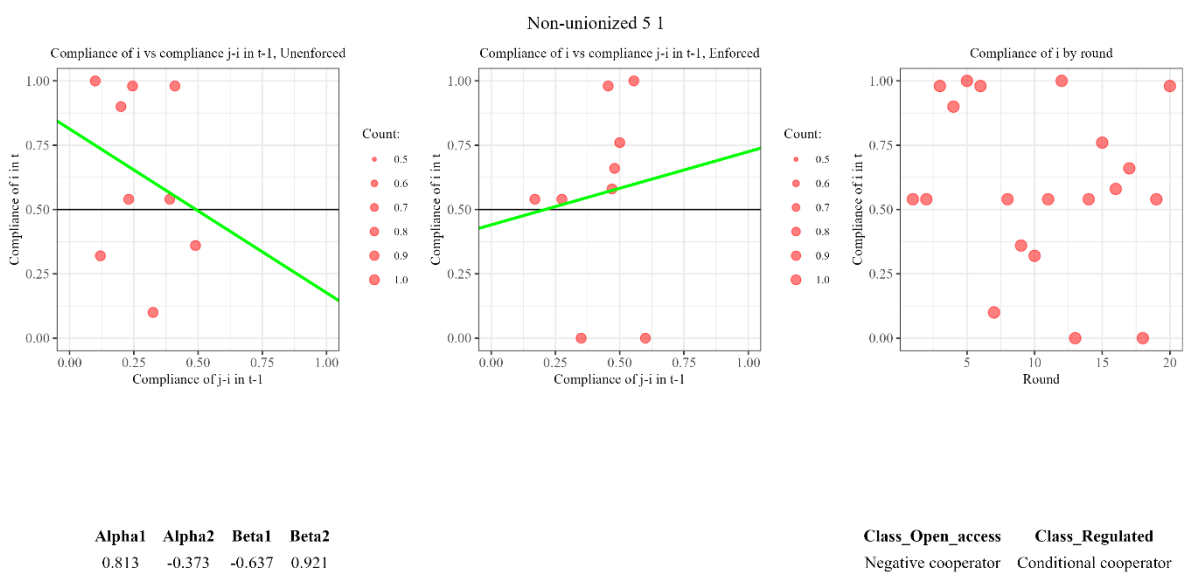
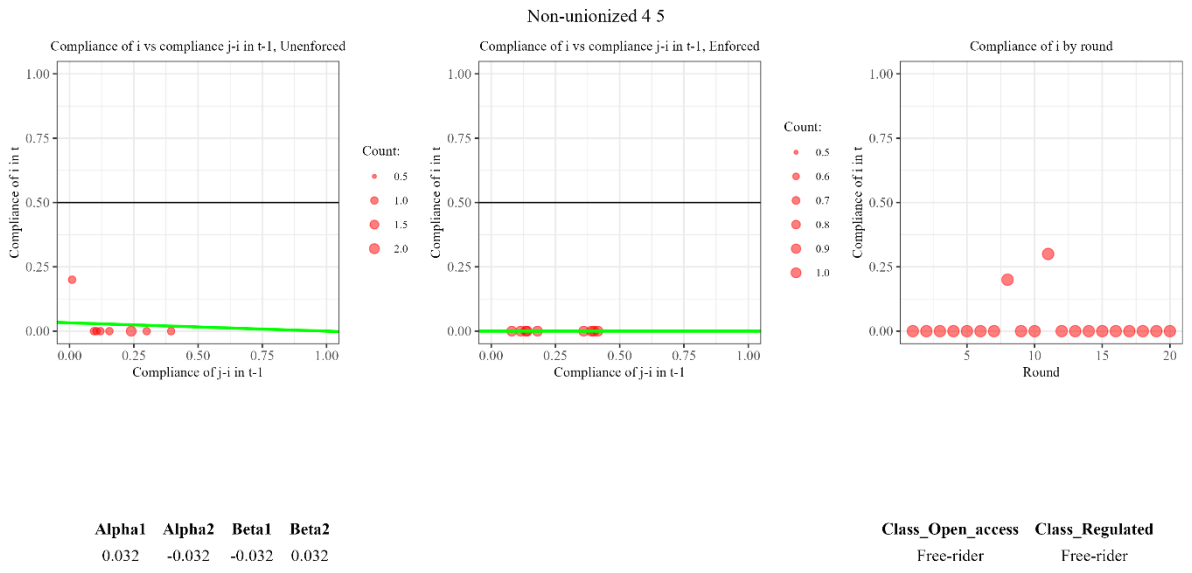
Class_Open_access	Class_Regulated
Free-rider	Conditional cooperator

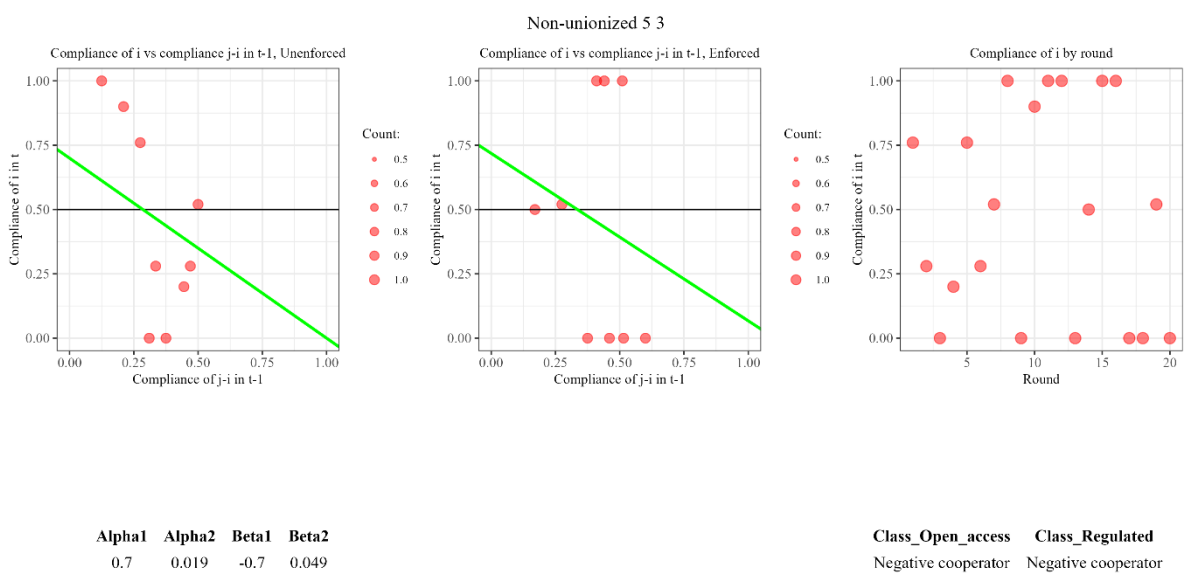
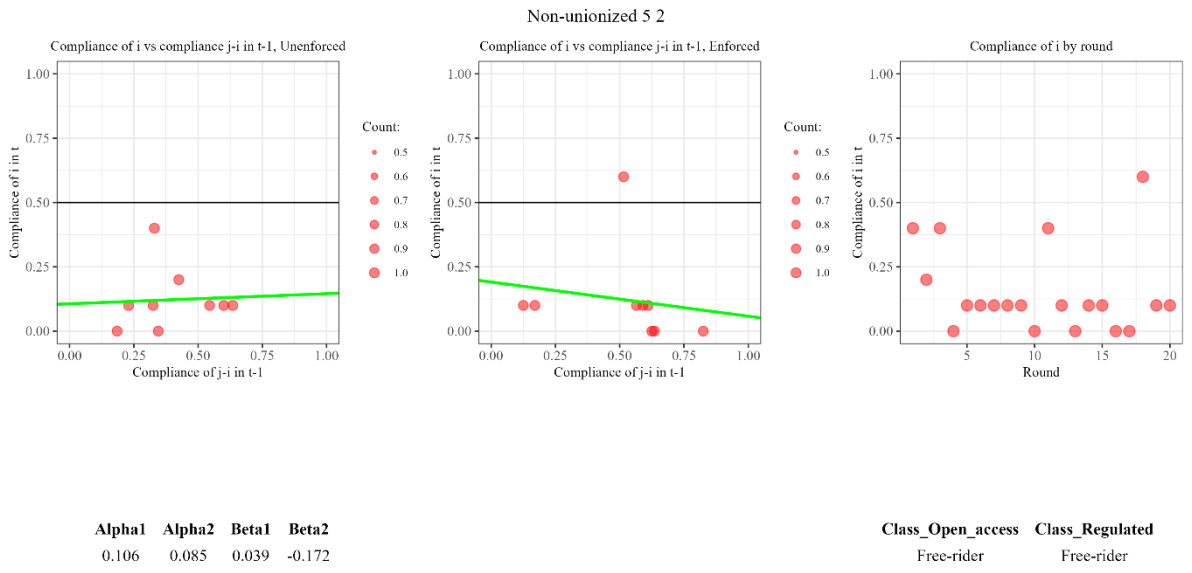


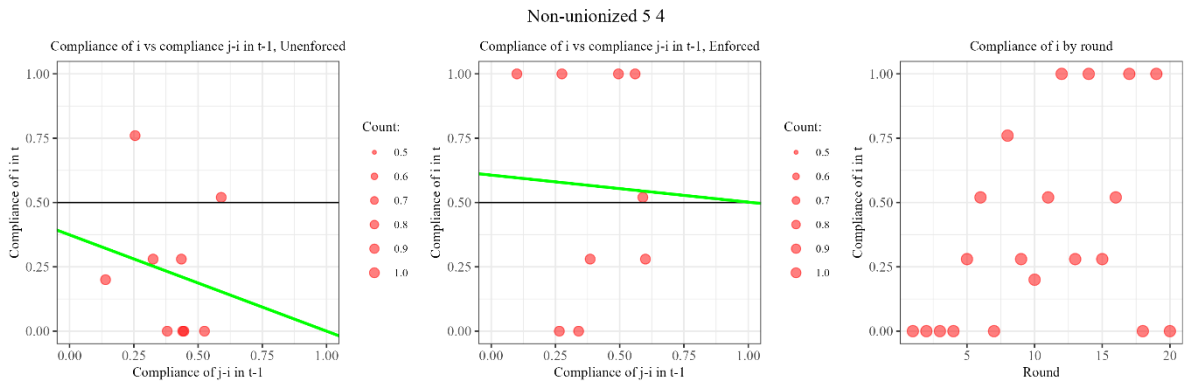






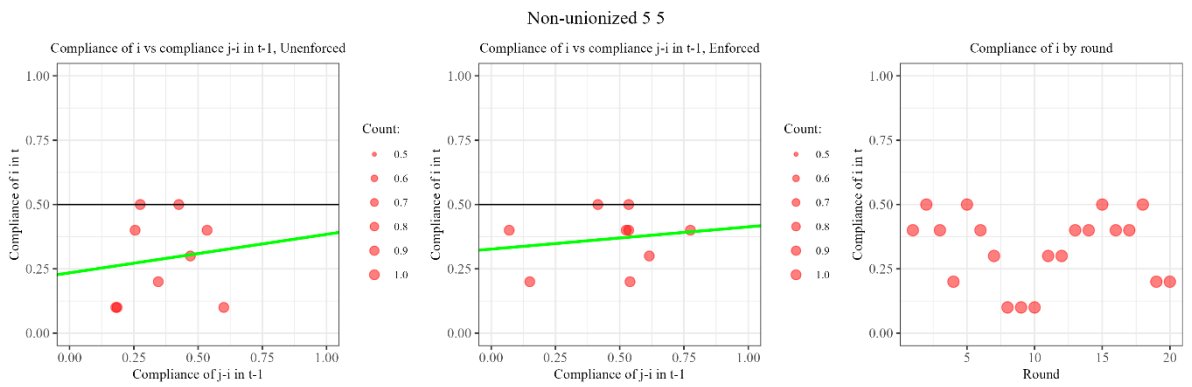






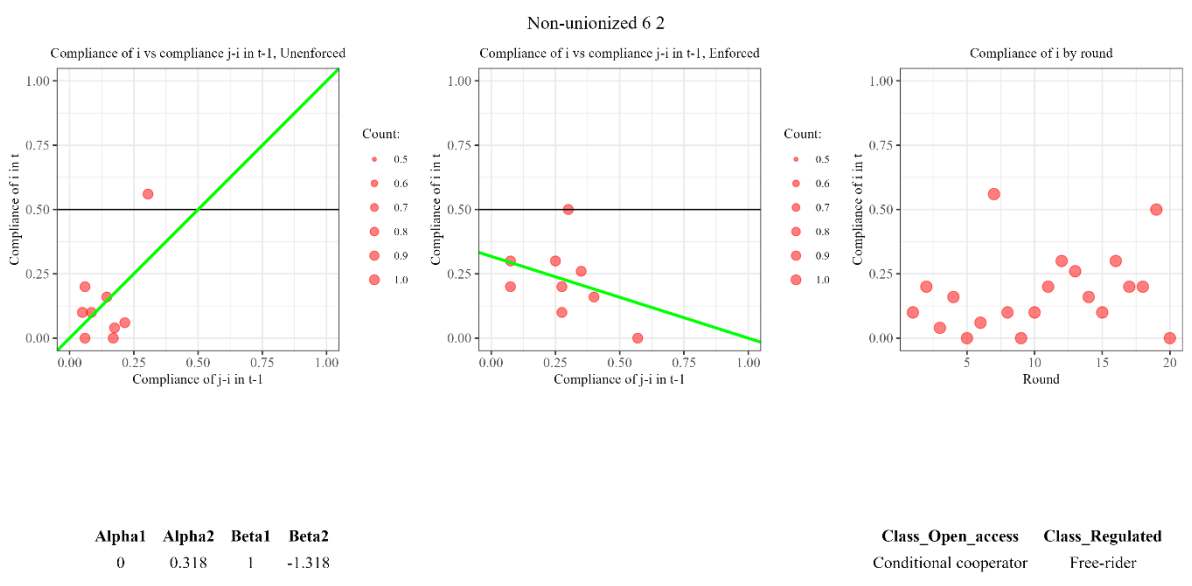
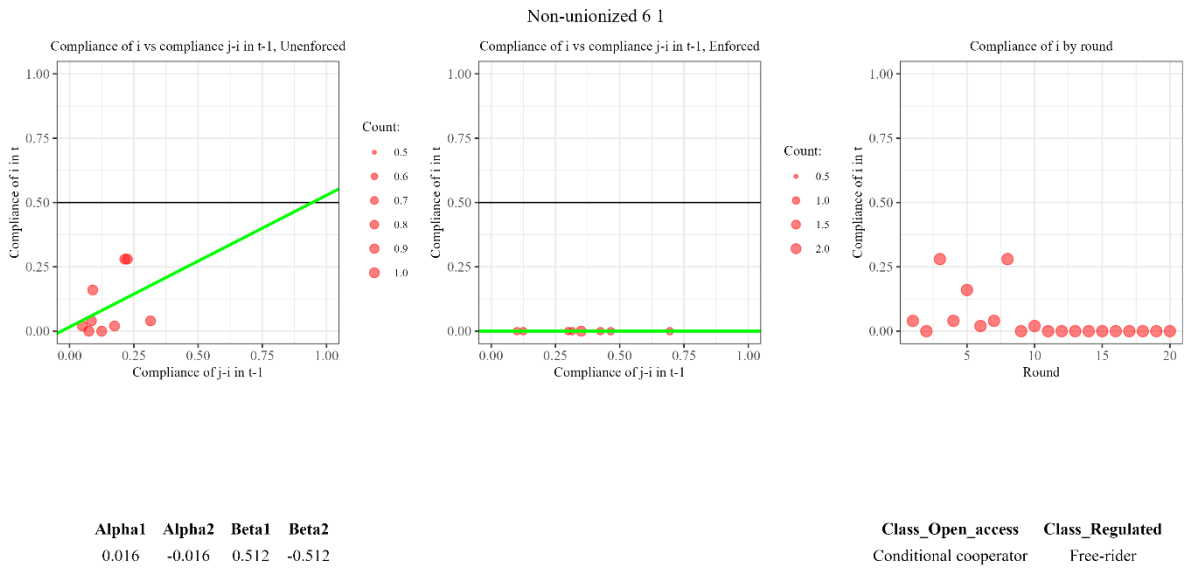
Alpha1	Alpha2	Beta1	Beta2
0.374	0.232	-0.374	0.269

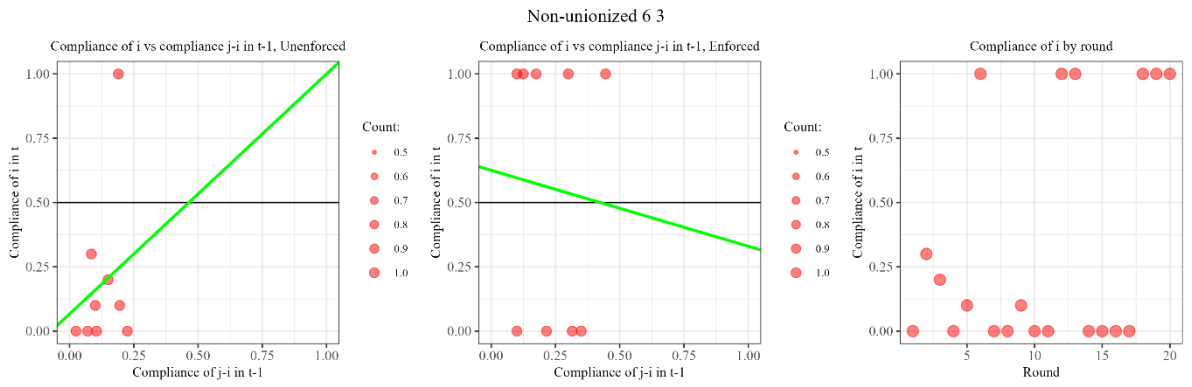
Class_Open_access	Class_Regulated
Free-rider	Unconditional cooperator



Alpha1	Alpha2	Beta1	Beta2
0.235	0.092	0.15	-0.063

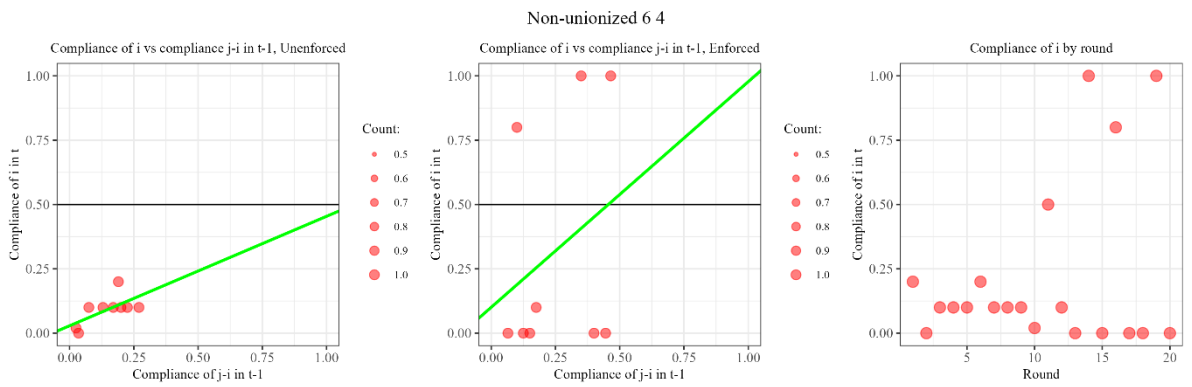
Class_Open_access	Class_Regulated
Free-rider	Free-rider





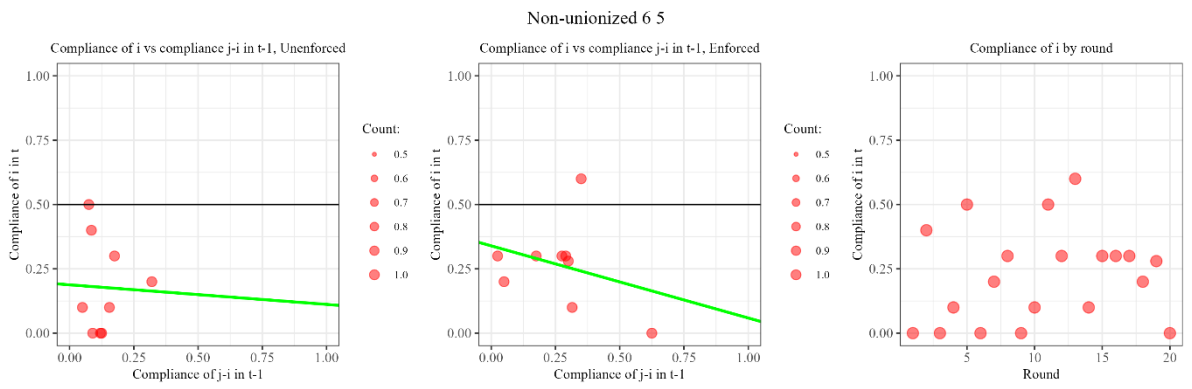
Alpha1	Alpha2	Beta1	Beta2
0.067	0.558	0.933	-1.228

Class_Open_access	Class_Regulated
Conditional cooperator	Negative cooperator



Alpha1	Alpha2	Beta1	Beta2
0.029	0.072	0.426	0.451

Class_Open_access	Class_Regulated
Free-rider	Conditional cooperator



Alpha1	Alpha2	Beta1	Beta2
0.188	0.152	-0.076	-0.204

Class_Open_access	Class_Regulated
Free-rider	Free-rider

Appendix 5. Classification of the entire experimental sample.

In the table below, we report the results of the classification method for the entire sample (without disaggregating by CPR user groups). The results in the unenforced distribution column show the proportion of strategies for the unenforced condition, while the enforced distribution row displays the percentages of each strategy in the enforced condition. In this transition matrix, each observation indicates the number of subjects that changed from one strategy to another. For example, in row 1 and column 1 (row CC and column CC), it indicates that 9% of the sample remained as conditional cooperators in both conditions; in the column to the right (row CC and column FR), it indicates that 6.5% of the sample changed their strategy from conditional cooperation in the unenforced condition to free-riders in the enforced condition.

Transition matrix of the entire sample (non-disaggregated results).

Strategies	CC	FR	NC	UC	Unenforced distribution
CC	9.09% (7)	6.49% (5)	3.90% (3)	11.69% (9)	31.17% (24)
FR	15.58% (12)	23.38% (18)	5.19% (4)	3.90% (3)	48.05% (37)
NC	3.90% (3)	1.30% (1)	1.30% (1)	0.00% (0)	6.49% (5)
UC	0.00% (0)	0.00% (0)	0.00% (0)	14.29% (11)	14.29% (11)
Enforced distribution	28.57% (22)	31.17% (24)	10.39% (8)	29.87% (23)	100.00% (77)

**** CC: Conditional cooperators; FR: Free-riders; NC: Negative cooperators; UC: Unconditional cooperators. Column “Unenforced distribution” gives the proportion of each strategy for the unenforced condition (rounds 1-10); “Enforced distribution” row gives the strategy distribution in the enforced condition (rounds 11-20). Number of cases inside parenthesis.**

Our results highlight substantial differences in the fraction of strategies between types of user groups and, for some cases, significant changes within user groups triggered by an external enforcement condition. Since the literature on player-types classification has predominantly used the Strategy Method (which usually does not involve external enforcement conditions or treatments), the results in Table 1 that are directly comparable to the literature correspond to the strategies in the unenforced column. According to Frey (2017), experimental results show that, on average (and with variable results across studies), the percentage of conditional cooperators corresponds to approximately half of the samples (52%), free-riders to 20% of the samples, triangle cooperators to 8% of the samples, high-cooperators to 15% of the samples, and others to 13% of the samples. The literature on heterogeneous strategy distribution has not consistently employed the term "unconditional cooperator," but rather that of "cooperators" (Kurzban and Houser 2005, Burlando and Guala 2005, Rustagi et al. 2010, Frey 2017). While

the results are limited, research that has included this category within the spectrum of strategies has reported that they account for an average of 15% of the sample. This calculation is based on the Strategy Method framework, which allows for a direct comparison only with our comprehensive sample and the unenforced condition, yielding a quite similar outcome. As can be seen, our results differ from the directly comparable categories in the rest of the literature (conditional cooperators, unconditional cooperators, and free-riders), although, as cautioned by Frey, results among studies using the Strategy Method are also highly variable.

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