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JEL Classification: C91, C73, D02, K49, P16, Z1

Keywords: Laws, social values, Cooperation, learning, Spillovers, persistence of institutions, repeated games, experiments.

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Spillovers, Persistence and Learning: Institutions and the Dynamics of Cooperation*

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Abstract

We study how cooperation-enforcing institutions dynamically affect values and behavior using a lab experiment designed to create individual specific histories of past institutional exposure. We show that the effect of past institutions is mostly due to "indirect" behavioral spillovers: facing penalties in the past increases partners' cooperation in the past, which in turn positively affects ones' own current behavior. We demonstrate that such indirect spillovers induce persistent effects of institutions. However, for interactions that occur early on, we find a negative effect of past enforcement due to differential learning under different enforcement institutions.

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1 Introduction

What makes societies or organizations (hereafter groups) cooperative environments? Social sciences have provided two main answers to this question: formal institutions—laws or regulation—

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and societal values—group members' taste for cooperation.[1] This paper studies the dynamic interaction of these two fundamental drivers of cooperation. We focus on two mechanisms. First, past institutions might shift individual values in the future through spillovers. Second, the institutional setting may affect how individuals learn about (otherwise unknown) values prevailing in the group. We rely on the combination of a lab experiment and a theoretical model to study both the structure of spillover effects of past institutions and its interactions with the dynamics of learning about the group's values. Our results are threefold. First, the main effect of past institutions goes through an "indirect" behavioral spillover: facing penalties in the past increases partners' cooperation in the past, which in turn positively affects ones' current behavior. Second, this specific kind of spillover induces persistent effects of institutions. Third, for interactions that occur early on, we find a negative effect of past enforcement, due to differential learning according to the enforcement institution.

In order to clarify how spillovers and learning might work, consider the following two situations. The first is a setting of a well-established group whose members know each other well. In this situation, values are commonly known so that past institutions can affect values only through spillovers. We focus on two sources of spillovers. A direct spillover occurs if strong enforcement in the past directly increases the current value attached to cooperation. However strong enforcement in the past can also affect values indirectly if past behavior of partners affects one's own current values—i.e., indirect spillovers.

Distinguishing between direct and indirect spillovers is essential since they have very different implications for the persistence of the effects of past institutions. Consider the extreme example of short-lasting shifts in values arising solely from experience in the immediate past. In this case, there will be no persistent effect in time of past institutions through direct spillovers: enforcement in the immediate past changes current cooperation but has no effect in the future. With indirect spillovers, by contrast, an institutional shock affects immediate cooperation of partners. This affects cooperation in the next period, which in turn transmits to cooperation in later periods, through subsequent indirect spillovers effects. This induces persistence of past institutions.

Now consider a second setting, in which a new group is formed (for instance a new firm, a new class in a school or a newly founded town or neighborhood) and group members do not know each other. In addition to spillover effects, members need to learn about values of the typical member of the group, as the expected behavior of partners matters to determine the expected payoff of different choices. If a very strict sanction was imposed on non-cooperativeness in the past, everyone cooperated and thus individuals cannot learn about others' values. As a consequence, by affecting the learning process, strong institutions in the past can negatively affect cooperation today once these sanctions are removed; past institutions determine the speed of the learning

[1]What we call societal values is sometimes referred to in the literature as "norms" (for instance in Tabellini, 2008). In other papers, norms represent the selection of a particular equilibrium in instances where multiple equilibria emerge either because of complementarities in actions or because of informational content of actions (for instance in Benabou and Tirole, 2011; Acemoglu and Jackson, 2015).

process. We provide a theoretical analysis of the combination of these mechanisms—direct and indirect spillovers and the dynamics of learning—by introducing them sequentially.

Our research design relies on a laboratory experiment where participants play a series of indefinitely repeated prisoners dilemma that, in their baseline version, build on Dal Bó and Fréchette (2011). At the beginning of each game, it is randomly determined whether a formal institution in the form of a fine will be imposed in all rounds of the game when a participant chooses to deviate rather than cooperate.[2] At the end of the game, each participant is re-matched with a new one and a new institution is drawn. This setup was chosen to allow for separate identification of direct and indirect spillovers. The design ensures that each participant *(i)* has a different history of institutional exposure and of past behavior of partners, and that this history both *(ii)* does not depend on self-selection into particular institutional environments, and *(iii)* is independent from the current environment faced by each individual. Still, spillovers and learning are intertwined in observed cooperation decisions as long as learning is ongoing. We rely on the structure of the model to disentangle the two, by focusing on late games to identify spillovers—under the assumption that learning has converged.

In games played late in the experiment, we find that facing fines in the previous game increases current cooperation by 5%—to be compared with an increase of 30% for fines in the current period (see Bowles and Polania-Reyes, 2012, for a review of the literature on the direct effect of incentives on cooperation in the lab)—highlighting a spillover effect of past institutions. Individual specific histories generated by design allow us to further measure separately indirect and direct spillovers. We show that the observed spillover effect is mostly an indirect effect of past institutions: strong enforcement in the past induces cooperation by the partner in the past, that in turn affects one's current cooperative behavior.

We provide direct evidence of persistent impacts of institutions, and show it is caused by indirect spillovers. Consider individual i in match t. We show empirically that fines experienced by individual i two matches ago have no impact on her current level of cooperation, suggesting that indeed direct spillovers are short lived. On the contrary, fines experienced in match $t-2$ by the partner of i in match $t-1$, have a strong and significant effect on i's cooperation level, although i did not experience directly these fines in $t-2$. In contrast with direct spillovers, indirect spillovers induce a persistent effect of past institutions over time.

In early games, we observe that learning dynamics counterbalance the spillover effects. As highlighted in the theoretical model, guide to our empirical analysis, the behavior of partners in previous games brings information about how cooperative the group is and thus affects current

[2] In our setting when fines are present they are exogenously enforced. In this sense our setting differs from Acemoglu and Jackson (2017) who study complementarities in the enforcement of cooperation between laws and social norms.

behavior.[3] We show that lab participants behave in accordance with these learning dynamics: cooperation by the partner in the previous game, if it was played with a fine, has a smaller positive effect than if this cooperation took place in a game without fines. It is indeed a weaker signal that the group is cooperative.

Our study provides several contributions to the existing literature. First we confirm the existence of institutional spillovers that have been previously documented both in the lab and in the field. For instance Peysakhovich and Rand (2016) build an experiment where each treatment is organized in two phases: in the first, participants play a series of infinitely repeated prisoners dilemma while in the second they play one shot games such as the dictator game. They show that in treatments where cooperation is supported in equilibrium in the games of the first phase, the participants are more cooperative in the one shot games that follow. In Cassar, d'Adda, and Grosjean (2014), subjects play a market game under different institutional treatments, which generate different incentives to behave honestly, preceded and followed by a non-contractible and non-enforceable trust game. They show a significant increase in individual trust and trustworthiness following exposure to better institutions. In the field, Fisman and Miguel (2007) show that the level of corruption in the country of origin has an impact on parking violations by UN diplomats in New York where they were not subject to fines. The existing literature cannot however distinguish the channels through which spillovers operate because of between-subject designs—all partners interacting in the target situation experienced the same institutions in the past. We identify the source of these spillovers by documenting the crucial role played by indirect spillovers, and we show that direct spillovers are in fact quite weak as fines experienced two matches earlier have no effect on current cooperation.

We also consider many repetitions of the game, which allows to document the dynamic interaction between institutions and learning about group values.[4] The main mechanism relies on the dynamic interactions between institutions and information provision, as in Benabou and Tirole (2011). In their setup, individuals care about the inferences made by other group members about their types. Institutions shape equilibrium behaviors and thus the amount of information conveyed by actions. In our setup, the learning is rather about the overall group cooperativeness.[5] In Acemoglu and Jackson (2015), the random variation in the presence of visible leaders in the past influences current learning about partners possible actions. They do not consider, however, the effect of institutional variations in the past.

[3]The presence of learning in infinitely repeated games has been already documented in other papers Dal Bó and Fréchette (2017), our study allows to clarify how learning dynamics are affected by the institutional setting in which players interact.

[4]In a related work, Dal Bó and Dal Bó (2014) show that explicit information about moral values affect cooperation in a standard voluntary contribution game. In their setting however the information is provided by the experimenter and does not allow for dynamic learning about the distribution of prevalent types in the lab.

[5]Some of the literature builds on the idea that formal rules can also convey information about the distribution of preferences or values, for instance Sliwka (2007); van der Weele (2009). These papers rely on a built-in social complementarity—some individuals have preferences to match the prevalent actions in a society. We abstract from this aspect and we focus on how enforcing institutions, operating as a veil, can hide social values.

Table 1: Stage-game payoff matrices

	C	D
C	40 ; 40	12 ; 60
D	60 ; 12	35 ; 35

(a) Baseline game

	C	D
C	40 ; 40	12 ; 60-F
D	60-F ; 12	35-F ; 35-F

(b) With fine

Finally we show that indirect spillovers can be the source of the long term persistence of past institutions that has been recently documented in the literature.[6] Guiso, Sapienza, and Zingales (2016); Tabellini (2010) for instance document that in cities and regions that were historically more exposed to institutions favoring cooperation, stronger cooperative values and beliefs are observed today. Based on variation in historical political institutions in Africa, Lowes, Nunn, Robinson, and Weigel (2015) find on the contrary a negative relation between strong institutions in the past and intrinsic motivation to follow rules nowadays. Our results contribute to the understanding of long term persistence by clarifying how past institutions can affect future cooperation via direct and indirect spillovers.[7] This last mechanism is particularly interesting since it does not require permanent shifts in individual values nor assumptions on the structure of the inter-generational transmission to explain persistent effects of past institutions.

2 Experimental design

The design of the experiment closely follows the experimental literature on infinitely repeated games and in particular Dal Bó and Fréchette (2011). Subjects in the experiment play infinitely repeated games implemented through a random continuation rule. At the end of each round, the computer randomly determines whether or not another round is to be played in the current repeated game ("match"). This probability of continuation is fixed at $\delta = 0.75$ and is independent of any choices players make during the match. Participants therefore play a series of matches of random length, with expected length of 4 rounds.[8] At the end of each match, players are randomly and anonymously reassigned to a new partner to play the next match. This corresponds to a quasi-stranger design since there is a non zero probability of being matched more than once with the same partner during the experiment. The experiment terminates once the match being played at the 15th minute ends.

The stage-game in all interactions is a Prisoner's dilemma. Institutions are randomly varied:

[6] There is a large literature focusing on the effects of past institutions on different cultural outcomes today surveyed, e.g., in Alesina and Giuliano (2017).

[7] Alternative channels for this persistence introduced in the theoretical literature include the transmission of values to children in Tabellini (2008); Bisin and Verdier (2001) or the role of visible leaders in Acemoglu and Jackson (2015).

[8] The expected number of rounds is given by $\sum_{k=1}^{+\infty} k(1-\delta)\delta^{k-1} = (1-\delta)\sum_{k=1}^{+\infty} k\delta^{k-1} = (1-\delta)\frac{1}{(1-\delta)^2} = \frac{1}{1-\delta}$.

at the beginning of each match, the computer randomly determines whether the match is played with a fine (payoffs in Table 1b) or without (Table 1a); the two events occur with equal probability. The result from this draw applies to both players of the current match, and to all its rounds. The fine when imposed is set at $F = 10$ so that the resulting stage-game payoff matrix is isomorphic to Dal Bó and Fréchette (2011) $\{\delta = 3/4; R = 40\}$ treatment, in which cooperation is a sub-game perfect and risk dominant action. When matched with a new partner, subjects are not provided with any information about the partner's history. Players however receive full feedback at the end of each round about the actions taken within the current match.

3 A theoretical model of cooperation dynamics

We build a model to understand how past and present institutions affect cooperative behavior in the experiment, and its interaction with individual learning about other participants' values. More generally the theory applies to any group whose members interact in pairs and the institutions governing the group may vary from one interaction to the next.

3.1 Setup of the model

In each match (we use index t for the match number), the players simultaneously choose between actions C and D to maximize their payoff in the current match and then observe the partner's decision. In the case where a match is a repeated prisoner's dilemma, as is the case in the experiment, this requires the first period action in a match to fully summarize strategies.[9] To ease exposition, we denote i the player under consideration, j_t the partner of i in match t, k_t the partner of player j_t in match $t-1$ and l_t the partner of player k_t in match $t-2$ (see Figure 4, in Appendix A). The institution experienced by player x in match t is denoted $F_{x,t} \in \{0,1\}$ and the action of this player in match t is denoted $a_{x,t} \in \{C, D\}$.[10] For instance the action taken in match $t-2$ by the partner of i in $t-1$ is denoted by $a_{j_{t-1},t-2}$.

The payoff of player i from playing $a \in \{C, D\}$ in match t is given by:

$$\begin{aligned} U_{it}^{C}(F_{it}, p_{it}) &= V_{it}^{C}(F_{it}, p_{it}) + \beta_{it} , \\ U_{it}^{D}(F_{it}, p_{it}) &= V_{it}^{D}(F_{it}, p_{it}) . \end{aligned}$$

where $V_{it}^{a}(F_{it}, p_{it})$ is the material payoff player i expects from choosing action a in match t. This expected payoff depends in particular on the beliefs player i holds on the probability that the partner j_t cooperates, p_{it}, and of course on whether the current match is played with a fine, F_{it}. Note that p_{it} is in fact a function of F_{it}, since the presence of a fine affects the probability that

[9] As explained in Section 4.2 we restrict the analysis to a set of strategies that imply that the first round action summarizes the strategies. Specifically, we restrict players to play either Grim Trigger, Tit for Tat or Always Defect.

[10] For player i we use the simplified notation F_{it} rather than $F_{i,t}$ and a_{it} rather than $a_{i,t}$.

the partner cooperates.[11]

The parameter β_{it} stands for individual personal values at match t: it measures the individual propensity to cooperate at each match. Each individual has a baseline propensity to cooperate, that we denote β_i. The aim of this paper is to account for the effect of past experience on the evolution of cooperation. To that end, we allow both past fines and past behaviors of the partners to affect values:[12]

$$\beta_{it} \;=\; \beta_i \;+\; \phi_F \; \mathbb{1}_{\{F_{it-1}=1\}} \;+\; \phi_C \; \mathbb{1}_{\{a_{j_{t-1},t-1}=C\}} \; . \tag{1}$$

According to this simple specification, personal values evolve through two channels. First, direct spillovers increase the value attached to cooperation in the current match if the previous one was played with a fine, as measured by parameter ϕ_F. Second, indirect spillovers, measured by ϕ_C, increase the value attached to cooperation if in the previous match the partner cooperated.[13]

In order to account for learning about values in the group, we suppose there is uncertainty on the set of group's values, i.e the set of baseline individual values β_i. We consider two possible states of the world. With probability q the state is high and β_i is drawn from the normal distribution $\Phi(\mu_H, \sigma^2)$, while with probability $1-q$, they are drawn from $\Phi(\mu_L, \sigma^2)$, with $\mu_L < \mu_H$. The value attached to cooperation by society is higher in the high state.

In this setting, past institutions influence the current decision to cooperate in two ways. First, past institutions affect values through direct and indirect spillovers, as expressed in (1). Second, formal rules also impact how fast individuals can learn about the societies values—i.e., whether the values are drawn from the low state, or the high state, distribution. To clarify the arguments we add the different channels gradually: we first consider a benchmark model with no behavioral components in values, then move to the effect of spillovers and, last, introduce learning dynamics in the model.

[11] We drop this dependency of p_{it} on F_{it} in the notation.

[12] This specification is consistent with several existing models of non-monetary incentives to cooperate. Indirect spillovers, ϕ_C, can for instance be interpreted as resulting from upstream reciprocity (as stated in Nowak and Roch, 2007, "*if someone is nice to you, you feel good and may be inclined to be nice to somebody else.*")—cooperation behavior of past partners is reciprocated by a higher propensity to cooperate with an unrelated current partner. Similarly, the model could be re-written to match the dual process model of Peysakhovich and Rand (2016), where each individual decides based on either a deliberative process determined by the comparison of U_{it}^C and U_{it}^D, or an intuitive process influenced by their past history.

[13] The model can easily be extended to allow for longer histories to impact values. For instance, the effect on past institutions on values could be extended to:

$$\beta_{it} \;=\; \beta_i \;+\; \sum_{\tau=1}^{T} \phi_{F\tau} \; \mathbb{1}_{\{F_{it-\tau}=1\}} \;+\; \sum_{j=1}^{T} \phi_{C\tau} \; \mathbb{1}_{\{a_{j_{t-\tau},t-\tau}=C\}},$$

with $\phi_{F\tau}$ and $\phi_{C\tau}$ increase in τ, in other words the more recent history having more impact. This could be introduced at the cost of added complexity.

3.2 Benchmark model

First consider a benchmark model with no uncertainty on values ($q = 1$) and no spillovers ($\phi_F = \phi_C = 0$). We now use the specific payoffs corresponding to the prisoner's dilemma in order to explicitly describe the impact of fines on payoffs. Denote π_{a_i,a_j} the monetary payoff of i in a round where a_i is played against a_j. Individual i, with beliefs p_{it} that her partner will cooperate, chooses action C if and only if the following condition is satisfied:[14]

$$
\begin{aligned}
p_{it}\frac{1}{1-\delta}\pi_{C,C} \quad &+ \quad (1-p_{it})\left[\pi_{C,D} + \left(\pi_{D,D} - F \times \mathbb{1}_{\{F_{it}=1\}}\right)\frac{\delta}{1-\delta}\right] \quad + \quad \beta_i \\
&\geq \quad p_{it}\left[\left(\pi_{D,C} - F \times \mathbb{1}_{\{F_{it}=1\}}\right) + \left(\pi_{D,D} - F \times \mathbb{1}_{\{F_{it}=1\}}\right)\frac{\delta}{1-\delta}\right] \\
&+ \quad (1-p_{it})\frac{1}{1-\delta}\left(\pi_{D,D} - F \times \mathbb{1}_{\{F_{it}=1\}}\right).
\end{aligned}
$$

This condition can be re-expressed as

$$
\beta_i \quad \geq \quad \beta^*(F_{it}) \equiv \Pi_1 - F \times \mathbb{1}_{\{F_{it}=1\}} \; + \; p_{it}\left[\Pi_2 \; - \; \frac{\delta}{1-\delta}\left(F \times \mathbb{1}_{\{F_{it}=1\}} + \Pi_3\right)\right], \tag{2}
$$

with the parameters defined as $\Pi_1 \equiv \pi_{D,D} - \pi_{C,D} > 0$, $\Pi_2 \equiv (\pi_{D,C} - \pi_{D,D}) - (\pi_{C,C} - \pi_{C,D})$ and $\Pi_3 \equiv \pi_{C,C} - \pi_{D,D} > 0$.[15]

Condition (2) implies that the decision to cooperate follows a cutoff rule, such that an individual i cooperates if and only if she attaches a sufficiently strong value to cooperation $\beta_i \geq \beta^*(F_{it})$, where the cutoff β^* depends on whether the current match is played with a fine. Since there is no uncertainty, and thus no learning, all players share the same belief over the probability that the partner cooperates, given by $p_{it}(F_{it}) = P[\beta_j \geq \beta^*(F_{it})] = 1 - \Phi_H[\beta^*(F_{it})]$. The cutoff value $\beta^*(F_{it})$ is thus defined by the indifference condition:

$$
\beta^*(F_{it}) \;=\; \Pi_1 - F \times \mathbb{1}_{\{F_{it}=1\}} \;+\; [1 - \Phi_H[\beta^*(F_{it})]]\left[\Pi_2 \;-\; \frac{\delta}{1-\delta}\left(F \times \mathbb{1}_{\{F_{it}=1\}} + \Pi_3\right)\right]. \tag{3}
$$

We show in Proposition 1 below that there always exists at least one equilibrium, and this equilibrium is of the cutoff form. There could exist multiple equilibria, but all stable equilibria share the intuitive property that individuals are more likely to cooperate in an environment with fines.

Proposition 1 *In an environment with no uncertainty on values ($q = 1$) and no spillovers ($\phi_F = \phi_C = 0$), there exists at least one equilibrium. Furthermore all equilibria are of the cutoff form, i.e individuals cooperate if and only if $\beta_i \geq \beta^*(F_{it})$ and, in all stable equilibria, β^* decreases with F and with μ_H.*

[14] We explicitly use the fact that players are restricted to choosing between Grim Trigger, Tit For Tat and Always Defect.

[15] In the case of the experiment, $\Pi_1 = 23$, $\Pi_2 = -3$ and $\Pi_3 = 5$.

Proof. See Appendix, Section A. ■

The benefit of cooperation is increasing in the probability that the partner cooperates. There exist equilibria where cooperation is prevalent, which indeed makes cooperation individually attractive. On the contrary there are equilibria with low levels of cooperation which makes cooperation unattractive. These equilibria can be thought of as different norms of cooperativeness in the group, driven by complementarities in cooperation.

3.3 Introducing spillovers

We now add to the benchmark model the possibility of spillovers, i.e we assume $\phi_F > 0$ and $\phi_C > 0$. The indifference condition (2) remains unchanged,[16] but now β_{it} is no longer constant and equal to β_i since past shocks affect values. In this context, individual i cooperates at t if and only if:

$$\beta_{it} \quad \geq \quad \Pi_1 - F \times \mathbb{1}_{\{F_{it}=1\}} \; + \; p_{it}\Pi_2 \; - \; \frac{\delta}{1-\delta} p_{it} \left(F \times \mathbb{1}_{\{F_{it}=1\}} + \Pi_3 \right) \; .$$

The cutoff value is defined in the same way as before:

$$\beta_t^*(F_{it}) \quad = \quad \Pi_1 - F \times \mathbb{1}_{\{F_{it}=1\}} \; + \; p_t^*(F_{it}) \left[\Pi_2 \; - \; \frac{\delta}{1-\delta} \left(F \times \mathbb{1}_{\{F_{it}=1\}} + \Pi_3 \right) \right] \; . \qquad (4)$$

The main difference with the benchmark model is in the value of $p_t^*(F_{it})$. There is now a linkage between the values of the cutoffs at match t, β_t^*, and the values of the cutoffs $\beta_{t'}^*$ in all the preceding matches $t' < t$ through $p_t^*(F_{it})$. Indeed, when an individual evaluates the probability that her current partner in t, player j_t, will cooperate, she needs to determine how likely it is that she received a direct and/or an indirect spillover from the previous period. The probability of having a direct spillover is given by $P[F_{jt-1} = 1] = 1/2$ and is independent of any equilibrium decision. By contrast, the probability of having an indirect spillover is linked to whether the partner of j_t in her previous match cooperated or not. This probability in turn depends on the cutoffs in $t-1$, β_{t-1}^*, which also depends on whether that individual himself received indirect spillovers, i.e on the cutoff in $t-2$. Overall, these cutoffs in t depend on the entire sequence of cutoffs.

In the remaining, we focus on stationary equilibria, such that β^* is independent of t. We show in Proposition 2 that such equilibria do exist.

Proposition 2 ***(Spillovers)*** *In an environment with spillovers ($\phi_F > 0$ and $\phi_C > 0$) and no*

[16] As stated above, we work under the assumption that players are myopic and choose between C and D to maximize their payoff in the current match. Without this assumption, when spillover are introduced, a player would need to take into account that her current action would influence her partner's future actions and thus influence the partner's future partners. An alternative would be to assume that players are negligible enough so that current actions cannot influence future beliefs.

uncertainty on values, there exists a stationary equilibrium. Furthermore all equilibria are of the cutoff form, i.e individuals cooperate if and only if $\beta_{it} \geq \beta^*(F_{it})$.

Proof. See Appendix, Section A. ■

Proposition 2 proves the existence of an equilibrium and presents the shape of the cutoffs. The Proposition also allows to express the probability that a random individual cooperates as:

$$1 - \Phi_H \left[\Lambda_1 - \phi_F \ \mathbb{1}_{\{F_{it-1}=1\}} \ - \ \phi_C \ \mathbb{1}_{\{a_{j_{t-1},t-1}=C\}} \ - \Lambda_2 \mathbb{1}_{\{F_{it}=1\}} \right] \ , \tag{5}$$

where:

$$\begin{aligned} \Lambda_1 \quad &\equiv \quad \beta^*(0) \ = \ \Pi_1 \ + \ p^*(0) \left[\Pi_2 \ - \ \frac{\delta}{1-\delta} \Pi_3 \right] \ , \\ \Lambda_2 \quad &\equiv \quad \beta^*(1) - \beta^*(0) \ = \ F \ + \ [p^*(0) - p^*(1)] \left[\Pi_2 \ - \ \frac{\delta}{1-\delta} \Pi_3 \right] + \frac{\delta}{1-\delta} p^*(1) F \ . \end{aligned}$$

This is the first relation we will test in the data to examine the existence and size of spillovers, direct and indirect (ϕ_F and ϕ_C), as well as the effect of current enforcement, Λ_2.[17]

We now examine whether the model can generate persistent effect of institutions.

Proposition 3 ***(Persistence)*** *In an environment with no uncertainty on values, if in two otherwise identical groups where group members play the same stationary equilibrium, a larger share of matches at match $t = 1$ are played with fines in group 1 compared to group 2, then:*

(i) If $\phi_C > 0$, the probability of cooperation in any match $t \geq 1$ of a randomly picked individual is higher in group 1 than in group 2;

(ii) If $\phi_C = 0$ and $\phi_F > 0$, the probability of cooperation in any match $t = 2$ of a randomly picked individual is higher in group 1 than in group 2, but the same for $t \geq 3$.

We considered an environment with little room for persistent effect of institutions since only the previous period institutions and actions affect current values and furthermore only in a temporary way (i.e the baseline value β_i does not shift) as presented in equation (1). Nevertheless, there is a transmission of shocks through time because of indirect spillovers. Consider, as in Proposition 3, two identical groups playing according to the same stable equilibrium. Suppose more individuals in group 1 randomly happen to experience stronger institutions in their first match. Since the groups are otherwise identical, individuals in group 1 are more likely to cooperate in the first match. In the second match the institutions are randomly drawn in both groups. However, on average, because group 1 members cooperated more in match 1, these members are more likely

[17]Note that another implication of the model is that the marginal effect of having a spillover (direct or indirect) on the current probability to cooperate is smaller when there is a fine in the current match than when there isn't. Indeed, when there is a fine, the probability of cooperation is already high and the marginal effect of additional spillovers is small.

to experience an indirect spillover ϕ_C and cooperate in their second match. This in turns implies a higher probability of cooperation in match 3 and in any subsequent match. There is thus a transmission of shocks. This persistent effect of institutions would not occur in our model if indirect spillovers were absent, as expressed in result *(ii)*.[18] Interestingly, this mechanism does not require a permanent shock in values and its inter-generational transmission to explain persistent effects of institutions.

3.4 Introducing learning

We now consider the more general formulation with uncertainty about the group's values. We denote q_{it} the belief held by player i at match t that the state is H. All group members initially share the same beliefs $q_{i0} = q$. They gradually learn about the group's values thanks to the decisions observed from others and we show how fines impact learning.

First consider the initial match, $t = 1$. All members of the group share the same belief q that the state is H. Furthermore, no member has yet obtained spillovers from the past. The equilibrium is defined by a single cutoff value $\beta^*(F_{it})$ as in the benchmark model,

$$\beta^*(F_{i1}) \quad = \quad \Pi_1 - F \times \mathbb{1}_{\{F_{i1}=1\}} \ + \ p_1^*(F_{i1}) \left[\Pi_2 \ - \ \frac{\delta}{1-\delta} \left(F \times \mathbb{1}_{\{F_{i1}=1\}} + \Pi_3 \right) \right] \ .$$

The only difference with the benchmark model is that the probability that the partner cooperates takes into account the uncertainty about the group's values:

$$p_1^*(F_{i1}) \ = \ q \ \left[1 - \Phi_H \left[\beta^*(F_{i1})\right]\right] \ + \ (1-q) \ \left[1 - \Phi_L \left[\beta^*(F_{i1})\right]\right] \ .$$

We now consider how beliefs about the state of the world are updated following the initial match. The update depends on the action of the partner and whether the match was played with or without a fine. The general notation we use is $q_{it}(F_{it-1}, a_{j_{t-1},t-1}, q_{it-1})$. For the update following the first match, we can drop the dependence on q_{it-1}, since all individuals initially share the same belief.

Clearly, the belief that the state is H decreases if the partner chose D, while it increases if the choice was C. The update however depends as well on whether the previous match was played with a fine or not. If the partner cooperated in presence of a fine, it is a less convincing signal that society is cooperative than if he cooperated in the absence of the fine—$q_{i2}(0, C) > q_{i2}(1, C)$. Similarly, deviation in the presence of a fine decreases particularly strongly the belief that the state is high—$q_{i2}(1, D) < q_{i2}(0, D)$. This is summarized in the following Lemma:[19]

[18] Note also that, in equilibrium, players are more cooperative in a match played without a fine if the amount of fine is higher in matches that do implement it. The intuition is that the higher fine increases the probability that a given individual cooperates when fines are implemented and thus, even in matches without fine, makes it more likely that the partner experienced a spillover from his previous match.

[19] Stability guarantees that when the current match is played with a fine, the probability of cooperation increases.

Lemma 1 *In any stable equilibrium, beliefs following the first period actions are updated in the following way:*

$$q_{i2}(0, C) > q_{i2}(1, C) > q \ ,$$
$$q_{i2}(1, D) < q_{i2}(0, D) < q \ .$$

Proof. See Appendix, Section A. ■

We show in Proposition 4 that this updating property is true in general for later matches. In these later matches, spillovers start playing a role. The decision to cooperate depends, as in the previous section, both on the current institution F_{it} and on the history $(F_{it-1}, a_{j_{t-1},t-1})$, but also on beliefs q_{it-1}. The cutoffs are defined by:

$$\beta^*_t(F_{it}, q_{it}) \quad = \quad \Pi_1 - F \times \mathbb{1}_{\{F_{it}=1\}} \ + \ p^*_t(F_{it}, q_{it}) \left[\Pi_2 \ - \ \frac{\delta}{1-\delta} \left(F \times \mathbb{1}_{\{F_{it}=1\}} + \Pi_3 \right) \right] \ .$$

The beliefs on how likely it is that the partner cooperates in match t, $p^*_t(F_{it}, q_{it})$, depends on the probability that the partner experienced spillovers (as in the previous section). In addition, the probability that the partner j had an indirect spillover, itself depends on whether his own partner k in the previous match did cooperate, and thus depends on the beliefs q_{kt-1} of that partner in the previous match. The general problem requires to keep track of the higher order beliefs. However if a stationary equilibrium exists, with the property that $\beta^*(0, q) > \beta^*(1, q)$ for all beliefs q, then the updating property of Lemma 1 is preserved. Furthermore, in the appendix we show existence of such a stationary equilibrium, under a natural restriction on higher order beliefs, i.e if we assume that a player who had belief q_{it} in match t believes that players in the preceding match had the same beliefs $q_{j',t-1} = q_{it}$.

Proposition 4 ***(Learning)*** *In an environment with spillovers and learning, if an equilibrium exists, all equilibria are of the cutoff form, i.e individuals cooperate if and only if $\beta_i \geq \beta^*(F_{it}, q_{it})$. Furthermore, if in equilibrium $\beta^*(0, q) > \beta^*(1, q)$ for all beliefs q, then the beliefs are updated in the following way following the history in the previous interaction:*

$$q_{it}(0, C, q_{it-1}) > q_{it}(1, C, q_{it-1}) > q_{it-1} \ ,$$
$$q_{it}(1, D, q_{it-1}) < q_{it}(0, D, q_{it-1}) < q_{it-1} \ .$$

Proof. See Appendix, Section A. ■

Proposition 4 derives a general property of equilibria. The Proposition also allows to express the probability of cooperation for given belief q_{it-1} as:

$$1-\Phi_H\Big[\Lambda_3-\phi_F\ \mathbb{1}_{\{F_{it-1}=1\}}\ -\ \phi_C\ \mathbb{1}_{\{a_{j_{t-1},t-1}=C\}}\ -\Lambda_4\mathbb{1}_{\{F_{it}=1\}} \\ -\sum_{j,k\in\{0,1\},l\in\{C,D\}}\Lambda^j_{k,l}\ \mathbb{1}_{\{F_{it}=j,F_{it-1}=k,a_{j_{t-1},t-1}=l\}}\Big]\ . \tag{6}$$

where:

$$\begin{aligned}
\Lambda_3 &\equiv \Pi_1\ +\ p^*(0,0,D,q)\left[\Pi_2\ -\ \frac{\delta}{1-\delta}\Pi_3\right]\ ,\\
\Lambda_4 &\equiv F\ -\ [p^*(1,0,D,q)-p^*(0,0,D,q)]\left[\Pi_2\ -\ \frac{\delta}{1-\delta}\Pi_3\right]+\frac{\delta}{1-\delta}p^*(1,0,D,q)F>0\ ,\\
\Lambda^0_{k,l} &\equiv [p^*(0,k,l,q)-p^*(0,0,D,q)]\left[\Pi_2\ -\ \frac{\delta}{1-\delta}\Pi_3\right]\ ,\\
\Lambda^1_{k,l} &\equiv -[p^*(0,k,l,q)-p^*(0,0,D,q)]\left[\Pi_2\ -\ \frac{\delta}{1-\delta}(F+\Pi_3)\right]\ .
\end{aligned}$$

Note that the parameters Λ_3, Λ_4 and $\Lambda^j_{k,l}$ in equation (6) depend on q_{it-1}. Compared to the case without learning, there are 6 additional parameters, reflecting the updating of beliefs. According to the result in Proposition 4, these parameters, both in the case where the current match is played with a fine and when it is not, are such that:

$$\begin{aligned}
\Lambda^1_{0,C} > \Lambda^1_{1,C} > 0 > \Lambda^1_{1,D}\ ,\\
\Lambda^0_{0,C} > \Lambda^0_{1,C} > 0 > \Lambda^0_{1,D}\ .
\end{aligned} \tag{7}$$

Overall, having fines in the previous match can potentially decrease average cooperation in the current match. There are two countervailing effects. On the one hand, a fine in the previous match increases the direct and indirect spillovers and thus increases cooperation. On the other hand, if the state is low, a fine can accelerate learning if, on average, sufficiently many people deviate in the presence of a fine. This then decreases cooperation in the current match.

4 Empirical strategy

The aim of the experiment is to identify the structural parameters driving the dynamics of cooperation based on (6). As the equation clearly shows, exogenous variations in legal enforcement are not enough to achieve separate identification of learning and spillover parameters—an exogenous change in any of the enforcement variables, or past behavior of the partner, involves both learning and a change in the values β_{it}. Our identification strategy relies on the assumption that learning has converged once a large enough number of matches has been played. Under this assumption, in late games, behavior is described by equation (5), which involves only spillover parameters.

Exogenous variations in enforcement thus provides identification of spillover parameters in late games, which in turn allows to identify learning parameters in early ones.

4.1 Procedures

Three sessions of the experiment were conducted at Ecole Polytechnique experimental laboratory. The 46 participants are both students (85% of the experiment pool) and employees of the university (15%). Individual earnings are computed as the sum of all tokens earned during the experiment, with an exchange rate equal to 100 tokens for 1 Euro. At the end of the experiment, participants are asked to answer a socio-demographic questionnaire about their gender, age, level of education, labor market status (student/worker/unemployed) as well as the Dohmen, Falk, Huffman, Sunde, Schupp, and Wagner (2011) self-reported measure of risk-aversion. Participants earned on average 12.1 Euros from an average of 20 matches, each featuring 3.8 rounds.[20] This data delivers 934 game observations, 48% of which are played with no fine. Figure 1a displays the empirical distribution of game lengths in the sample split according to the draw of a fine. With the exception of two-rounds matches, the distributions are very similar between the two environments. This difference in the share of two-rounds matches mainly induces a slightly higher share of matches longer than 10 rounds played with a fine. In both environments, one third of the matches we observe lasts one round, and one half of the repeated matches last between 2 and 5 rounds. A very small fraction of matches (less than 5% with a fine, less than 2% with no fine) feature lengths of 10 rounds or more.

4.2 Empirical measures: strategies

Our empirical strategy relies on between match variations induced by the exogenous change in the institutional environment. While the first round decision in a given match is a measure of the effect of past history of play on individual behavior, the decisions made within the course of a match are a mix of this component and the strategic interaction with the current partner. For matches that last more than one round (2/3 of the sample), we thus reduce the observed outcomes to the first round decision in each match, consistently with the theory.

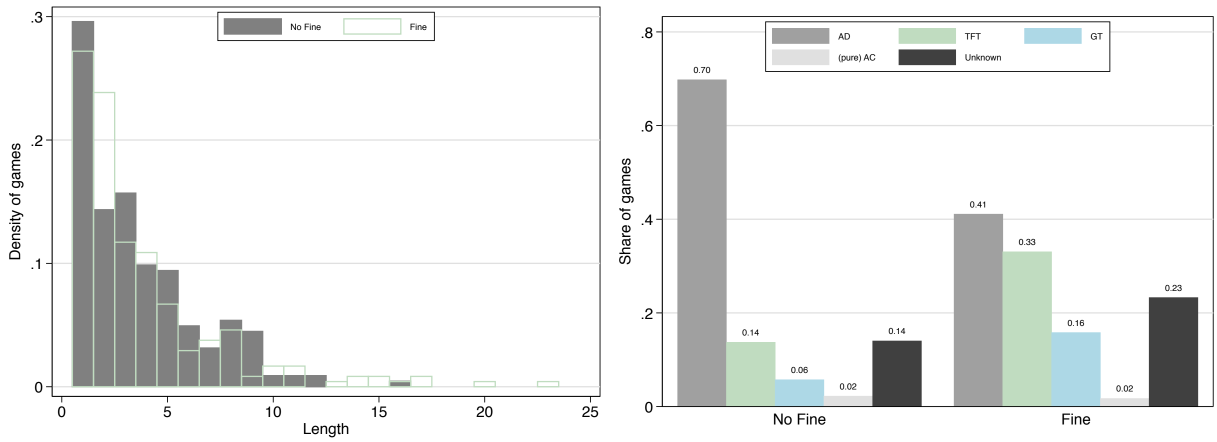
The first round decision is a sufficient statistic for the future sequence of play if subjects choose among the following repeated-game strategies: Always Defect (AD), Tit-For-tat (TFT) or Grim Trigger (GT). While AD dictates defection at the first round, both TFT and GT induce cooperation and are observationally equivalent if the partner chooses within the set restricted to these three strategies and give rise to the same expected payoff. Figure 1b displays the distribution of strategies we observe in the experiment (excluding games that last one round only).[21]

[20] The size of each session is: 16, 18 and 12 participants.

[21] Decisions are classified in each repeated game and for each player based on the observed sequence of play. For instance, a player who starts with C and switches forever to D when the partner starts playing D will be classified as playing GT. In many instances, TFT and GT cannot be distinguished: it happens for instance for subjects who always cooperate against a partner who does the same (in which case, TFT and GT also include Always Cooperate,

Figure 1: Sample characteristics: distribution of game lengths and repeated-game strategies

(a) Distribution of game lengths (b) Individual strategies



Note. *Left-hand side*: empirical distribution of game lengths in the experiment, split according to the draw of the fine. *Right-hand side*: distribution of repeated-games strategies observed in the experiment. One-round matches are excluded. AD: Always Defect; AC: Always Cooperate; TFT: Tit-For-Tat; GT: Grimm Trigger.

All sequences of decisions that do not fall in any of these strategies cannot be classified—this accounts for 14% of the games played without a fine, and 24% of those played with fine. The three strategies on which we focus are thus enough to summarize a vast majority of match decisions.[22] In the remainder of the text, we restrict the sample to player-game observations for which the first round decision summarizes the future history. Our working sample is made of 40 subjects, 785 games among which 50.3% are played with a fine, and with an average duration of 3.3 rounds. Our outcome variable of interest is the first round decision made by each player in each of these matches. All lagged variables are computed according to actual past experience: one's own cooperation at previous match, partner's decision and whether the previous match was played with a fine are all defined according to the match played just before the current one, whether or not this previous match belongs to the working sample.

4.3 Descriptive statistics

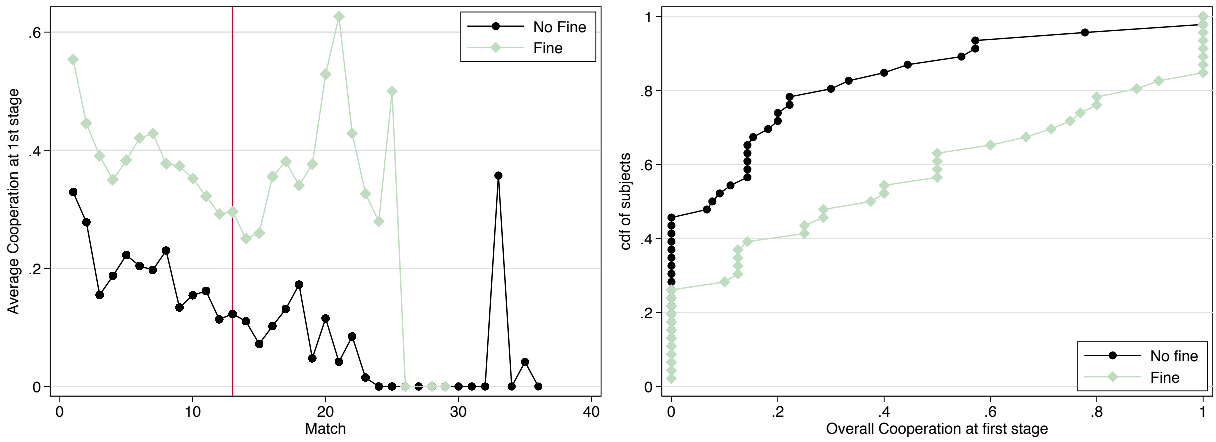
Figure 2 provides an overview of the cooperation rate observed in each of the two environments. The overall average cooperation rate is 32%, with a strong gap depending on whether a fine enforces cooperation: the average cooperation rate jumps from 19% in the baseline, to 46% with a fine. This is clear evidence of a strong disciplining effect of current enforcement. Figure 2a documents the time trend of cooperation over matches. The vertical line identifies the point in

AC), or if defection is played forever by both players once it occur. Last, we also add the share of Always Cooperate that can be distinguished from other match strategies—when AC is played against partners who do defect at least once.

[22]AD accounts for 70% of the repeated-game observations with no fine, and 41% with a fine, while TFT and GT account for 14% and 34% of them.

Figure 2: The disciplining effect of current enforcement

(a) Game level behavior (b) Individual level cooperation



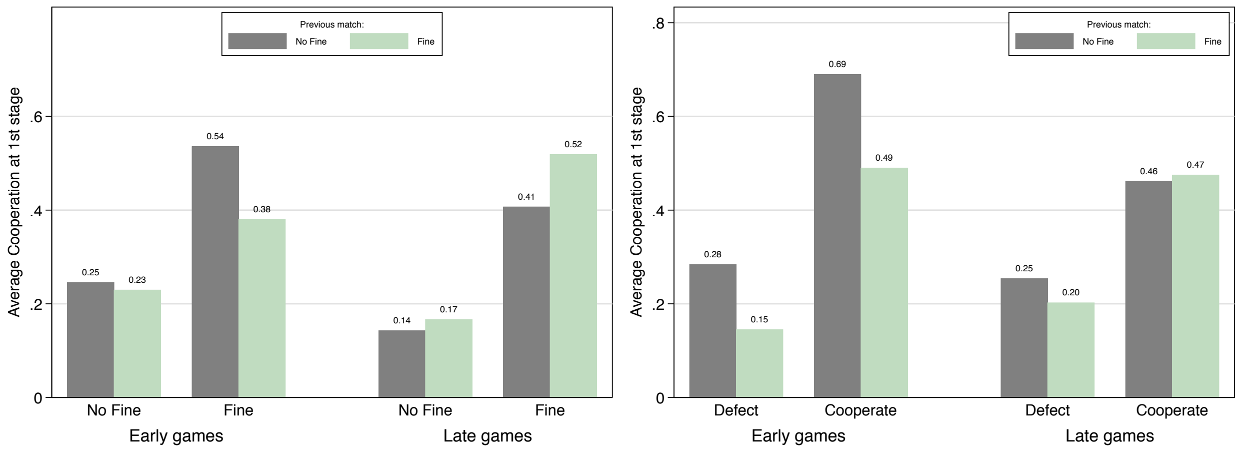
Note. Cooperation observed at first round of each match in the working sample as a function of the current fine. *Left-hand side*: observed evolution over the number of matches played in the past. *Right-hand side*: cumulative distribution of individual cooperation rate at first round of all matches played respectively with and without a fine.

time beyond which we no longer observe a balanced panel—the number of matches played within the duration of the experiment is individual specific, since it depends on game lengths. Time trends beyond this point are strongly driven by the size of the sample. Focusing on the balanced panel, our experiment replicates in both environments the standard decrease in cooperation rates—from 15% at the initial match in the baseline, 69% with a fine, to 11% and 41% at the 13th game. The time trends are parallel between the two conditions. Note that since the history of past institutions is both individual specific and random, it is statistically the same for the two curves for any match number.

Figure 2b organizes the same data at the individual level, based on the cumulative distribution of cooperation in a given environment. We observe variations in both the intensive and the extensive margin of cooperation in the adjustment to the fine—resulting in first order stochastic dominance of the distribution of cooperation with no fine. First, regarding the extensive margin, we observe a switch in the mass probability of subjects who always choose the same first round response: 45% never cooperate with a fine, while only 26% do so with a fine, and the share of subjects who always cooperate raises from 4% to 17% along with the fine. More than half the difference in mass at 0 thus moves to 1. Turning to the intensive margin, the distribution of cooperative decisions with no fine is more concentrated toward the left: 70% of individuals who switch between cooperation and defection cooperate less than 30% of the time with no fine, while it is the case of only 40% of individuals who switch from one match to the other in the fine environment.

Figure 3: The dynamic effects of past enforcement

(a) The effect of past enforcement (b) The effect of the history of play



Note. Cooperation at first stage in the working sample according to the draw of a penalty at previous match. In each figure, the data is split according to whether the match occurs early (before the 7th match) or late. *Left-hand side*: each subpanel refers to current enforcement; *Right-hand side* each sub-panel refers to the partner's decision experienced at previous match.

5 Results

Figure 3 presents graphically the main results that we then examine in detail in the rest of the section. As explained in Section 4, the sequence of matches is classified based on the time at which they occur: observed matches are described as "early" up to the 7^{th}, as late after the 13^{th}.[23] According to the theoretical model, both learning and spillovers explain observed cooperation levels in early games. In late games, by contrast, beliefs about the state of the world should have converged so that changes in behavior in line with the environment should be mainly driven by spillovers.

Figure 3a presents graphical evidence about the effect of the current and past institutional environment in early and late games. We observe that current institutional environment affect cooperation in both instances. In late matches, we also find evidence of legal enforcement spillovers: past enforcement induces a slight increase of cooperation in the current match. This result is reversed in early matches, where past enforcement seem to have a detrimental effect and undermines cooperation in current matches.

Table 2 presents a set of regressions providing more systematic estimates of the effects of current and past institutions. We estimate a Probit model on $C_{it} = \mathbb{1}_{\{a_{it}=C\}} \in \{0,1\}$, the observed decision to cooperate of participant i at the first round of match t in the experiment.[24]

[23] These thresholds are chosen in such a way that one third of the observed decisions are classified as "early", and one third as "late". We use matches, rather than periods, as a measure of time since we focus on games for which the first stage decision summarizes all future actions within the current repeated game—hence ruling out learning within a match. All results are robust to alternative definitions of these thresholds.

[24] The econometric specification of the model is the same as in Section 5.1.

Table 2: Treatment effects of current and past enforcement on cooperation

	(1) Enforcement		(2) Spillovers		(3) Early		(4) Late	
	Coeff.	Marg. Eff.	Coeff.	Marg. Eff.	Coeff.	Marg. Eff.	Coeff.	Marg. Eff.
$\mathbb{1}_{\{F_{it}\}}$	1.147***	0.297***	1.156***	0.299***	0.960**	0.221**	1.620***	0.364***
	(0.178)	(0.054)	(0.170)	(0.052)	(0.409)	(0.086)	(0.287)	(0.070)
$\mathbb{1}_{\{F_{it-1}\}}$			0.088	0.023	-0.237	-0.055	0.241***	0.054**
			(0.055)	(0.014)	(0.180)	(0.042)	(0.085)	(0.021)
N	752	—	752	—	228	—	325	—
σ_u	1.107	—	1.107	—	1.293	—	1.410	—
ρ	0.551	—	0.551	—	0.626	—	0.665	—
LL	-303.910	—	-303.682	—	-101.236	—	-126.385	—

Note. Probit models with individual random effects on the decision to cooperate at first stage estimated on the working sample. Standard errors (in parenthesis) are clustered at the session level. All specifications include control variables for gender, age, whether participant is a student, whether a fine applies to the first match, the decision to cooperate at first match, the length of the previous game and match number. Marginal effects are computed at sample mean, assuming random effects are 0. *Significance levels*: *10%, **5%, ***1%.

Column (1) reports the effect of the current enforcement. In the presence of a fine punishing deviation we observe a 30% increase in the probability of cooperation, this effect is statistically significant. This result is in line with the hypothesis that people respond to the incentives set by formal sanctions and the empirical evidence in the field (Becker, 1968; Drago, Galbiati, and Vertova, 2009). In column (2), we add the effect of the past institutional environment, focusing on the effect of penalties in match $t-1$ on the individual choice to cooperate in match t. The effect of the past institutional environment is positive but not statistically significant, the average increase in cooperation being in the order of 2.3%. Columns (3) and (4) present the effect of current enforcement and institutional spillover in early and late matches, using the same split as in Figure 3. In early matches, where both learning and spillovers are present, past enforcement institutions do not have a statistically significant effect on the individual propensity to cooperate in subsequent matches. In late games, when beliefs about the state of the world should have converged, we can observe a positive and significant institutional spillover effect. Fines in the previous match imply a 5.4% increase in cooperation in the current match. In late games, institutional spillovers from previous matches have an effect on current cooperation equal to 15% of the effect of a current fine.[25]

Figure 3b displays cooperation levels according to the previous history of play. This provides graphical evidence on *(i)* the process of learning in early matches and *(ii)* the presence of indirect spillovers in late matches. In late matches, the cooperation rate among players who faced a cooperative partner in the previous match is twice the cooperation rate of those who faced defectors. This suggests a strong indirect behavioral spillover of cooperation. Importantly, this effect does

[25]The results are robust to an OLS specification instead of a Probit model.

not interact with past enforcement in late matches: the rate of cooperation in the previous match is the same whether or not cooperation resulted from strong legal enforcement. This is indirect evidence validating our distinction of late matches as those where learning converged.

The other lesson we can draw from Figure 3b is that learning do seem to occur in early matches. The effect of past cooperation on the current willingness to cooperate is stronger in early matches if such history occurred in a weak enforcement environment, while the detrimental effect of defection is stronger if experienced with strong enforcement. This is consistent with learning-based dynamics: the amount of information delivered by observing cooperation (defection) from others is higher when it occurs in the absence (presence) of external incentives to do so. The rest of this section confirms the intuitions obtained from the graphical analysis and shows how this combination of learning and behavioral spillovers explain the dynamics of cooperation observed in the experiment. Furthermore, Section 5.2 draws implications for the persistence of institutions.

5.1 The combined effect of learning and institutions: statistical test of the model

The main behavioral insights from the model are summarized by equation (6), which involves both learning and spillover parameters. As discussed in Section 4, these parameters cannot be separately identified. To achieve identification, we assume that behavior in late games is rather described by (5). Denote $\mathbb{1}_{\{\text{Early}\}}$ the dummy variable equal to 1 in early games and to 0 in late games.[26] Under this assumption, the model predicts that behavior in the experiment is described by:

$$P(C_{it}=1) = 1 - \Phi_H \Big[\Lambda_1 + (\Lambda_3 - \Lambda_1)\ \mathbb{1}_{\{\text{Early}\}} - \phi_F\ \mathbb{1}_{\{F_{it-1}=1\}}\ -\ \phi_C\ \mathbb{1}_{\{a_{j_{t-1},t-1}=C\}}\ - \Lambda_2 \mathbb{1}_{\{F_{it}=1\}}$$
$$- (\Lambda_4 - \Lambda_2)\ \mathbb{1}_{\{F_{it}=1\}} \times \mathbb{1}_{\{\text{Early}\}} - \sum_{j,k\in\{0,1\},l\in\{C,D\}} \Lambda^j_{k,l}\ \mathbb{1}_{\{F_{it}=j,F_{it-1}=k,a_{j_{t-1}},t-1=l\}} \times \mathbb{1}_{\{\text{Early}\}} \Big]$$

which is the structural form of a Probit model on the individual decision to cooperate. This probability results from equilibria of the cutoff form involving the primitives of the model. Denoting ε_{it} observation specific unobserved heterogeneity, θ the vector of unknown parameters embedded in the above equation, X_{it} the associated set of observable describing participant i experience up to t and C^*_{it} the latent function generating player i willingness to cooperate at match t, observed decisions inform about the model parameters according to:

$$C_{it} = \mathbb{1}[C^*_{it} = X_{it}\theta + \varepsilon_{it} > 0]$$

[26]Games are defined as early or late in accordance with the descriptive statistics in Section 5: early up the 7^{th} and late beyond the 13^{th}. We disregard data coming from intermediary stages.

The structural parameters govern the latent equation of the model. Our empirical test of the model is thus based on estimated coefficients, $\theta = \frac{\partial C^*}{\partial X}$, rather than marginal effects ($\frac{\partial C}{\partial X} = \theta \frac{\partial \Phi(X\theta)}{\partial X}$).

In the set of covariates, both current ($\mathbb{1}_{\{F_{it}=1\}}$) and past enforcement ($\mathbb{1}_{\{F_{it-1}=1\}}$) are exogenous by design. The partner's past decision to cooperate, C_{jt-1}, is exogenous to C_{it} as long as player i and j have no other player in common in their history. Moreover, due to the rematching of players from one match to the other, between subjects correlation might arise if player j met another player with whom i has already played once. We address these concerns in three ways. We include the decision to cooperate at the first stage of the first match in the set of control variables, as a measure of individual unobserved *ex ante* willingness to cooperate. To further account for the correlation structure in the error of the model, we specify a panel data model with random effects at the individual level, control for the effect of time thanks to the inclusion of the match number, and cluster the errors at the session level to account in a flexible way for within sessions correlation.

Table 3 reports the estimation results from several specifications, in which each piece of the model is introduced sequentially. The parameters of interest are the two spillovers components of individual values, ϕ_F and ϕ_C, and the learning parameters $\Lambda_{k,l}, k \in \{0,1\}, l \in \{C,D\}$.[27] Columns (1) and (2) focus on the effect of past and current enforcement. While we do not find any significant change due to moving from early to late games *per se* (the Early variable is not significant), the effect of current enforcement on the current willingness to cooperate is much weaker in early games. This is consistent with participants becoming less confident that the group is cooperative, thus less likely to cooperate, as time passes—i.e., prior belief over-estimate the average cooperativeness of the group. The disciplining effect of current fines is thus stronger in late games.

Column (3) introduces learning parameters. As stressed in Section 3.4, the learning parameters play a role before beliefs have converged. They are thus estimated in interaction with the Early dummy variable. Once learning is taken into account, enforcement spillovers turn-out significant. More importantly, the model predicts that learning is stronger when observed decisions are more informative about societal values, which in turn depends on the enforcement regime under which behavior has been observed—i.e., cooperation (defection) is more informative under weak (strong) enforcement. This results in a clear ranking between learning parameters—see equation (7). We use defection under weak enforcement as a reference for the estimated learning parameters. The results show that cooperation under weak enforcement (Early $\times\, C_0$) leads to the strongest increase in the current willingness to cooperate. Observing this same decision but under strong enforcement institutions rather than weak ones (Early $\times\, C_1$) has almost the same impact as observing defection under strong institutions (the reference): in both cases, behavior is aligned with the incentives implemented by the rules and barely provides any additional insights about the distribution of values in the group. Last, defection under strong institutions (Early $\times$ D_0) is informative about

[27] Note that we do not separately estimate these parameters according to the current enforcement environment, but rather estimate weighted averages $\Lambda_{k,l} = \mathbb{1}_{\{F_{it}=0\}}\Lambda^0_{k,l} + \mathbb{1}_{\{F_{it}=1\}}\Lambda^1_{k,l}$.

Table 3: Learning and spillovers arising from past enforcement

Variable	*Model parameter*	(1)	(2)	(3)	(4)	(5)
Constant	$(-\Lambda_1)$	-1.986***	-2.020***	-2.290***	-2.302***	-2.291***
		(0.392)	(0.362)	(0.298)	(0.317)	(0.220)
$\mathbb{1}_{\{F_{it}\}}$	(Λ_2)	1.448***	1.454***	1.480***	1.473***	1.472***
		(0.164)	(0.149)	(0.150)	(0.142)	(0.137)
Early	$(-\Lambda_3 + \Lambda_1)$	0.285	0.292	0.348	0.460	0.453
		(0.411)	(0.415)	(0.440)	(0.383)	(0.377)
Early $\times \mathbb{1}_{\{F_{it}\}}$	$(\Lambda_4 - \Lambda_2)$	-0.698***	-0.698***	-0.646**	-0.644**	-0.643**
		(0.243)	(0.245)	(0.258)	(0.261)	(0.271)
$\mathbb{1}_{\{F_{it-1}\}}$	(ϕ_F)		0.049	0.306**	0.094	0.085
			(0.120)	(0.140)	(0.193)	(0.306)
$\mathbb{1}_{\{a_{jt-1}=C\}}$	(ϕ_C)				0.693***	0.674***
					(0.169)	(0.121)
Early $\times C_0$	$(\Lambda_{0,C})$			1.066***	0.430	0.448*
				(0.186)	(0.363)	(0.246)
Early $\times C_1$	$(\Lambda_{1,C})$			0.233	-0.228**	-0.230**
				(0.168)	(0.096)	(0.094)
Early $\times D_1$	$(\Lambda_{1,D})$			-0.876**	-0.631*	-0.621*
				(0.423)	(0.329)	(0.334)
C_1						0.029
						(0.380)
N		553	553	553	553	553
σ_u		1.063	1.064	1.063	1.060	1.060
ρ		0.531	0.531	0.530	0.529	0.529
LL		-234.677	-234.624	-224.416	-220.033	-220.031

Note. Probit models with individual random effects on the decision to cooperate at first stage estimated on the working sample restricted to early (before the 7^{th}) and late (beyond the 13^{th}) games. Standard errors (in parenthesis) are clustered at the session level. All specifications include control variables for gender, age, whether participant is a student, whether a fine applies to the first match, the decision to cooperate at first match, the length of the previous game and match number. *Significance levels*: *10%, **5%, ***1%.

a low willingness to cooperate in the group, and results in a strongly significant drop in current cooperation.

Column (4) adds indirect spillovers, induced by the cooperation of the partner in the previous game. The results confirm that indirect spillovers are stronger than direct spillovers. Once both learning and indirect spillovers are taken into account, we even fail to find a significant effect of past enforcement: most of the apparent effect of past institutions goes through the resulting change in behavior of people exposed to these rules. The identification of learning parameters in this specification is quite demanding since both past enforcement and past cooperation are included as dummy variables in this specification. We nevertheless observe a statistically significant effect of learning in early games, with the expected ordering according to how informative the signal is, with the exception of C_1—i.e., when cooperation has been observed under fines.[28] Finally, column

[28]These results are robust to the variation of the definition of early and late. In particular, when less games are

(5) provides a robustness check for the reliability of the assumption that learning has converged in late games. To that end, we further add the interaction between observed behavior from partner in the previous game and the enforcement regime. Once learning has converged, past behavior is assumed to affect the current willingness to cooperate through indirect spillovers only. Absent learning, this effect should not interact with the enforcement rule that elicited this behavior. As expected, this interaction term is not significant: in late games, it is cooperation per se, rather than the enforcement regime giving rise to this decision, that matters for current cooperation.

5.2 Persistent effect of institutions

As explained in Section 3.3, indirect spillovers, even if they are assumed to be short-living, can induce persistent effects of past institutions. This is highlighted in Proposition 3 based on the comparison between two groups that differ only in their exposition to fines in the very first match. The more exposed is a group, the higher its rate of cooperation in all subsequent matches.

This section provides a direct test of this persistence in the data. The setup of the experiment, that creates individual specific histories of institutional exposure, allows to test persistence based on the effect of the history in match $t-2$. To summarize our results, we show that the fine experienced by player i two matches ago has no effect on her current cooperation rate. On the contrary, if the partner in the previous match experienced a fine two matches ago, this has a strong and significant effect on the current cooperation of i even though i did not experience the fine herself.

First note that in our theoretical model F_{it-2} has no effect on current cooperation in t because direct spillovers are assumed to be short-living. F_{it-2} affects β_{it-1} but does not affect β_{it}, neither directly, nor even indirectly since j_{t-1}, the partner of player i in match $t-1$, does not experience F_{it-2}:

$$\begin{aligned}
\beta_{it-1} &= \beta_i + \phi_F \mathbb{1}_{\{F_{it-2}=1\}} + \phi_C \mathbb{1}_{\{a_{j_{t-2},t-2}=C\}} , \\
\beta_{it} &= \beta_i + \phi_F \mathbb{1}_{\{F_{it-1}=1\}} + \phi_C \mathbb{1}_{\{a_{j_{t-1},t-1}=C\}} .
\end{aligned}$$

On the contrary, $F_{j_{t-1},t-2}$ theoretically affects $a_{j_{t-1},t-1}$ in two ways. On the one hand, player j_{t-1} experienced a direct spillover from match $t-2$ when playing in $t-1$. Second, j_{t-1} is more likely to have experienced indirect spillovers from $t-2$, since $F_{j_{t-1},t-2}$ make it more likely that the partner cooperated at the time. Both these effects imply that j_{t-1} was more likely to cooperate in match $t-1$ thus inducing an indirect spillover for i in t. Note that by construction, player i does not experience the fine $F_{j_{t-1},t-2}$ in match $t-2$.

We empirically test these mechanisms by extending the empirical specification of Table 3 to the inclusion of a dummy variable for F_{it-2} (whether individual i experienced a fine two matches

included in early and late, all the learning parameters have the right ordering and are significant (the results re available upon request).

Table 4: Evidence on the persistence of past institutions

	(1) Direct Spillovers		(2) Persistence		(3) Early		(4) Late	
	Coeff.	Marg. Eff.	Coeff.	Marg. Eff.	Coeff.	Marg. Eff.	Coeff.	Marg. Eff.
$\mathbb{1}_{\{F_{it}\}}$	1.219***	0.307***	1.222***	0.306***	1.181**	0.248***	1.601***	0.359***
	(0.154)	(0.046)	(0.155)	(0.046)	(0.569)	(0.093)	(0.238)	(0.052)
$\mathbb{1}_{\{F_{it-1}\}}$	0.067	0.017	0.070	0.018	-0.203	-0.042	0.229*	0.051*
	(0.086)	(0.022)	(0.090)	(0.023)	(0.313)	(0.069)	(0.124)	(0.029)
$\mathbb{1}_{\{F_{it-2}\}}$	0.157	0.040	-0.039	-0.010	0.230	0.048	-0.183	-0.041
	(0.259)	(0.064)	(0.268)	(0.067)	(0.386)	(0.086)	(0.329)	(0.076)
$\mathbb{1}_{\{F_{j_{t-1},t-2}\}}$			0.300***	0.075***	0.325	0.068	0.250**	0.056**
			(0.091)	(0.020)	(0.475)	(0.093)	(0.120)	(0.028)
N	710	—	710	—	186	—	325	—
σ_u	1.134	—	1.152	—	1.451	—	1.423	—
ρ	0.562	—	0.570	—	0.678	—	0.669	—
LL	-283.305	—	-281.957	—	-79.588	—	-126.022	—

Note. Probit models with individual random effects on the decision to cooperate at first stage estimated on the working sample. Standard errors (in parenthesis) are clustered at the session level. All specifications include control variables for gender, age, whether participant is a student, whether a fine applies to the first match, the decision to cooperate at first match, the length of the previous game and match number. Marginal effects are computed at sample mean, assuming random effects are 0. *Significance levels*: *10%, **5%, ***1%.

before) and for $F_{j_{t-1},t-2}$ (whether the partner in match $t-1$ experienced a fine in his $t-2$ match). The results are provided in Table 4. Column (1) shows that the fine experienced by player i two matches ago has no effect on her current cooperation rate. This provides an indirect validation of our assumption that the direct spillover is a short term effect on preferences as expressed in equation (1). Column (2) adds the effect of $F_{j_{t-1},t-2}$. The effect is positive and significant: if the partner in the previous match experienced a fine two matches ago, player i is more likely to cooperate even though i did not experience the fine herself. Columns (3) and (4) split the estimation between early and late matches. Since we need to track the history two matches before, the number of observations is smaller for early matches in this specification. The magnitude of the effect is however similar in early and late matches, which is consistent with learning in early matches, since player i does not experience directly $F_{j_{t-1},t-2}$, this fine does not affect the learning process. Focusing on late matches, in which the sample size is the same as in previous specifications, we find that if the partner of i in $t-1$ experienced a fine in $t-2$ then the cooperation of i increases by 6%.

Table 4 clearly shows that the assumption that direct spillovers are short lasting, i.e. that F_{it-2} has no impact on β_{it}, is validated in the data. We now examine whether indirect spillovers are also short lasting. Table 5 introduces the past history of cooperation to this effect. Column (1), in coherence with Table 4, shows that the number of fines in a row experienced in the past

Table 5: Speed of decay of indirect spillovers

	(1) Direct spillovers		(2) Cumulative indirect spillovers		(3) Lagged indirect spillovers	
	Coeff.	Marg. Eff.	Coeff.	Marg. Eff.	Coeff.	Marg. Eff.
$\mathbb{1}_{\{F_{it}\}}$	1.615***	0.365***	1.636***	0.361***	1.675***	0.358***
	(0.276)	(0.063)	(0.282)	(0.056)	(0.316)	(0.056)
F_{it} in a row	0.058	0.013	0.019	0.004	0.019	0.004
	(0.077)	(0.017)	(0.106)	(0.023)	(0.119)	(0.025)
$a_{jt} = C$ in a row			0.202***	0.045***	-0.037	-0.008
			(0.037)	(0.006)	(0.063)	(0.014)
$\mathbb{1}_{\{a_{jt-1}=C\}}$					0.588***	0.126***
					(0.117)	(0.032)
$\mathbb{1}_{\{a_{j_{t-2},t-2}=C\}}$					0.511**	0.109**
					(0.204)	(0.051)
$\mathbb{1}_{\{a_{j_{t-3},t-3}=C\}}$					0.182**	0.039**
					(0.092)	(0.017)
N	325	—	325	—	325	—
σ_u	1.402	—	1.346	—	1.319	—
ρ	0.663	—	0.644	—	0.635	—
LL	-126.631	—	-124.323	—	-121.671	—

Note. Probit models with individual random effects on the decision to cooperate at first stage estimated on the working sample. Standard errors (in parenthesis) are clustered at the session level. All specifications include control variables for gender, age, whether participant is a student, whether a fine applies to the first match, the decision to cooperate at first match, the length of the previous game and match number. Marginal effects are computed at sample mean, assuming random effects are 0. *Significance levels*: *10%, **5%, ***1%.

has no effect on current cooperation, while column (2) shows that the number of partners who cooperated in a row has a significant and large effect. Column (3) breaks up this effect and shows that indirect spillovers are long lasting: not only does the behavior of the partner $a_{j_{t-1},t-1}$ in the previous match matter, but also the behavior of the partner two and three matches ago $a_{j_{t-2},t-2}$ and $a_{j_{t-3},t-3}$. This creates an additional channel for the persistent effect of institutions: indirect spillovers do not only have snowball effects, they also have long lasting effects.

6 Conclusion

An emerging literature studies how institutions affect individual choices over and beyond shaping incentives when they are present (e.g., Guiso, Sapienza, and Zingales, 2016; Fisman and Miguel, 2007). This paper focuses on situations in which individuals interact without knowing each others' propensity to cooperate. In these situations, institutions that enforce cooperation affect individuals' capacity to make inferences about the prevalent types in the society and, as a consequence, their propensity to cooperate. At the same time, the institutional environment can affect directly individuals' propensity to cooperate through two kinds of spillover effects: direct ones, arising from past institutions, and indirect ones, arising from past behavior of others.

We analyze this situation through the lens of a theoretical model tailored to interpret the results from an experiment where individuals play a series of infinitely repeated games with random re-matching. Our experimental data provides strong support for the main behavioral insights of the model. The institutional environment affects the dynamics of learning about others' and creates spillovers affecting individuals' cooperation. We show that indirect spillovers are particularly important and have long lasting effects. Furthermore we show that they can cause persistent effects of institutions: stronger institutions in the past, increase cooperation in the past and by a snowball effect, also increase cooperation in later periods.

Our identification strategy relies on the fact that histories of institutional exposures and behavior of partners are individual specific. To separately identify spillovers from learning, we assume that in late matches, learning has converged. The next step in our research agenda is to specify a full structural model of learning that will allow us to dispense with this assumption.

References

Acemoglu, D., and M. O. Jackson (2015): "History, Expectations, and Leadership in the Evolution of Social Norms," *Review of Economic Studies*, 82(2), 423–456.

——— (2017): "Social Norms and the Enforcement of Laws," *Journal of the European Economic Association*, 15(2), 245–295.

Alesina, A., and P. Giuliano (2017): "Culture and Institutions," *Journal of Economic Literature*, Forthcoming.

Becker, G. S. (1968): "Crime and Punishment: An Economic Approach," *Journal of Political Economy*, 76(2), 169–217.

Benabou, R., and J. Tirole (2011): "Laws and Norms," *NBER WP*, 17579.

Bisin, A., and T. Verdier (2001): "The Economics of Cultural Transmission and the Dynamics of Preferences," *Journal of Economic Theory*, 97(2), 298–319.

Bowles, S., and S. Polania-Reyes (2012): "Economic Incentives and Social Preferences: Substitutes or Complements?," *Journal of Economic Literature*, 50(2), 368–425.

Cassar, A., G. d'Adda, and P. Grosjean (2014): "Institutional Quality, Culture, and Norms of Cooperation: Evidence from Behavioral Field Experiments," *Journal of Law & Economics*, 57(3), 821–863.

Dal Bó, E., and P. Dal Bó (2014): "'Do the right thing': The effects of moral suasion on cooperation," *Journal of Public Economics*, 117, 28–38.

Dal Bó, P., and G. R. Fréchette (2011): "The Evolution of Cooperation in Infinitely Repeated Games: Experimental Evidence," *American Economic Review*, 101(1), 411–29.

Dal Bó, P., and G. R. Fréchette (2017): "On the Determinants of Cooperation in Infinitely Repeated Games: A Survey," *Journal of Economic Literature*, Forthcoming.

Dohmen, T., A. Falk, D. Huffman, U. Sunde, J. Schupp, and G. G. Wagner (2011): "Individual risk attitudes: Measurement, determinants, and behavioral consequences," *Journal of the European Economic Association*, 9(3), 522–550.

Drago, F., R. Galbiati, and P. Vertova (2009): "The Deterrent Effects of Prison: Evidence from a Natural Experiment," *Journal of Political Economy*, 117(2), 257–280.

Fisman, R., and E. Miguel (2007): "Corruption, Norms, and Legal Enforcement: Evidence from Diplomatic Parking Tickets," *Journal of Political Economy*, 115(6), 1020–1048.

Guiso, L., P. Sapienza, and L. Zingales (2016): "Long-Term Persistence," *Journal of the European Economic Association*, 14(6), 1401–1436.

Lowes, S., N. Nunn, J. A. Robinson, and J. Weigel (2015): "The Evolution of Culture and Institutions: Evidence from the Kuba Kingdom," *NBER WP*, 21798.

Nowak, M. A., and S. Roch (2007): "Upstream reciprocity and the evolution of gratitude," *Proceedings of the Royal Society of London B: Biological Sciences*, 274(1610), 605–610.

Peysakhovich, A., and D. G. Rand (2016): "Habits of Virtue: Creating Norms of Cooperation and Defection in the Laboratory," *Management Science*, 62(3), 631–647.

Sliwka, D. (2007): "Trust as a Signal of a Social Norm and the Hidden Costs of Incentive Schemes," *American Economic Review*, 97(3), 999–1012.

Tabellini, G. (2008): "The Scope of Cooperation: Values and Incentives," *Quarterly Journal of Economics*, 123(3), 905–950.

——— (2010): "Culture and Institutions: Economic Development in the Regions of Europe," *Journal of the European Economic Association*, 8(4), 677–716.

van der Weele, J. (2009): "The Signaling Power of Sanctions in Social Dilemmas," *Journal of Law, Economics, and Organization*, 28(1), 103–126.

Appendix

A Proofs

Proof of Proposition 1

As derived in the main text, if an equilibrium exists, it is necessarily such that players use cutoff strategies. Reexpressing characteristic equation (3), we can show that the cutoffs are determined by the equation $g(\beta^*[F_{it})] = 0$, where g is given by

$$g(x) = -x \ + \ \Pi_1 - F \ \mathbb{1}_{\{F_{it}=1\}} \ + \ (1 - \Phi_H(x)) \left[\Pi_2 \ - \ \frac{\delta}{1-\delta} \left(F \ \mathbb{1}_{\{F_{it}=1\}} + \Pi_3 \right) \right] .$$

The function g has the following properties: $g(x) > 0$ when x converges to $-\infty$ and $g(x) < 0$ when x converges to $+\infty$. Thus, since g is continuous, there is at least one solution to the equation $g(\beta^*[F_{it})] = 0$. At least one equilibrium exists.

If g is non monotonic, there could exist multiple equilibria. However, in all stable equilibria, β^* is such that g is decreasing at β^*, i.e.

$$-1 - \phi_H[\beta^*] \left[\Pi_2 \ - \ \frac{\delta}{1-\delta} \left(F \ \mathbb{1}_{\{F_{it}=1\}} + \Pi_3 \right) \right] < 0 \ . \tag{8}$$

Using the implicit theorem we have:

$$\frac{\partial \beta^*}{\partial F} = -\frac{\partial g}{\partial F} \Big/ \frac{\partial g}{\partial \beta^*} = -\frac{-1 - (1 - \Phi_H[\beta^*]) \frac{\delta}{1-\delta}}{-1 - \phi_H[\beta^*] \left[\Pi_2 \ - \ \frac{\delta}{1-\delta} \left(F \ \mathbb{1}_{\{F_{it}=1\}} + \Pi_3 \right) \right]} \ ,$$

where ϕ_H is the density corresponding to distribution Φ_H. For stable equilibria, the denominator is negative as shown in (8), so that overall

$$\frac{\partial \beta^*}{\partial F} < 0 \ .$$

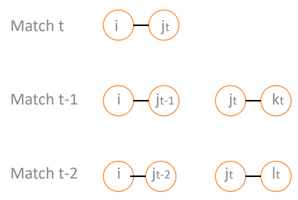
Similarly,

$$\frac{\partial \beta^*}{\partial \mu_H} \quad = \quad -\frac{-\frac{\partial \Phi_H[\beta^*]}{\partial \mu_H} \left[\Gamma_2 \ - \ \frac{\delta}{1-\delta} \left(F \ \mathbb{1}_{\{F_{it}=1\}} + \Pi_3 \right) \right]}{-1 - \phi_H[\beta^*] \left[\Pi_2 \ - \ \frac{\delta}{1-\delta} \left(F \ \mathbb{1}_{\{F_{it}=1\}} + \Pi_3 \right) \right]} \ .$$

Again, in stable equilibria the denominator is negative by (8). Furthermore we have $\frac{\partial \Phi_H[\beta^*]}{\partial \mu_H} < 0$ since an increase in the mean of the normal distribution decreases $\Phi_H[x]$ for any x. Overall we get

$$\frac{\partial \beta^*}{\partial \mu_H} < 0 \ .$$

Figure 4: Notations for player's partner and decision time



Proof of Proposition 2

We establish the existence of a stationary equilibrium. As derived in the main text, if an equilibrium exists, it is necessarily such that players use cutoff strategies, where the cutoff is defined by equation (4):

$$\beta^*(F_{it}) \;=\; \Pi_1 - F\,\mathbb{1}_{\{F_{it}=1\}} \;+\; p^*(F_{it})\left[\Pi_2 \;-\; \frac{\delta}{1-\delta}\left(F\,\mathbb{1}_{\{F_{it}=1\}} + \Pi_3\right)\right] .$$

We now determine the probabilities of cooperation $p^*(1)$ and $p^*(0)$ of the partner in the current match, player j_t who interacted with individual k_t in the previous match (see Figure 4 for a graphical presentation of our notations). The probability individual j_t cooperates depends on whether he faced a fine in the previous period and whether the individual k_t cooperated:

$$\begin{aligned} p^*(F_{it}) &= P[a_{j_t,t} = C|F_{it}] \\ &= \sum_{(F_{j_t,t-1}\in\{0,1\},a_{k_t,t-1}\in\{C,D\})} \left[1 - \Phi_H\left[\beta^*(F_{it}) - \phi_F\,\mathbb{1}_{\{F_{j_t,t-1}=1\}} \;-\; \phi_C\,\mathbb{1}_{\{a_{k_t,t-1}=C\}}\right]\right] \\ &\qquad \times P[F_{j_t,t-1}, a_{k_t,t-1}]. \end{aligned}$$

Furthermore, since we focus on stable equilibria, using the fact that j_t and k_t faced the same institution in the previous period (i.e. $F_{j_t,t-1} = F_{k_t,t-1}$), we have that $P[F_{j_t,t-1}, a_{k_t,t-1}]$ can be derived as

$$\begin{aligned} P[1,C] &= P[F_{j_t,t-1} = 1]P[a_{k_t,t-1} = C|F_{k_t,t-1} = 1] = \frac{1}{2}p^*(1) , \\ P[0,C] &= P[F_{j_t,t-1} = 0]P[a_{k_t,t-1} = C|F_{k_t,t-1} = 0] = \frac{1}{2}p^*(0) , \\ P[1,D] &= P[F_{j_t,t-1} = 1]P[a_{k_t,t-1} = D|F_{k_t,t-1} = 1] = \frac{1}{2}(1-p^*(1)) , \\ P[0,D] &= P[F_{j_t,t-1} = 0]P[a_{k_t,t-1} = D|F_{k_t,t-1} = 0] = \frac{1}{2}(1-p^*(0)) . \end{aligned}$$

So we have:

$$\begin{aligned} p^*(F_{it}) \;&=\; [1-\Phi_H[\beta^*(F_{it}) - \phi_F - \phi_C]]\,\frac{1}{2}p^*(1) \;+\; [1-\Phi_H[\beta^*(F_{it}) - \phi_F]]\,\frac{1}{2}[1-p^*(1)] \\ &+\; [1-\Phi_H[\beta^*(F_{it}) - \phi_C]]\,\frac{1}{2}p^*(0) \;+\; [1-\Phi_H[\beta^*(F_{it})]]\,\frac{1}{2}[1-p^*(0)] . \end{aligned} \tag{9}$$

The equilibrium, if it exists, is thus defined by the solution of the following system of equations, defined by equation (4) with and without fines, and by equation (15) above, using the fact that $p^*(1)$ and $p^*(0)$ are functions of $\beta^*(1)$ and $\beta^*(0)$

$$A = \begin{cases} \beta^*(1) - \quad \Big[\Pi_1 - F \ + \ p^*(1)\left[\beta^*(0), \beta^*(1)\right]\Pi_2 \ - \frac{\delta}{1-\delta} p^*(1)\left[F + \Pi_3\right]\Big] = 0 \\ \\ \beta^*(0) - \quad \Big[\Pi_1 \ + \ p^*(0)\left[\beta^*(0), \beta^*(1)\right]\Pi_2 \ - \frac{\delta}{1-\delta} p^*(0)\Pi_3\Big] = 0 \end{cases}$$

Given that $p^*(1)$ is bounded between 0 and 1, when $\beta^*(0)$ goes from $-\infty$ to $+\infty$, $\beta^*(1)$, solution to the first equation remains bounded. Similarly, given that $p^*(0)$ is bounded between 0 and 1, when $\beta^*(1)$ goes from $-\infty$ to $+\infty$, $\beta^*(0)$, solution to the second equation remains bounded. This implies that in the space $[\beta^*(0), \beta^*(1)]$, the two curves intersect at least once and there therefore exists a stationary equilibrium.

Proof of Proposition 3

We show the result recursively, proving that since more individuals cooperated in the first match in group 1 than in group 2 because of the fines, this effect spills over to later matches.

Denote $p_t^g(F)$ the equilibrium probability that a random individual i of group g cooperates in match t if facing F and denote $P_t^g[F, a]$ the probability that i experienced F in the previous period ($F_{it-1} = F$) and faced a player j_{t-1} who played a ($a_{j_{t-1},t-1} = a$)

We establish the recursive property: $p_t^1(F_{it}) > p_t^2(F_{it})$ for $F_{it} \in \{0, 1\}$ and $t \geq 2$.

We assume the property is true for match $t-1$ and establish it for match t. The probability that a random individual i of group g cooperates is given by:

$$\begin{aligned} p_t^g(F_{it}) \quad &= \sum_{(F_{it-1}\in\{0,1\}, a_{j_{t-1},t-1}\in\{C,D\})} \Big[1 - \Phi_H\Big[\beta^*(F_{it}) - \phi_F \ \mathbb{1}_{\{F_{it-1}=1\}} \ - \ \phi_C \ \mathbb{1}_{\{a_{j_{t-1},t-1}=C\}}\Big]\Big] \\ &\qquad \times \ P_{t-1}^g[F_{it-1}, a_{j_{t-1},t-1}] \ . \end{aligned}$$

This expression can be rearranged as:

$$\begin{aligned} p_t^g(F_{it}) \quad &= \quad \frac{1}{2}\left(1 - \Phi_H\left[\beta^*(F_{it}) - \phi_F\right]\right) + \frac{1}{2}\left(1 - \Phi_H\left[\beta^*(F_{it})\right]\right) \\ &+ \quad \frac{1}{2}\left(\Phi_H\left[\beta^*(F_{it}) - \phi_F\right] - \Phi_H\left[\beta^*(F_{it}) - \phi_F - \phi_C\right]\right) \ p_{t-1}^g(1) \\ &+ \quad \frac{1}{2}\left(\Phi_H\left[\beta^*(F_{it})\right] - \Phi_H\left[\beta^*(F_{it}) - \phi_C\right]\right) \ p_{t-1}^g(0) \ . \end{aligned}$$

We have:

$$\Phi_H\left[\beta^*(F_{it}) - \phi_F\right] > \Phi_H\left[\beta^*(F_{it}) - \phi_F - \phi_C\right] \ ,$$
$$\Phi_H\left[\beta^*(F_{it})\right] > \Phi_H\left[\beta^*(F_{it}) - \phi_C\right] \ .$$

So that indeed, using the recursive property for match $t-1$, the recursive property is established for match t: $p_t^1(F) > p_t^2(F)$.

Proof of Lemma 1

We first show the result: $q_{i2}(1,D) < q_{i2}(0,D) < q$. According to Baye's rule, the belief that the state is H following a deviation by the partner in the first match (which has been played with a fine) is:

$$\begin{aligned} q_{i2}(1,D) &= \frac{q\ P[D|F_{i1}=1,s=H]}{q\ P[D|F_{i1}=1,s=H]+(1-q)\ P[D|F_{i1}=1,s=L]} \\ &= \frac{q\ \Phi_H\left[\beta^*(1)\right]}{q\ \Phi_H\left[\beta^*(1)\right]+(1-q)\ \Phi_L\left[\beta^*(1)\right]} \\ &= \frac{1}{1+\frac{1-q}{q}\ \frac{\Phi_L[\beta^*(1)]}{\Phi_H[\beta^*(1)]}}\ . \end{aligned} \tag{10}$$

Furthermore, since $\Phi_L\left[\beta^*(1)\right] > \Phi_L\left[\beta^*(1)\right]$, we have $q_{i2}(1,D) > q$. Similarly we have:

$$q_{i2}(0,D) = \frac{1}{1+\frac{1-q}{q}\ \frac{\Phi_L[\beta^*(0)]}{\Phi_H[\beta^*(0)]}} > q\ . \tag{11}$$

Thus,

$$q_{i2}(1,D) < q_{i2}(0,D) \Leftrightarrow \frac{\Phi_L\left[\beta^*(0)\right]}{\Phi_H\left[\beta^*(0)\right]} < \frac{\Phi_L\left[\beta^*(1)\right]}{\Phi_H\left[\beta^*(1)\right]}\ .$$

Using the fact that $\frac{\Phi_L[x]}{\Phi_H[x]}$ is decreasing in x as shown in Property 1 below, and the fact that in stable equilibria, we have $\beta^*(1) \leq \beta^*(0)$, as shown in Proposition 1, implies directly that $q_{i2}(1,D) < q_{i2}(0,D)$. The proof that $q_{i2}(0,C) > q_{i2}(1,C) > q$ follows similar lines.

Property 1 $\frac{\Phi_H[x]}{\Phi_L[x]}$ *is increasing in* x.

Proof. Denote ϕ_H (resp. ϕ_L) the density of Φ_H (resp. Φ_L). Given that ϕ_H (resp. ϕ_L) is the density of a normal distribution with standard deviation σ and mean μ_H (resp. μ_L), it is the case that:

$$\begin{aligned} \frac{\phi_H\left[x\right]}{\phi_L\left[x\right]} &= \frac{\frac{1}{\sigma\sqrt{2\pi}}e^{-(x-\mu_H)^2/\sigma^2}}{\frac{1}{\sigma\sqrt{2\pi}}e^{-(x-\mu_L)^2/\sigma^2}} \\ &= e^{-(x-\mu_H)^2/\sigma^2+(x-\mu_L)^2/\sigma^2} \\ &= e^{\frac{1}{\sigma^2}(\mu_H-\mu_L)(2x-\mu_L-\mu_H)}\ . \end{aligned}$$

Thus $\frac{\phi_H}{\phi_L}$ is increasing in x. In particular for $y < x$, we have: $\phi_H\left[y\right]\phi_L\left[x\right] < \phi_L\left[y\right]\phi_H\left[x\right]$. By definition, $\Phi_s(x) = \int_{-\infty}^{x}\phi_s(y)dy$. Integrating with respect to y between $-\infty$ and x thus yields:

$$\Phi_H\left[x\right]\phi_L\left[x\right] < \Phi_L\left[x\right]\phi_H\left[x\right]\ . \tag{12}$$

Consider now the function $\frac{\Phi_H}{\Phi_L}$. The derivative of this function is given by $\frac{\phi_H\Phi_L-\phi_L\Phi_H}{\Phi_L^2}$, which is positive by equation (12). This establishes Property 1 that $\frac{\Phi_H[x]}{\Phi_L[x]}$ is increasing in x. ■

Proof of Proposition 4

In the first part of the proof we assume a stationary equilibrium exists and is such that the equilibrium cutoffs are always higher without a fine in the current match $\beta^*(0,q) > \beta^*(1,q)$ for any given belief q. We then derive the property on updating of beliefs. In the second part of the proof we show existence under a natural restriction on beliefs.

Part 1: We first derive the properties on updating. We have

$$q_{it}(F_{it-1}, a_{j_{t-1},t-1}, q_{it-1}) = \frac{q_{it-1}P[a_{j_{t-1},t-1}|F_{it-1}, s = H]}{q_{it-1}P[a_{j_{t-1},t-1}|F_{it-1}, s = H] + (1 - q_{it-1})P[a_{j_{t-1},t-1}|F_{it-1}, s = L]} \ . \tag{13}$$

We can express the probability that the partner j_{t-1} in match $t-1$ cooperated, by considering all the possible environments this individual might have faced in the past, in particular what his partner in match $t-2$, individual k_{t-1} chose:

$$\begin{aligned} P[a_{j_{t-1},t-1} = D \quad | \quad & F_{it-1}, s = H] = \\ & \sum_{F_{j_{t-1},t-2}, a_{k_{t-1},t-2}, q_{j_{t-1},t-1}} \Phi_H \left[\beta^*(1, q_{j_{t-1},t-1}) - \phi_F \ \mathbb{1}_{\{F_{j_{t-1},t-2}=1\}} \ - \ \phi_C \ \mathbb{1}_{\{a_{k_{t-1},t-2}=C\}}\right] \\ & \qquad \times \ P[F_{j_{t-1},t-2}, a_{k_{t-1},t-2}, q_{j_{t-1},t-1}]. \end{aligned}$$

Denote

$$\gamma^* \left(F_{j_{t-1},t-2}, a_{k_{t-1},t-2}, q_{j_{t-1},t-1}\right) = \beta^*(1, q_{j_{t-1},t-1}) - \phi_F \ \mathbb{1}_{\{F_{j_{t-1},t-2}=1\}} \ - \ \phi_C \ \mathbb{1}_{\{a_{k_{t-1},t-2}=C\}}.$$

and

$$R(x) \equiv \frac{\sum_{F_{j_{t-1},t-2}, a_{k_{t-1},t-2}, q_{j_{t-1},t-1}} \Phi_H \left[\gamma^* \left(x, a_{k_{t-1},t-2}, q_{j_{t-1},t-1}\right)\right] P[F_{j_{t-1},t-2}, a_{k_{t-1},t-2}, q_{j_{t-1},t-1}]}{\sum_{F_{j_{t-1},t-2}, a_{k_{t-1},t-2}, q_{j_{t-1},t-1}} \Phi_L \left[\gamma^* \left(x, a_{k_{t-1},t-2}, q_{j_{t-1},t-1}\right)\right] P[F_{j_{t-1},t-2}, a_{k_{t-1},t-2}, q_{j_{t-1},t-1}]} \ .$$

Using expression (13), we have: $q_{it}(1, D, q_{it-1}) < q_{it}(0, D, q_{it-1}) \Leftrightarrow R(1) \geq R(0)$. We then use all possible values of the vector $(F_{j_{t-1},t-2}, a_{k_{t-1},t-2}, q_{j_{t-1},t-1})$ in turn. Take such a value v for this vector and denote

$$\begin{aligned} a \equiv & \sum_{(F_{j_{t-1},t-2}, a_{k_{t-1},t-2}, q_{j_{t-1},t-1}) \neq v} \Phi_H \left[\gamma^* \left(x, a_{k_{t-1},t-2}, q_{j_{t-1},t-1}\right)\right] P[F_{j_{t-1},t-2}, a_{k_{t-1},t-2}, q_{j_{t-1},t-1}] \ , \\ b \equiv & \sum_{(F_{j_{t-1},t-2}, a_{k_{t-1},t-2}, q_{j_{t-1},t-1}) \neq v} \Phi_L \left[\gamma^* \left(x, a_{k_{t-1},t-2}, q_{j_{t-1},t-1}\right)\right] P[F_{j_{t-1},t-2}, a_{k_{t-1},t-2}, q_{j_{t-1},t-1}] \ . \end{aligned}$$

We clearly have $a < b$. Furthermore, we can write

$$R(x) \equiv \frac{a + \Phi_H \left[\gamma^* \left(v\right)\right] P[v]}{b + \Phi_L \left[\gamma^* \left(v\right)\right] P[v]}$$

We have $\beta^*(0,q) > \beta^*(1,q)$ imply that $\gamma^* \left(0, a_{k't-2}, q_{j't-1}\right) > \gamma^* \left(1, a_{k't-2}, q_{j't-1}\right)$. Thus using Property 2 below, it implies that $R(1) \geq R(0)$ and thus $q_{it}(1, D, q_{it-1}) < q_{it}(0, D, q_{it-1})$.

Property 2 $\frac{a+p\Phi_H[x]}{b+p\Phi_L[x]}$ *where $b > a$ is increasing in x.*

Proof. The derivative of the ratio is given by

$$\frac{\phi_H\left(b+p\Phi_L\right)-\phi_L\left(a+p\Phi_H\right)}{\left(b+p\Phi_L\right)^2} \tag{14}$$

We showed in the proof of Property 1 that: $\phi_H\Phi_L - \phi_L\Phi_H > 0$. Furthermore, we also showed that $\frac{\phi_H}{\phi_L}$ is increasing and since $a < b$ this implies: $\phi_H b - \phi_L a > 0$. Combining these two results in condition (14) establishes Property 2. ■

Part 2: We show that an equilibrium exists if we assume that a player who has belief q_{it} in match t believes that other players in match t and $t-1$ shared the same belief $q_{j_t,t} = q_{k_t,t} = q_{it}$. If a stationary equilibrium exists, it is necessarily such that players use cutoff strategies where the cutoff is defined by:

$$\beta_t^*(F_{it}, q_{it}) \quad = \quad \Pi_1 - F\ \mathbb{1}_{\{F_{it}=1\}} \ + \ p_t^*(F_{it}, q_{it})\left[\Pi_2 \ - \ \frac{\delta}{1-\delta}\left(F\ \mathbb{1}_{\{F_{it}=1\}} + \Pi_3\right)\right]$$

We have:

$$\begin{aligned}
p_t^*(F_{it}, q_{it}) \quad &= \quad P[a_{j_t,t} = C|F_{it}, q_{it}] \\
&= \quad q_{it} \sum_{(F_{j_t,t-1}, a_{k_t,t-1}, q_{j_t,t-1})} \left[1 - \Phi_H\left[\beta^*(F_{j_t,t}, q_{j_t,t-1}) - \phi_F\ \mathbb{1}_{\{F_{j_t,t-1}=1\}} \ - \ \phi_C\ \mathbb{1}_{\{a_{k_t,t-1}=C\}}\right]\right] \\
&\qquad \times P[F_{j_t,t-1}, a_{k_t t-1}, q_{j_t,t-1}|s = H] \\
&+ \quad (1-q_{it}) \sum_{(F_{j_t,t-1}, a_{k_t,t-1}, q_{j_t,t-1})} \left[1 - \Phi_L\left[\beta^*(F_{j_t,t}, q_{j_t,t-1}) - \phi_F\ \mathbb{1}_{\{F_{j_t,t-1}=1\}} \ - \ \phi_C\ \mathbb{1}_{\{a_{k_t,t-1}=C\}}\right]\right] \\
&\qquad \times P[F_{j_t,t-1}, a_{k_t t-1}, q_{j_t,t-1}|s = L]
\end{aligned}$$

Furthermore, we have

$$\begin{aligned}
P[F_{j_t,t-1}, a_{k_t,t-1}, q_{j_t,t-1}|s = H] \quad &= \quad P[F_{j_t,t-1}]\ P[a_{k_t,t-1}|F_{j_t,t-1}, s = H]\ f_t(q_{j_t,t-1}|s = H) \\
&= \quad \frac{1}{2}\ P[a_{k_t,t-1}|F_{j_t,t-1}, s = H]\ f_t(q_{j_t,t-1}|s = H)
\end{aligned}$$

we assumed that a player who had belief q_{it-1} in match $t-1$ believes that all other players in that match share the same belief q_{it-1}. Under this restriction, we have $f_t(q_{j't-1}|s = .) = \mathbb{1}_{(q_{j't-1}=q_{it-1})}$

$$P[1, D, q|s = H] \quad = \quad \frac{1}{2}\ p_t^*(1, q)$$

We get a similar expression as in the proof of Proposition 2:

$$\begin{aligned}
p^*(F_{it}, q_{it}) \quad &= \quad \left[1 - \Phi_H\left[\beta^*(F_{it}, q_{it}) - \phi_F - \phi_C\right]\right]\frac{1}{2}p^*(1, q_{it}) \ + \ \left[1 - \Phi_H\left[\beta^*(F_{it}, q_{it}) - \phi_F\right]\right]\frac{1}{2}[1 - p^*(1, q_{it})] \\
&+ \quad \left[1 - \Phi_H\left[\beta^*(F_{it}, q_{it}) - \phi_C\right]\right]\frac{1}{2}p^*(0, q_{it}) \ + \ \left[1 - \Phi_H\left[\beta^*(F_{it}, q_{it})\right]\right]\frac{1}{2}[1 - p^*(0, q_{it})]\ .
\end{aligned} \tag{15}$$

This implies that for each belief q, there is a system of equation equivalent to system A in the proof if Proposition 2. We thus have a solution of this system for each value q.