Accepted: 10 June 2024

DOI: 10.1111/ecca.12539

ORIGINAL ARTICLE

Economica LSE

Endogenous monitoring through voluntary reporting in an infinitely repeated prisoner's dilemma game: experimental evidence

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Abstract

Exogenous reputational information is known to improve cooperation. This study experimentally investigates how people create such information by reporting their partner's action choices, and whether endogenous monitoring helps to sustain cooperation, in an indefinitely repeated prisoner's dilemma game with random matching. The experimental results show that most subjects report their opponents' action choices, thereby successfully cooperating when reporting does not involve costs. However, when reporting is costly, participants are strongly discouraged from doing so. Consequently, they fail to achieve strong cooperative norms when the reported information is conveyed privately only to their next-round interaction partners. Costly reporting occurs only occasionally even when there is a public record whereby all future partners can check the reported information, but significantly more frequently relative to the condition in which it is sent to the next partner only. With public records, groups can foster cooperative norms aided by reported information that gradually accumulates and becomes more informative over time.

1 | INTRODUCTION

Simultaneous-move interactions in which cooperation is beneficial from a long-term perspective but individuals have strong short-term incentives to defect are ubiquitous in real life, such as in economic transactions in online markets. Public monitoring may play a key role into facilitating cooperation in such interactions, thereby enabling members to implement effective punishment strategies (Mailath and Samuelson 2006). Reputational information must be created gradually through motivated actors' voluntary reporting of partners' behaviours for signalling and public monitoring, as many interactions are made privately.

The burgeoning experimental literature on cooperation in infinitely repeated dilemma games with random matching has largely confirmed the strong impact of exogenously given reputational information on sustaining cooperation under certain conditions (e.g. Camera and Casari 2009; Kamei 2017; Stahl 2013; Schwartz *et al.* 2000).[1,2] But where does reputational information originate from? There have been recent successful scholar investigations of people's possible *endogenous* formation of reputational information, suggesting that community members can effectively create information and achieve high cooperation norms by voluntarily disclosing their own identifiable information (Kamei 2017) or by acquiring partners' history information at private costs (Duffy *et al.* 2013). However, this also suggests that while information sharing through emotion- or preference-triggered costly reporting of partners' cheating or opportunistic behaviour is ubiquitous (Kamei and Putterman 2018), such reporting alone may not be enough to sustain cooperation (Camera and Casari 2018). Specifically, in Camera and Casari (2018), allowing 'buyer' subjects (which have no action to take) in a helping game to pay a cost to convey the actions of their matched 'sellers' (cooperate or defect) to the partners' future counterparts is not enough to improve cooperation, with which the authors conclude that 'information about past conduct alone thus appears to be ineffective in overcoming coordination challenges'. This result is at odds with real-world observations that users overcome trust problems in online markets (such as eBay, Uber and Airbnb) by relying on feedback mechanisms (Dellarocas 2003). What makes the voluntary reporting function effective on such online platforms?

In Camera and Casari (2018), their partner's action is reported privately to the partner's future partners, but for *only up to six* rounds, if the buyer *spends a cost* for reporting. Therefore, two important questions remain unanswered. First, how does the presence of a reporting cost influence the effectiveness of endogenous monitoring? Reporting usually involves a cost, because users need to spend time, effort and mental energy leaving a report. Their negative result may have been driven by the positive reporting cost, considering that players' disclosure decisions have recently been shown to be sensitive to a positive cost in the case of revealing their own information (e.g. Kamei 2017, 2020b).[3] Second, what happens to people's reporting and cooperation behaviour if there is a publicly available platform that stores *all* endogenously reported information? This study proposes and demonstrates that such a publicly available platform may be crucial in overcoming the hurdle of positive reporting costs in online markets to enhance signalling effects, disseminate reputational information effectively, and improve cooperation.

While Camera and Casari (2018) use the setup of a helping game in which only the buyer can report the seller's action, the present study adopts the setup of a prisoner's dilemma game in which both parties can report each other's behaviour because economic interactions in some online markets (e.g. eBay, the sharing economy such as Uber and Airbnb) can be better expressed by a prisoner's dilemma game. For example, transactions among Uber users are simultaneous; a passenger decides whether to behave arrogantly towards a driver, while the driver decides whether to behave poorly towards the passenger, and a two-way rating system is available.[4] The differences in the design setup make the comparison between Camera and Casari (2018) and the present study less straightforward. However, the attempt here is to re-evaluate the role of endogenous monitoring, focusing on the effects of reporting costs and the reputational platform under (indefinitely repeated) simultaneous-move interactions, such as in online markets.

Gossiping, closer to the topic of voluntary information transmission, has long been studied actively in neighbouring fields, such as anthropology, biology, (evolutionary) psychology and sociology, and has been discussed as helping to create a reputation, thereby promoting cooperation in human societies (Dunbar 2004; Feinberg *et al.* 2012). For example, as summarized by Kamei and Putterman (2018), the literature suggests that gossiping can be initiated by prosocial individuals when observing others' norm violations or misdeeds, and that gossiping activities are linked to reporters' emotional states.

Costly reporting is similar to costly punishment in that other-regarding preferences or emotions cause agents to engage in costly reporting. However, costly reporting differs largely from costly punishment because in costly reporting, others' misdeeds are judged by those receiving the reports, not by the reporters themselves. While scholars have extensively studied costly punishment over the last few decades (for a survey, see Gächter and Herrmann 2009; Chaudhuri 2011), surprisingly little attention has been paid to costly reporting until recently in the experimental economics literature. In addition to Camera and Casari (2018), four recent economic experiments explore the functioning of costly reporting and provide useful evidence. However, these studies are all built on finitely repeated games, unlike this study and Camera and Casari (2018); thus their focus is different from that of the present study. Because costly reporting is never a materially beneficial act under finite repetition, the prior research has explored non-material reasons for reporting.[5] By contrast, endogenous monitoring may lead to cooperation as an equilibrium outcome under infinite repetition. Hence the focus of this paper is to study the possible evolution of cooperation and players' strategy choices under endogenous monitoring, with the aim of contributing not only to the experimental literature on cooperation and infinitely repeated dilemma games, but also to the literature on reputation, by providing new evidence that reporting may be deterred to a large extent by the presence of a positive reporting cost even in long-term interactions with multiple equilibria, and the efficiency of monitoring may depend on the availability of a platform that stores reported information.

In the experiment, recruited participants played an indefinitely repeated prisoner's dilemma game under random matching. In each main treatment, the subjects were given an opportunity to report their partners' actions to the partners' future partners. Four main treatments were constructed by varying the two factors (2×2 factorial design). The first treatment factor is the reporting cost: reporting is either free or costly. While reporting usually costs the reporter, the costs (e.g. time and mental energy to write a report) may differ by platform. The second treatment factor is the information structure: the reported action choice is informed either to the partner's next interaction partner only or to all future partners. In addition to the four treatments, a control treatment was conducted in which subjects had no opportunity to engage in reporting.

The experimental results showed that cooperation collapses easily in the control setup where endogenous monitoring is not possible, which is consistent with prior research findings (Camera and Casari 2009; Kamei 2017). However, subjects can achieve strong cooperation norms if they can report another's action for free under the weak condition, that is, even when the reported action choice is informed to the partner's next partner only. Nevertheless, the effect of endogenous monitoring is sensitive to reporting costs. Under this information transmission condition, endogenous monitoring has almost no effect when reporting is costly as the cost discourages reporting. This implies that a device that mitigates the cost of reporting (whether time or mental energy) may help to foster cooperation in a community by encouraging reporting, even without any additional mechanism such as storing reports.

When a community has a publicly available platform that stores all the reported information, monitoring efficiency *does not* depend on reporting costs. Subjects can gradually accumulate information and refer to all previously reported behaviours of their matched partners when deciding on an action, thereby sustaining cooperation. Storing compromises the negative effect of a positive reporting cost in discouraging reporting, underscoring the beneficial effect of storing reputational information.

Further, a structural estimation was conducted to gain insights into the subjects' strategy choices. The results show that subjects' strategy choices are greatly affected by endogenous monitoring institutions. For example, a large fraction of subjects are estimated to cooperate conditionally upon their partners' reputations when a platform that stores all reports is present.

Note that there are two main discrepancies between real online markets and the present experimental setup. First, while reporting was always truthful in the present experiment, reviews in real online markets are cheap talk based on users' subjective judgements. To the authors' view, the experimental setup with truthful information is an acceptable simplification, because prior experiments on gossiping found that almost all reviews are truthful even when lying is possible (e.g. Fonseca and Peters 2018). The advantage of using truthful information in the experiment is that it tightens the connection between the experimental design and theory with a simplified setup. As discussed in Section 3, Takahashi (2010) provides theory on how the information of a partner's past play affects equilibrium strategies. Second, competition in partner choice was absent in the present experiment, whereas users in most real markets can choose their partners. Competition typically strengthens the value of information because reputational information serves as a basis for users' partner selection (Kamei and Putterman 2017). Thus the present experiment can be treated as a conservative test of the role of endogenous monitoring, whose results show that even without partner choice, revealed information boosts cooperation under certain conditions.[6]

The remainder of the paper proceeds as follows. Section 2 describes the experimental design. Section 3 discusses the theoretical analyses and results of the computer simulation exercises for the possible evolution of cooperation. Section 4 presents the experimental results. Section 5 concludes the study.

2 EXPERIMENTAL DESIGN

This study implements an infinitely repeated game based on a random continuation rule. A multiple supergame design is adopted to allow subjects to learn and update strategy choices from supergame to supergame (Dal Bó and Fréchette 2018). Specifically, subjects can play an indefinitely repeated prisoner's dilemma game with random matching up to six times.[7] An 'indefinitely repeated prisoner's dilemma game' is also called a supergame in this paper (it was called a 'phase' in the instructions distributed to subjects).

Subjects are assigned randomly to a group of eight at the beginning of each supergame, and the group composition does not change throughout the supergame.[8] Each subject is randomly paired with another member within their group in every round, and plays a prisoner's dilemma game (four pairs are randomly formed in their group); see Figure 1 for the payoff matrix of the stage game. Because the group size is eight, the probability that a subject will interact with a specific group member in a round is one-seventh; they do not interact with those outside their groups within a supergame. The subjects' interactions are anonymous in the sense that they do not know their partners' IDs. However, they learn about their partners' action choices in the prior rounds in which they were reported. Neither decisions nor past interaction outcomes affect the matching process. The duration of each supergame is not predetermined: subjects' interactions in a given supergame will end with a probability of 5%.[9] The expected length of each supergame is therefore 20 $(= 1/(1 - 0.95))$.

As discussed previously, group assignment across supergames follows a random matching protocol. Specifically, once a given supergame is over, all groups are dissolved in the session, and subjects are assigned randomly to a group of eight in the following supergame. Information from a given supergame is not transferred to future supergames.

All the experimental design pieces, such as group size, matching conditions, payoff matrix of the stage game, and continuation probability, are common knowledge for the subjects.

		Player 2	
		Cooperate	Defect
Player 1	Cooperate	25, 25	5, 30
	Defect	30, 5	10,10

FIGURE 1 Payoff matrix of the stage game.
Notes: This matrix was used by Camera and Casari (2009) and Kamei (2017). Their studies used a group size of four.

This experiment comprises five treatments. The first treatment, denoted as the 'No Reporting' treatment (dubbed 'N'), serves as a control condition. Subjects repeat the prisoner's dilemma game under random matching without any information revelation, subject to the random continuation rule. In each round, the subjects learn that they are randomly matched with one of the seven other members of their groups, after which they play the prisoner's dilemma game. The other four treatments allow subjects to report their partner's action choice (cooperate or defect) to that person's future partner(s). For simplicity, it is set that the subjects' reporting is always truthful, and they know that their peers' reports are also always verifiable.[10]

2.1 | The four reporting treatments

At the end of every round, each subject can report their partner's action choice to that person's future partner(s) in a given supergame. This 'two-way' reporting design is different from that of Camera and Casari (2018), in which only one party can engage in reporting in a helping game. The treatment conditions are designed using a 2×2 factorial design with two dimensions (Table 1). The first dimension is the presence of a cost that a subject must pay to report; that is, reporting is either cost-free or costly. Reporting may not be considered free in reality because individuals need to incur time (opportunity cost) or effort to spread information, for example, to warn others.[11] For instance, it may take time and mental energy for users to log into the website and leave a report; however, the cost differs depending on the user-friendliness of the platform. In the costly reporting condition, a subject needs to pay one point to report his/her current-round partner's action choice. If the subject does not report it, then no points will be deducted from his or her payoff. The payoff gain from the total surplus maximization of the stage game is 15 points (= 25 − 10; see Figure 1). Therefore this reporting cost is sufficiently small, at only one-fifteenth of the gain. Camera and Casari (2018) also use the minimum reporting cost, that is, one point, in a helping game for the buyer to (truthfully) report his or her matched seller's action. However, the unit cost in their study is considered arguably larger than the present one because the payoff

TABLE 1 Summary of treatments.

Treatment	Available history information on round t partner before deciding whether to cooperate in round t	Cost of reporting	Number of subjects (sessions)	Number of observations	Average supergame length (rounds)[b,c]
N	n.a.	n.a.	72 (3)	9,120	19.41
F-Min	Round t partner's action choices made in round $t-1$ if the partner was reported in that round	0 points	88 (4)[a]	7,336	17.62
C-Min		1 point	64 (3)	10,080	27.33
F-Full	Round t partner's action choices made in all past rounds up to round $t-1$ in a given supergame in which the partner was reported by group members	0 points	72 (3)	10,320	25.63
C-Full		1 point	64 (3)	6,480	16.88
Total			360 (16)	43,336	21.37

Notes: [a]Four sessions were conducted for the F-Min treatment (unlike the other treatments) because one session could not be completed as one subject withdrew from the experiment in the middle of the session. The observations up to the time of the student's withdrawal were used as data along with the three other sessions, because the session proceeded without any issues until then. [b]As explained in note 7, the subjects in the five sessions did not complete all six supergames. The average supergame lengths were calculated using only the supergames completed by subjects. [c]Online Appendix Table B.1 reports the average realized supergame lengths in the first, middle and final thirds of the experiment.

gain of the total surplus maximization in their stage game is six points (Camera and Casari 2018, p. 675).

The second dimension of the 2×2 design is the consequences of reporting. In the 'Min' ('Minimum') condition, if a subject reports his or her partner's action choice in round t, then only that partner's round $t+1$ counterpart will be informed of the choice before deciding how to act. This one-round memory condition is used in Kamei and Putterman (2018). In the 'Full' condition, by contrast, if a subject reports his or her partner's action choice in round t, then all future counterparts of this partner will learn the choice reported in round t. In other words, it is the perfect-memory condition, and reporting is more cost-effective in the Full condition. As the expected future duration of plays after reporting is 20 ($= 1/(1-0.95)$) rounds, the cost per receiver of the report is one-twentieth in the Full condition, while the cost is 0.95 in the Min condition. The signalling value of reporting is therefore stronger in the Full condition than in the Min condition.

Subjects in each treatment are fully informed of the two-way reporting process and their respective information conditions. The information setup of Camera and Casari (2018) falls in the middle between the Min and Full conditions: in an indefinitely repeated helping game, their subjects can observe partners' action choices reported during the six preceding rounds.

The four main treatments are called the 'Free Reporting, Minimum' (F-Min), 'Costly Reporting, Minimum' (C-Min), 'Free Reporting, Full' (F-Full) and 'Costly Reporting, Full' (C-Full) treatments.

2.2 | Using a block design to collect a large number of observations

Considering that infinite repetition is designed using a random continuation rule, a block design is employed to collect large observations in each supergame (Fréchette and Yuksel 2017).[12] In each supergame, the subjects play blocks of ten rounds in sequence. That is, they will play ten rounds, assuming a random continuation probability of 95%. In a given round, each subject is randomly paired with a member of their group, and they interact with each other in the prisoner's dilemma game (Figure 1). However, they are not informed of an integer randomly drawn for each round until the end of the tenth round in a given block. After the tenth round, the subjects are informed of the integers drawn for all ten rounds. Their payoffs are determined based on the rounds before the round in which an integer greater than 95 is first realized.[13]

It should be noted here that with the block design, all subjects have interactions in each supergame for at least ten rounds. Mengel *et al.* (2022) demonstrate that a realized supergame length has an impact on subjects' cooperation rates in the following supergames (see also Dal Bó and Fréchette 2018; Engle-Warnick and Slonim 2006). The block design is quite useful for avoiding extremely short supergames, which may discourage subjects from learning to cooperate.

2.3 | Experimental procedure

Sixteen sessions were conducted at the EXEC laboratory at the University of York, UK, from July to November 2018 (Table 1). A total of 360 students there participated in the experiment, of whom 58.1% (209 students) were female, and 16.9% (61 students) were economics majors.[14] All the subjects were recruited through solicitation messages sent through *hroot* (Bock *et al.* 2014). None of the subjects participated in more than one session. No communication among the subjects was allowed after entering the laboratory and before the experiment ended. Except for the instructions, the experiment was programmed using the z-Tree software (Fischbacher 2007). Only neutrally framed words were used in the instructions (any loaded words such as cooperate and defect were avoided); see Online Appendix C. The instructions were read aloud by the researcher. The subjects were also asked to answer a few control questions at the beginning of each session to check their understanding of the experiment. The conversion rate was 150 points in the experiment to one pound sterling. The average per-subject payment was 16.50 pounds sterling.[15]

3 | THEORETICAL DISCUSSIONS ON SUBJECTS' BEHAVIOURS

One instance of defection can quickly spread across a given group under random matching if members act according to certain trigger strategies (e.g. Kandori 1992; Ellison 1994). This contagious process makes it difficult for cooperation to evolve unless the continuation probability is sufficiently high. In the present experimental environment, no strict equilibrium exists regardless of the information condition, as explained below. Considering that the group composition is fixed in the experiment, contagion and a possible evolution of cooperation can be studied theoretically using a Markov transition matrix in the N treatment, assuming that all members act according to the grim trigger (GT) strategy (see Camera and Casari (2009) when the group size is four).[16] In the grim trigger strategy, a player cooperates only if he has not yet experienced any defection. Online Appendix Subsubsection A.1.1 derives the transition matrix when the group size is eight in the N treatment. As is usual for this area of theoretical work (e.g. Kandori 1992; Camera and Casari 2009), the strategy set is restricted to only two: the 'grim trigger' and 'always defect' strategies. Online Appendix A proves that there are no material incentives for any member to deviate from the grim trigger strategy provided that all other members follow the trigger strategy. The threshold probability above which players have no profitable deviation from the grim trigger strategy, δ^*, is 0.574 (Online Appendix Subsubsection A.1.1), whereas the continuation probability used in the experiment is 0.95. Thus under this assumption, not only mutual defection but also mutual cooperation holds as an equilibrium outcome in the N treatment (even when reputational information is unavailable).

However, once we allow players to select any strategy, the off-equilibrium condition is not met in the N treatment. As shown in Online Appendix Subsubsection A.1.2, a cooperator who was defected in a given round would refrain from engaging in punishment if allowed, unlike in the grim trigger strategy (i.e. he would deviate by choosing cooperation in the next round under certain conditions), because such a deviation helps to delay the propagation of defection to other group members. A calculation finds that δ must be less than 0.84 to avoid such a deviation in the off-equilibrium path (see Online Appendix Subsubsection A.1.2 for details). Therefore acting according to the grim trigger strategy is not an equilibrium in the N treatment if players are allowed to select any strategy. Note that the number of possible strategies in an infinitely repeated environment is not finite.

The presence of reputational information does not change the existence of strict equilibrium. Theoretical analysis with information on a partner's past play available is a challenging task, but Takahashi (2010) successfully derives the condition in which strict equilibrium exists when information on the partner's past play is available. Based on the pairwise grim trigger strategy (Takahashi 2010, p. 48), his Proposition 1 explains that $g < l$ and $\delta > g(1+l)/[(1+g)l]$ must hold for cooperation to evolve as an equilibrium outcome, where g and l are normalized payoff parameters.[17] However, this condition for g and l does not hold in the present experiment because $g = l = 1/3$.[18] Thus a strict equilibrium does not exist. In summary, no treatment differences are predicted in terms of strict equilibrium (Table 2).

However, there are at least three reasons to expect information on partner's past play to have a positive effect.

TABLE 2 Cooperation and information on partner's past play.

Method	Without information on partner's past play	With information on partner's past play
1. Strict equilibrium based on grim trigger	Do not exist[a]	Do not exist[b]
2. Independent and indifferent equilibrium (Takahashi 2010)	Do not exist	Exist if δ* >0.250; the memory length does not matter for its existence
3. Simulation[c]	Cooperation collapses easily when some members deviate	• Cooperation is sustained more with than without the information • Cooperation is sustained more under free than costly reporting, and in the Full rather than in the Min conditions • Conditionally cooperative strategies based on the information of the partner's reported record are more common in the C-Full (F-Full) than in the C-Min (F-Min) treatment

Notes: [a]Calculation results based on the method of Kandori (1992) and Camera and Casari (2009); see Online Appendix A. [b]The theoretical suggestion based on a pairwise grim trigger strategy (Proposition 1 of Takahashi 2010). [c]Simulation results based on conditionally cooperative strategies (see Online Appendix B).

The first reason is the difference in the speed at which defection spreads in the community. Uncooperative actions are more contagious in the reporting treatments than in the N treatment if (a) some members engage in reporting, and (b) group members act according to a strict form of the grim trigger strategy (e.g. members start to defect unconditionally in all future rounds as soon as they learn from reports that their partners defected in the past or the partners defect now). As Camera and Casari (2009) and Kamei (2017) discuss, in the *equilibrium path*, δ^* (the threshold value for the continuation probabilities that induce players to select the trigger strategy) is not greater in the reporting treatments than in the N treatment. A quicker contagious process with the reputational information available means that players have more material incentives to refrain from behaving uncooperatively with than without endogenous monitoring.

Second, Takahashi (2010) proves that with the information on partner's past play, cooperation can hold as what he calls the 'independent and indifferent equilibrium' (i.e. 'players choose actions independently of their own records of play, and they are indifferent between cooperation and defection at all histories'; Takahashi 2010, p. 43). Proposition 6(2) of his paper provides the existence condition ($g = l$, $\delta^* > g/(1+g) = 0.250$), and memory length 1 suffices.[19] Similar to the case of strict equilibrium (see note 17), the memory length—1 (Min condition), 6 (Camera and Casari 2018), ∞ (full condition)—does not make any difference in a player's behaviour. This type of belief-free equilibrium does not exist in the N treatment (for details, see Takahashi 2010). Row 2 of Table 2 summarizes this prediction.

Third, Heller and Mohlin (2018) prove mathematically that in the absence of history information, the contagious equilibrium by Kandori (1992) and Ellison (1994) fails if a small percentage of people do not maximize their payoffs, for example, due to idiosyncratic preferences. However, they argue that full cooperation can be sustained as an equilibrium outcome when people observe a randomly selected sample of their opponents' past behaviours.

These three theoretical suggestions imply that there would be substantial reporting when reporting does not involve costs, as reputational information helps to sustain cooperation, thereby increasing lifetime payoffs. Some subjects may also engage in reporting even if doing so is costly for strategic reasons, for example, because the gain from mutual cooperation is large considering the random continuation probability 95%. Some subjects' reporting may be driven in part by non-material reasons (Kamei and Putterman 2018). Having said that, the presence of reporting costs would discourage reporting, thus making reporting less frequent under costly reporting than free reporting, because players have incentives to free-ride on others' reporting if it is costly.

> **Hypothesis 1.** (a) Cooperation can be sustained at a higher level with than without reputational information. (b) Reporting is on average more frequent when it is free than costly.

However, recent experiments suggest that analyses based solely on strategies in which players never forgive defection, such as the grim trigger, may not be accurate. For example, Dal Bó and Fréchette (2011) estimate the distribution of subjects' strategy choices under partner matching, showing that the tit-for-tat strategy is the most frequently adopted cooperative strategy, whereas the grim trigger strategy is not common.[20] Kamei (2017) studies subjects' behaviours when they can hide their IDs in an indefinitely repeated prisoner's dilemma game with random matching. His experiment reveals that subjects' average behaviours are characterized by conditionally cooperative strategies. For example, the higher fraction of cooperation his partner had in the reputational information, the more likely a subject was to choose cooperation.[21]

In order to accommodate the findings of these related studies, and also to discuss possible treatment differences in great depth, a large simulation analysis was additionally performed by assuming that some group members engage in reporting and act according to a conditionally cooperative strategy based on the information of the partner's reported records (CC players hereafter), while the rest follow the 'always defect' strategy (AD players hereafter).[22] The CC strategy is similar to what will be defined as 'RepL' or 'Rep*K*' in the structural estimation of our subjects' strategy choices (Subsection 4.3). In the simulation exercise, for simplicity, the strategy space is restricted only to the CC and AD strategies. For comparison, a conditionally cooperative strategy *based on own interaction experience* is considered for the N treatment, as no reputational information is available.[23] The aim of this exercise is to explore how reports facilitate cooperation. For simplicity, CC players are assumed to always engage in reporting. An additional analysis is provided near the end of this section by alternatively assuming that a cooperative type decides whether to engage in reporting and whether to use the reputation record for their action choice.

While the simulation shows the presence of a symmetric cooperation situation in which every group member selects cooperation in the equilibrium path under all five treatment conditions, clear treatment differences emerge (Online Appendix Subsection A.2).

First, it is difficult to sustain cooperation in the N treatment. As detailed in Online Appendix Subsubsection A.2.1, cooperative equilibrium is volatile because defection spreads quickly to all members as soon as more than one player deviates from the cooperative strategy. The simulated pattern in the N treatment is consistent with prior findings that cooperation tends to remain at low levels without reputational information.[24]

Second, reputational information helps to prevent a breakdown of cooperation if CC players choose cooperation conditionally upon their partners' reputations based on reports (Online Appendix Subsubsections A.2.2 and A.2.3).[25] This simulated pattern is consistent with Hypothesis 1(a) discussed based on standard theory. Having said this, the effectiveness of endogenous monitoring depends on reporting costs and information structure. On the one hand, symmetric cooperation is very stable when reporting does not involve costs. This holds for both the F-Min and F-Full treatments. For example, the simulation results indicate that a player in the F-Min treatment has material incentives to follow the CC strategy (rather than the AD strategy) under reasonable assumptions, unless more than the majority of group members act according to the AD strategy (Online Appendix Subsubsection A.2.2). Having a public platform that stores previously reported information in the F-Full treatment strengthens the stability of the cooperative equilibrium (Online Appendix Subsubsection A.2.3). These positive effects are driven by a large quantity of reported information, thereby enabling CC players to discriminate accurately between members based on their observable cooperation history. Hence players are deterred from behaving uncooperatively because of future material concerns.

However, the impact of endogenous monitoring is weaker under costly reporting than free reporting in the simulation. As detailed in Online Appendix Subsubsections A.2.2 and A.2.3, the simulated results show that cooperation can be sustained at a high level in the C-Min treatment if players select actions as their partners' reputational information indicates, like a parrot (e.g. a player selects cooperation if his partner selected cooperation in the last round and it is observable). Such information effects as coordination devices are stronger in the C-Full than in the C-Min treatment.[26] However, the positive effects diminish if players consider their own prior interaction experiences and then adjust their cooperation decisions, instead of simply relying on the tit-for-tat-like strategy. This is because the number of reports is not large, and such adjustments create miscoordination among CC players, which weakens the impact of reported information compared with the parrot-like approach.[27] The simulation results are summarized in Hypothesis 2.

> **Hypothesis 2.** (a) Cooperation decreases over periods in the N treatment. (b) The level of cooperation is higher in the F-Min (F-Full) than in the C-Min (C-Full) treatment. (c) The impact of endogenous monitoring is stronger in the C-Full (F-Full) than in the C-Min (F-Min) treatment.

One unanswered question is which conditional strategy subjects choose in the four reporting treatments: conditional cooperation based on the information of the partner's reported records while they themselves contribute to reporting, or conditional cooperation based on their own interaction experience without engaging in costly reporting. To answer this question, an additional simulation was performed by considering three strategies: AD and the two types of CC strategies. The results reveal that players are more likely to obtain higher lifetime payoffs when they cooperate based on the reported records in the C-Full (F-Full) than in the C-Min (C-Full) treatment (see Online Appendix Subsubsection A.2.4). This is because, similar to what has already been discussed, CC players can discriminate between their partners more accurately based on observable cooperation history in the Full than in the Min treatments, thus enabling easier coordination in the former than in the latter. This additional simulation leads to Hypothesis 3.

> **Hypothesis 3.** The conditionally cooperative strategy based on the information about the partner's reported records is more frequently adopted in the C-Full (F-Full) than in the C-Min (F-Min) treatment.

These simulations assume that (some) CC players engage in reporting irrespective of the reporting cost because the cost is just one point. Note, however, that they may be reluctant to report partners' actions in the costly reporting treatments, even though the reporting cost is the lowest positive amount and interactions are infinitely repeated. In the context of voluntary disclosure of own information, Kamei (2017) demonstrates that people may have a discontinuity in disclosure decisions between zero and positive costs (for evidence under finite repetition, see also Abraham *et al.* 2016; Kamei 2020b; Kamei and Putterman 2018; Shampanier *et al.* 2007). To explore the possible heterogeneity in subjects' reporting, a structural estimation of reporting strategy choices will be performed using the experimental data in Subsection 4.3.

4 | EXPERIMENT RESULTS

An overview of the subjects' cooperation rates and the effects of endogenous monitoring is provided in Subsection 4.1. The subjects' reporting behaviours are examined in Subsection 4.2.

Finally, as the driving forces behind the observed treatment differences, the structural estimation results of the subjects' strategy choices are discussed in Subsection 4.3.

4.1 | Cooperation rates

As shown in Figure 2, the average cooperation rates were calculated using data from round 1 in supergames, the first block (first ten rounds) in supergames, and all rounds, as the random continuation rule was adopted in the experiment (Dal Bó and Fréchette 2018).[28] It shows first that the subjects' cooperation rates were modest when reporting was not possible (Figure 2(a)), a result that is consistent with Hypothesis 2(a). For example, the average cooperation rate in the N treatment was 46.5% in round 1, and 35.2% across all rounds. A higher cooperation rate in round 1 than in later rounds implies that some subjects turned to punishment mode for some duration after a negative experience.[29]

Figure 2 also summarizes the average cooperation rates under endogenous monitoring.[30] A subject random effects probit regression was then used to evaluate each treatment difference, while estimating standard errors bootstrapped and clustered at the subject level to allow for correlation between observations from the same subject.[31] As realized previous supergame lengths may affect subjects' decision to cooperate in the current supergame (Mengel *et al.* 2022), the previous supergame length is also added as a control in the regressions (e.g. Dal Bó and Fréchette 2018; Engle-Warnick and Slonim 2006). This reveals that the effects of endogenous monitoring depend on both reporting costs and information structure.

First, under the Min condition, endogenous monitoring has a strong effect on improving cooperation if reporting does not involve costs (F-Min treatment). The positive effect in the F-Min treatment relative to the N treatment was significant regardless of the data used

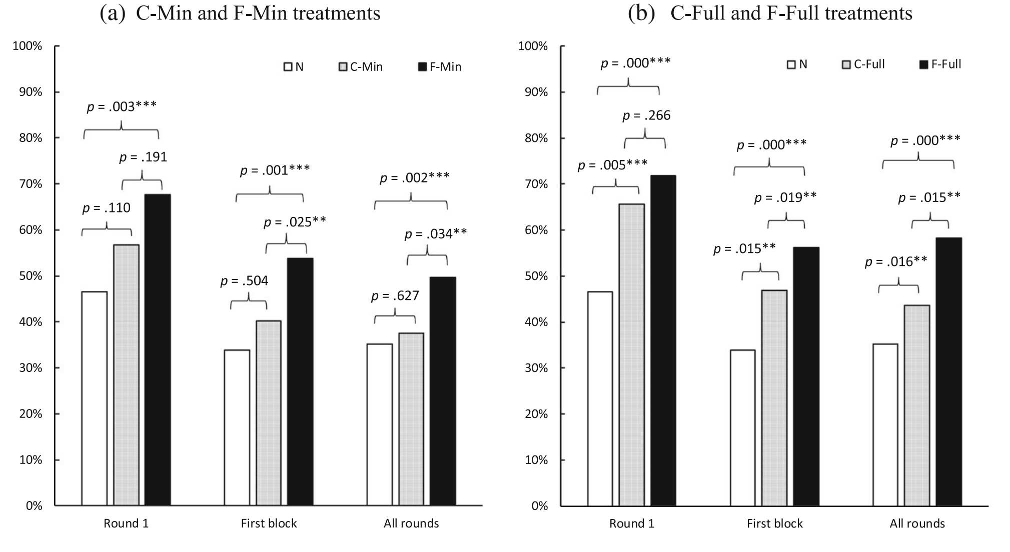

FIGURE 2 Average cooperation rate by treatment.

Notes: The *p*-values (two-sided) were calculated based on subject random effects probit regressions with robust standard errors bootstrapped and clustered at the subject level (300 replications). In the regressions, the length of the previous supergame was controlled as an independent variable for observations after the first supergame, while having a dummy equal to 1 for the first supergame.

*, **, *** indicate significance at the 0.10, 0.05, 0.01 level, respectively.

(Figure 2(a)). By contrast, costly reporting has only mild effects under this information condition. The average cooperation rate was not significantly higher in the C-Min than in the N treatment (again see Figure 2(a)). The discrepancy between the C-Min and F-Min treatments is consistent with Hypothesis 2(b).

Second, under the Full condition (Figure 2(b)), subjects achieved strong cooperation in the first round, and they sustained it relatively well over time in a given supergame, when reporting did not involve costs (F-Full treatment). Similar to the Min condition, the presence of a positive reporting cost undermined cooperation in the Full condition (Figure 2(b)), as the positive cost discouraged reporting, as will be explained in Subsection 4.2. However, costly reporting still improved cooperation significantly in the C-Full treatment relative to the N or C-Min treatment, supporting Hypothesis 2(c). In particular, the average round 1 cooperation rate for the C-Full treatment was very high, 65.6%.

It should be noted here that a comparison between the F-Min and F-Full treatments shows a positive effect of having larger history information; however, the effect is small. The average cooperation rate in round 1 (over all rounds) was 67.7% (49.7%) in the F-Min treatment versus 71.8% (58.2%) in the F-Full treatment. This suggests that having additional mechanisms in addition to the available reputational platform is desirable to induce subjects to use reputation more effectively for cooperation in the F-Full treatment than in the F-Min treatment.

Result 1. (a) Cooperation was only around 35% in the N treatment. (b) The level of cooperation was higher in the F-Min (F-Full) than in the C-Min (C-Full) treatment. (b) The impact of endogenous monitoring was stronger in the C-Full than in the C-Min treatment, but the impact was similar for the F-Min and F-Full treatments.

The impact of endogenous monitoring is also evident in the across-supergame cooperation dynamics. However, these trends provide new insights (Figure 3). First, the supergame-average cooperation rate decreased over time in the N treatment. The rate of decrease was significant (see Online Appendix Table B.2). This supports Hypotheses 1(a) and 2(a): in the absence of reputational information, subjects fail to cooperate even after gaining experience. Second, under the Min condition (Figure 3(a)), free reporting has a positive effect on cooperation uniformly across the six supergames. The round 1 cooperation rates were around 70% across the experiment in the F-Min treatment, which means that the subjects' high willingness to cooperate persisted over time (Figure 3(a)(i)). Overall, the groups in the F-Min treatment achieved significantly stronger cooperation norms compared with the N treatment, whether data from earlier (supergames 1–3) or later supergames (supergames 4–6) are used.[32] By contrast, Figure 3(a) suggests that costly reporting has only mild effects across the six supergames in the C-Min treatment. This strengthens Result 1(b).[33] Although the subjects in the C-Min treatment cooperated somewhat more frequently than those in the N treatment in the first round (Figure 3(a)(i)), the overall average cooperative behaviour in the former was almost similar to that in the latter (Figures 3(a)(ii) and 3(a)(iiii)).

Figure 3(b) reveals the different dynamics between the two reporting costs under the Full condition. Similar to the F-Min treatment, the subjects achieved high cooperation norms from the first supergame in the F-Full treatment. However, when reporting was costly (C-Full), the subjects took time to learn cooperation. Nevertheless, the learning was significant and successful.[34] The groups in the C-Full treatment achieved significantly higher cooperation rates than those in the N treatment in the second half of the experiment (supergames 4–6)—see Online Appendix Figure B.2. This implies that the subjects gradually learned how to utilize the recorded reports. Such gradual learning is reasonable considering that only a subset of actions was reported (Subsection 4.2), and the distribution of accumulated information might have been biased.

Result 2. (a) Under the Min condition, subjects learned to cooperate over the supergames and selected cooperation by more than 20 percentage points in the F-Min than in the N treatment for

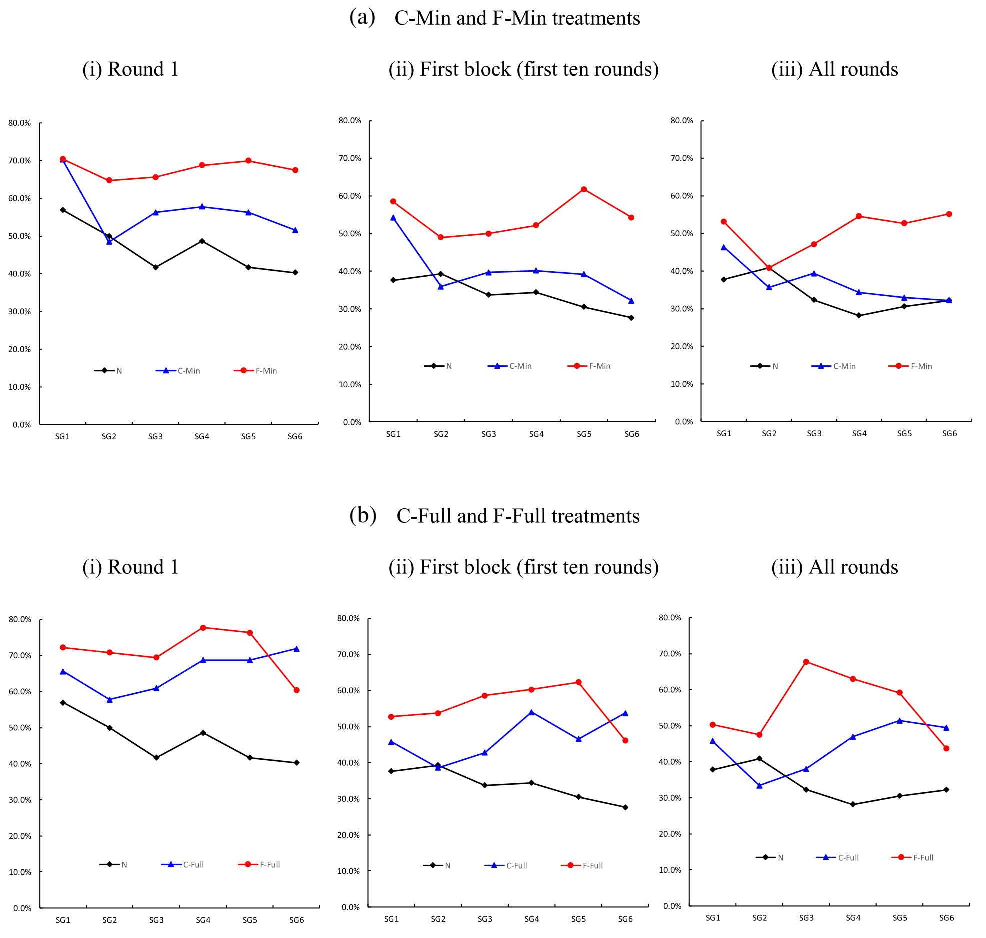

FIGURE 3 Average cooperation rate, supergame by supergame.

the final three supergames. However, subjects failed to do so in the C-Min treatment. (b) Under the Full condition, subjects sustained cooperation from the onset in the F-Full treatment. In the C-Full treatment, they gradually learned to cooperate, and achieved a similarly high level of cooperation to the F-Full treatment in later supergames.

The analyses discussed did not consider potential correlation resulting from the dynamic feedback within the session. An analysis to accommodate this possibility is difficult because of the small number of sessions. Nevertheless, a GLS regression with two-way clustering (session and subject) was additionally performed, which finds that the key results are not affected by such correlation, as follows. First, costly reporting significantly undermined cooperation under the Min condition. Specifically, the subjects' cooperation rates in the first round, the first block and for all rounds were detected to be significantly lower in the C-Min treatment at two-sided p-values 0.097, 0.031 and 0.047, respectively, than in the F-Min treatment. Second, strong effects of endogenous monitoring were detected for the two Full treatments. The subjects' cooperation rates in the first round, the first block and for all rounds were significantly higher in the F-Full than in the N treatment at two-sided p-values 0.001, 0.049 and 0.050, respectively. While it took some time to learn cooperation when reporting was costly, these rates were significantly higher in the C-Full than in the N treatment at two-sided p-values 0.004, 0.041 and 0.038, respectively, for supergames 4–6.

4.2 | Reporting

Subjects' failure to learn cooperation in the C-Min treatment (Figures 2 and 3) can be explained by the small amount of reputational information. Table 3 summarizes the subjects' reporting rates by treatment. It shows that the subjects were far less likely to engage in reporting in the C-Min than in the F-Min treatment. The strong negative impact of positive reporting costs is remarkable, considering that the cost is only one point (= 0.67 pence). However, this is consistent with the results of recent research that showed players' sensitivity to cost in the context of voluntary disclosure of their own information (Kamei 2017, 2020b).

Subjects' frequency of reporting did not differ by information condition when reporting did not involve costs (see again Table 3). This implies that perhaps, since already more than 70% of the subjects engaged in reporting even in the F-Min treatment, having a publicly available platform in the F-Full treatment did not improve material incentives to report.

Turning to costly reporting, subjects engaged in reporting significantly more frequently in the C-Full than in the C-Min treatment, but reporting in the C-Full treatment was still far weaker than that in the F-Full treatment. Thus the negative effect of positive reporting costs is robust to the information condition (Min or Full).

The reporting frequencies (Table 3) and success/failure of cooperation (Figures 2 and 3) are roughly consistent with the prediction from Takahashi (2010). As summarized in row 2 of Table 2, cooperation evolves under endogenous monitoring, provided that the memory length is at least 1. A report is expected to stay for 0.95 rounds (20 rounds) in the Min (Full) condition, as the continuation probability is 95%. The average quantity of the partner's past play is therefore roughly calculated as 0.197 (= 20.7% × 0.95), 0.682 (= 71.7% × 0.95), 5.68 (= 28.4% × 20) and 15.5 (= 77.5% × 20) in the C-Min, F-Min, C-Full and F-Full treatments, respectively. Here, 20.7%, 71.7%, 28.4% and 77.5% are the average realized reporting rates of the respective treatments (Table 3). Thus the memory length was much less than 1 in the C-Min treatment only. The memory length was much larger than 1 in the two Full treatments.

Result 3. (a) Subjects were significantly more likely to report partners when reporting was free than costly. (b) While the reporting rates were at high levels similarly for the F-Min and F-Full treatments, the rates were significantly higher in the C-Full than in the C-Min treatment.

Table 4 summarizes the average reporting rates by stage game outcome.[35] Here, the reporting rates were calculated separately for cooperators (those who selected cooperation in given rounds) and defectors (those who selected defection in given rounds). Three further interesting patterns emerge. First, cooperators were more likely than defectors to engage in reporting under each

TABLE 3 Average reporting rates by treatment.

	Data used for calculations								
	Round 1			First block			All rounds		
Reporting:	Costly		Free	Costly		Free	Costly		Free
Information:									
Min	28.1%	<***	76.0%	23.5%	<***	72.6%	20.7%	<***	71.7%
	∧**		=	∧*		=	∧**	=	
Full	41.9%	<***	74.0%	30.8%	<***	74.2%	28.4%	<***	77.5%

Notes: Each treatment comparison was based on a subject random effects probit regression with robust standard errors bootstrapped and clustered at the subject level (300 replications). In the regressions, the length of the previous supergame was controlled as an independent variable for observations after the first supergame, while also having a dummy that equals 1 for the first supergame. Online Appendix Figure B.4 summarizes the average reporting rates by supergame.
*, **, *** indicate significance at the 0.10, 0.05, 0.01 level, respectively.

TABLE 4 Average reporting rates by stage game outcome.

	Data used for calculations								
	Round 1			First block			All rounds		
Decision-maker:	Cooperator		Defector	Cooperator		Defector	Cooperator		Defector
Panel A: C-Min treatment									
Partner:									
Cooperator	31.5%	=	19.1%	36.6%	>***	19.1%	35.5%	>***	17.7%
	=		=	=		∨***	=		∨***
Defector	47.9%	>**	8.3%	42.4%	>***	9.4%	38.6%	>***	7.6%
Panel B: F-Min treatment									
Partner:									
Cooperator	86.3%	>**	59.0%	86.5%	>***	67.3%	87.2%	>***	66.0%
	=		=	∨**		∨*		∨***	=
Defector	82.1%	=	54.3%	77.6%	>***	55.3%	75.6%	>***	57.5%
Panel C: C-Full treatment									
Partner:									
Cooperator	48.9%	>***	13.9%	38.6%	>***	17.8%	39.2%	>**	18.0%
	∧***		=	∧***		=	∧***		∨*
Defector	77.8%	>*	11.7%	59.8%	>***	17.0%	56.2%	>***	14.4%
Panel D: F-Full treatment									
Partner:									
Cooperator	82.0%	>***	44.8%	84.8%	>***	52.9%	86.3%	>***	57.9%
	=		=	=		∧***	=		∧***
Defector	85.1%	=	9.7%	79.7%	>**	69.2%	79.3%	=	73.6%

Notes: Each treatment comparison was based on a subject random effects probit regression with robust standard errors bootstrapped and clustered at the subject level (300 replications). In the regressions, the length of the previous supergame was controlled as an independent variable for observations after the first supergame, while also having a dummy that equals 1 for the first supergame. Online Appendix Table B.3 reports the average reporting rates by supergame.
*, **, *** indicate significance at the 0.10, 0.05, 0.01 level, respectively.

treatment condition, regardless of whether they were matched with cooperators or defectors. This suggests that some defectors may not have appreciated the benefits of creating reputational information and/or may have free-ridden on cooperators' reporting. Second, cooperators were more likely to engage in costly reporting when matched with defectors rather than when matched with cooperators (panels A and C). These differences were significant in the C-Full treatment. This pattern resonates with the idea that cooperators' reporting is partly driven by other-regarding motives or emotional responses (Kamei and Putterman 2018). On the other hand, cooperators reported both cooperators and defectors quite frequently when reporting was free. Third, both the cooperators and defectors frequently engaged in reporting when reporting did not involve costs. However, not everyone has done so. This is not surprising considering that some people are known to behave uncooperatively,[36] even though a Pareto-dominant cooperative equilibrium exists in an infinitely repeated dilemma game.[37]

One may wonder how subjects' reporting was affected by *others'* previous reporting. It is possible that their reporting was partly characterized by *conditional* behaviours. For example, a reciprocal subject may be more likely to engage in reporting to help the community if he enjoys the benefits of receiving larger information about the current-round partner than otherwise.[38] To explore possible conditional reporting behaviours, partial correlations between subjects' reporting decisions and the quantity of reputational information they received were calculated, confirming significantly positive relationships (see Online Appendix Table B.5). The subjects in the C-Min and F-Min treatments were likely to report by approximately 17.4 and 10.7 percentage points more, respectively, when they received a report than otherwise. In the C-Full and F-Full treatments, a 10% increase in subject *i*'s quantity of reported information raises the likelihood that his current-round partner reports *i* by around 1.3 and 1.4 percentage points, respectively.

Result 4. (a) Cooperators were more likely than defectors to engage in reporting under each treatment condition. (b) Cooperator–defector reporting was more common than in any other stage game situation when reporting was costly. (c) Both cooperators and defectors frequently engaged in reporting when reporting did not involve a cost. (d) Subjects' reporting was positively correlated with their partners' frequencies of being reported in the past.

4.3 | Structural estimation of subjects' strategy choices

In Subsection 4.1, it was found that endogenous monitoring greatly affected subjects' decisions to cooperate. However, it is still unclear how subjects' strategy choices changed by endogenous monitoring. To answer this question, the subjects' strategy choices regarding cooperation were estimated by applying the maximum likelihood method developed by Dal Bó and Fréchette (2011).[39] This method assumes a fixed number of strategies that subjects can adopt, then estimates a probability distribution over the strategies in the dataset to maximize the likelihood. While the theoretical analysis in Section 3 assumes a few specific strategies such as AD, GT, and what we call the conditionally cooperative (CC) strategies, a larger number of specific strategies were considered in the structural estimation to avoid missing important strategies and to obtain detailed insights.[40] As summarized in Table 5, the two types of CC strategies were considered so that the structural estimation is parallel to the argument in Section 3.[41] The first type is the CC strategy in which players' decisions are conditional upon their interaction experience; it includes variants of grim trigger, tit for tat, and trigger strategies, namely GT, GT2, GT3, SGT, TFT, TF2T, TF3T, 2TFT, T2, T3, T4 and T5, in all five treatments. The second type is the CC strategy based on their partners' reputations rather than their interaction experience; it was considered for the four reporting treatments (further details below).[42] In addition to these two types of strategies, AD, AC and WSLS were added to the structural estimation following prior research (Dal Bó and Fréchette 2011).

The estimated distribution in the N treatment (Table 6) shows that the highest fraction (38.1%) of subjects' strategy choices is explained by the AD strategy. The popularity of the AD strategy increased over time, and the fraction was estimated at 47.7% in the second half of the experiment (Online Appendix Table B.9). The high prevalence of the AD strategy can be thought of as causing cooperation breakdown in the N treatment (Figures 2 and 3) and underlines the difficulty of sustaining cooperation under random matching in an anonymous community, even with infinite repetition. However, it resonates with the so-called 'anti-folk theorem' idea, which proposes negative consequences of strong commitment types in communities (Sugaya and Wolitzky 2020).

Other than the AD strategy, Grims and TFTs accounted for a relatively large fraction of strategy choices in the N treatment, that is, 28.7% and 26.1% of the subjects' strategies, respectively. As discussed in Section 3, Dal Bó and Fréchette (2011) found that in their partner-matching design, almost all subjects' decisions were explained by the AD or TFT strategy. The equal prevalence of the Grims and TFTs in the present study implies that the matching protocol (partner or random matching) affects subjects' strategy choices.

Subjects had reputational information in the four reporting treatments. As such, the distributions of subjects' strategy choices were estimated by including additional strategies (Table 5).

TABLE 5 List of strategies assumed in the structural estimation.

Strategy		Definition
AD	Always Defect	A subject who defects always
AC	Always Cooperate	A subject who cooperates always
Grims		A subject who acts according to GT, GT2, GT3 or SGT
GT	Grim Trigger	A subject who cooperates if he has not yet experienced any defection
GTK	Grim Trigger K ($K=2,3$)	A subject who cooperates until K consecutive rounds occur in which either player's action was defection; otherwise, he defects forever
SGT	Strong Grim Trigger	A subject who selects cooperation if he did not experience defection in his stage game interactions so far and also did not see any instance of defection in his partners' observable reputation records
TFTs		A subject who acts according to TFT, TF2T, TF3T or 2TFT
TFT	Tit for Tat	A subject who cooperates (defects) if the last partner cooperated (defected)
TFKT	Tit for K Tats ($K=2,3$)	A subject who cooperates unless partner's action was defection in any of the last K rounds
2TFT	2 Tits for 1 Tat	A subject who defects two rounds (cooperates) if the last partner defected (if his two recent partners both cooperated)
WSLS	Win Stay, Lose Shift	A subject who cooperates if either mutual cooperation or mutual defection was realized in his last round
TKs		A subject who acts according to T2, T3, T4 or T5
TK	Trigger strategy with K rounds of punishment	A subject who defects K rounds after experiencing defection, after which he returns to cooperation
Reps		A subject who acts according to a reputation strategy listed below
RepL	Reputation Last Round	A subject who cooperates in round t if his/her matched partner selected cooperation in round $t-1$ and it is observable (he defects otherwise)
Rep$K$	Reputation K% ($K=25,50,75,100$)	A subject who cooperates (defects) if his partner cooperated at least K% ($<K$%) of the time in the partner's observable reputation record
6Rep$K$	6-Round Reputation K% ($K=50,100$)	A subject who cooperates (defects) if his partner cooperated at least K% ($<K$%) of the time in the partner's observable reputation record up to round $t-6$.

Notes: The definitions of AD, AC, GT, TFT, T2 and WSLS are the same as those in Dal Bó and Fréchette (2011). The definitions of GTK, TFKT and 2TFT are the same as those used by Rand *et al.* (2015).

First, the RepL strategy was considered in all the four treatments. A RepL subject is assumed to choose an action based solely on their partner's previous round's reputation; that is, the subject cooperates in round t if his round t partner cooperated in round $t-1$ and it is observable; otherwise, he defects in round t. Second, Rep$K$ and 6Rep$K$ were also considered in the C-Full and F-Full treatments, as all previously reported information was available, and memory length may have affected choices. Parameter K reflects the threshold of the partner's reputational quality that induces a subject to cooperate. A Rep$K$ subject is assumed to cooperate in round t if his partner cooperated at least K% of the time thus far in the observable reputation record. Four threshold

TABLE 6 Estimated frequencies of strategy choices regarding cooperation.

Strategy	Treatment N	C-Min	F-Min	C-Full	F-Full
AD	0.381 (0.050)***	0.332 (0.068)***	0.276 (0.054)***	0.305 (0.067)***	0.184 (0.099)*
AC	0.044 (0.114)	0.062 (0.065)	0.177 (0.077)**	0.031 (0.103)	0.062 (0.085)
Grims[a]	0.287	0.296	0.338	0.216	0.106
TFTs	0.261	0.212	0.164	0.065	0.080
WSLS	0.000 (0.033)	0.000 (0.020)	0.000 (0.000)	0.015 (0.011)	0.037 (0.016)**
TKs	0.028	0.047	0.018	0.062	0.044
Reps[b]	n.a.	0.051	0.027	0.306	0.488
Breakdown:					
RepL	—	0.051 (0.048)	0.027 (0.014)*	0.000 (0.031)	0.027 (0.044)
6Rep100	—	—	—	0.006 (0.000)***	0.001 (0.050)
6Rep50	—	—	—	0.000 (0.000)	0.038 (0.058)
Rep100	—	—	—	0.051 (0.029)*	0.033 (0.013)***
Rep75	—	—	—	0.049 (0.049)	0.054 (0.034)
Rep50	—	—	—	0.153 (0.066)**	0.250 (0.048)***
Rep25	—	—	—	0.048 (0.062)	0.084 (0.116)
Gamma	0.544 (0.050)***	0.638 (0.068)***	0.632 (0.054)***	0.732 (0.067)***	0.779 (0.099)***
Beta	0.863	0.827	0.829	0.797	0.783

Notes: [a]Grims includes GT, GT2, GT3 and SGT; TFTs includes TFT, TF2T, TF3T and 2TFT; TKs includes T2, T3, T4 and T5. The rows for Grims, TFTs and TKs show the sums of estimated frequencies in these subcategories. The detail of the estimation result can be found in Online Appendix Table B.9. [b]Reps includes RepL in the C-Min and F-Min treatments (RepL, 6Rep100, 6Rep50, Rep100, Rep75, Rep50 and Rep25 in the C-Full and F-Full treatments). The numbers in parentheses are standard errors.
*, **, *** indicate significance at the 0.10, 0.05, 0.01 level, respectively, based on two-sided z-tests.

strategies—Rep25, Rep50, Rep75 and Rep100—were considered by varying the value of K. The 6Rep$K$ strategy is a threshold strategy based on the partner's choices in the last six rounds. This strategy was considered as reports were observable to subjects for only six rounds in Camera and Casari (2018), and one may wonder whether memory length matters. Third, as subjects can learn their partners' past action choices through reporting (Camera and Casari 2009; Kamei 2017), the SGT strategy was also considered in all four reporting treatments, in addition to the GT and GTK strategies. An SGT subject i is assumed to select cooperation only when i did not experience defection in his stage game interactions thus far, and i also did not see any instance of defection in the partner's observable reputation records.

The estimation results (Table 6) show first that the percentages of subjects who acted according to the AD strategy were smaller under endogenous monitoring than in the N treatment. This suggests that the availability of a reputational platform altered subjects' strategy choices. Second, there is a clear contrast in the impact of endogenous monitoring on subjects' strategy choices between the Min and Full conditions. On the one hand, under the Min condition, the most generous strategy was quite popular in the F-Min treatment: around 17.7% of subjects acted according to the AC strategy. Endogenous monitoring encouraged only a few subjects—around 5.1% (C-Min) and 2.7% (F-Min) of subjects—to choose an action based on their partner's reputation (last-round action choice). However, under the Full condition, remarkably, 30.6% and 48.8% of the subjects were estimated to have acted based on the Reps strategy in the C-Full and F-Full treatments, respectively. The difference in the percentage of the Reps strategy between the C-Min (F-Min) and C-Full (F-Full) treatments is significant at the 1% level (see Online Appendix Table B.9). Instead, both the TFTs and Grims were estimated to be smaller in the two Full treatments than in the N treatment. It follows that the availability of a publicly available reputational platform drastically altered subjects' strategy choices in the Full condition relative to the Min condition, whose result is consistent with Hypothesis 3. This strategy distribution in the Full condition is reasonable because all reported action choices are stored on the platform, and subjects can rely on reputational information when choosing an action.

Result 5. (a) The most frequently used strategy in the N treatment was the AD strategy. (b) The popularity of the AD strategy was lower when endogenous monitoring was possible. (c) In the C-Full and F-Full treatments, a large percentage of subjects chose actions conditionally upon their partner's reputation. The percentages of the Reps subjects were significantly larger compared to the corresponding Min treatments.

Which reputation strategy has gained popularity in the Full condition? As already discussed, the structural estimation includes seven reputation strategies—RepL, 6Rep100, 6Rep50, Rep100, Rep75, Rep50 and Rep25—to accommodate heterogeneity in the subjects' strategy choices. Table 6 also reports the estimated frequencies for the seven reputation strategies. This shows that when choosing an action, most of the Reps subjects took reports from all the previous rounds into account rather than focusing on the reports in the last round or in the last six rounds. It also indicates that the most frequently used threshold was 50% (Rep50, i.e. the strategy in which a subject cooperates if his partner cooperated at least 50% thus far according to the record).[43]

The final question that remains unanswered is exactly what motivates subjects to engage in reporting. A structural estimation shown below reveal heterogeneous reasons for reporting.

Six reporting strategies were assumed for this estimation. The first strategy is called the 'Always Not Report' strategy, shortened as AN. A subject in this category never engages in reporting. The second strategy, called 'Always Report' (shortened as AR), is defined literally as the one in which a subject always engages in reporting. Considering that subjects' reporting was on average conditional upon others' reporting (Online Appendix Table B.5), the 'Conditional Reporting' strategy (shortened as CR) was included as the third strategy. The CR subjects reciprocate others' previous reporting. The specific definition is as follows: a CR subject i reports his partner in round t if i received a report in that round in the Min condition; and the subject reports his partner if the matched partner was reported at least 50% thus far in the Full condition. A threshold of 50% was set here, as Rep50 was found to be by far the most popular reputation strategy for deciding whether to cooperate (see the discussion above). The CR subject is assumed to engage in reporting in the first round of each supergame.

Three more strategies were further included to capture the possibility that their reporting is driven by other-regarding preferences or emotions. First, the IA (shortened from 'Inequity Aversion') strategy is defined as one where subject i reports his partner only when i cooperated but the current partner defected (i does not report the partner for the other three prisoner's dilemma outcomes). Notice that an inequity-averse cooperator incurs a utility loss when exploited by a defector because of a feeling of disadvantage (Fehr and Schmidt 1999). Second, an RR (shortened from 'Reciprocal Reporting') type i reports his partner when i cooperated, but not when i defected. This reporting is driven by reciprocity in the prisoner's dilemma interaction (Rabin 1993; Dufwenberg and Kirchsteiger 2004). A reciprocal cooperator is assumed to engage in reporting when matched with a cooperator (defector) through positive (negative) reciprocity. Third, the PD (shortened from 'Punishing Defecting Partner') strategy is defined as one where i always reports when matched with a defector due to negative emotions.

Table 7 reports the estimation results. It shows first that more than the majority of subjects acted according to the AR strategy when reporting did not involve costs. This means that most subjects appreciated the beneficial effects of reputational information on cooperation. Second, however, the AN strategy was by far the most popular strategy when reporting was costly. This is in clear contrast to the treatment where reporting did not involve a cost: the percentage of the AN subjects was estimated at only 10.1% (7.3%) in the F-Min (F-Full) treatment, which is significantly smaller than that in the C-Min (C-Full) treatment. The difference in the reporting

TABLE 7 Estimated frequencies of chosen reporting strategies.

Strategy	Treatment: C-Min	F-Min	C-Full	F-Full
AN	0.527 (0.064)***	0.101 (0.065)	0.398 (0.087)***	0.073 (0.066)
AR	0.013 (0.071)	0.595 (0.048)***	0.075 (0.083)	0.679 (0.044)***
CR	0.092 (0.018)***	0.040 (0.090)	0.043 (0.057)	0.000 (0.078)
IA	0.107 (0.048)**	0.000 (0.024)	0.321 (0.032)***	0.013 (0.000)***
RR	0.245 (0.081)***	0.179 (0.020)***	0.143 (0.094)	0.077 (0.018)***
PD	0.016 (0.084)	0.085 (0.072)	0.019 (0.064)	0.158 (0.050)***
Gamma	0.567 (0.064)***	0.548 (0.066)***	0.606 (0.087)***	0.544 (0.066)***
Beta	0.854	0.861	0.839	0.863

Notes: Online Appendix Table B.10 reports results when reporting strategies are structurally estimated supergame by supergame. The numbers in parentheses are standard errors.
*, **, *** indicate significance at the 0.10, 0.05, 0.01 level, respectively, based on two-sided z-tests.

strategy choices between free versus costly reporting suggests a strong discontinuity in people's reporting between zero and positive costs. It follows that some non-material motives and/or emotions are required to overcome the hurdle of positive reporting costs. Third, consistent with this conjecture, a significantly larger proportion of subjects acted according to the IA strategy under costly reporting than under free reporting in each information structure (Table 7). This means that cooperators who were averse to disadvantageous inequality were motivated to warn others, to prevent the defecting partners from earning high by exploiting their peers.

Result 6. (a) The AN strategy was by far the most prevalent strategy when reporting was costly. (b) By contrast, this strategy was rarely selected when reporting did not involve a cost. Instead, more than the majority of subjects acted according to the AR strategy in the F-Min and F-Full treatments. (c) Costly reporting was partly driven by cooperators' inequity aversion.

5 | CONCLUSION

This study investigated experimentally how endogenous monitoring can improve cooperation among strangers in an indefinitely repeated prisoner's dilemma game. The results first indicated that its effectiveness is affected to a large extent by reporting costs. On the one hand, when reporting did not involve a cost, subjects reported their partners' action choices more than 70% of the time on average, and then achieved strong cooperation under random matching. Remarkably, the strong impact of endogenous monitoring did not depend on the availability of a platform whereby all future partners could check the previously reported information.

On the other hand, subjects only occasionally engaged in reporting when it was costly. As a result, costly reporting had almost no effects on boosting cooperation when the reported information was transmitted only to the next-round partners. This result, along with the strong positive effect detected in the F-Min treatment, suggests that a policy that reduces reporting costs (e.g. time and mental energy) may help to foster cooperation norms in a community without any mechanism, such as a data-storing platform. In clear contrast, costly reporting had a positive effect when a publicly available platform that stores reputational information was present. The strong interaction effect between costly reporting and the reputational platform can explain why reputation mechanisms in real online markets, such as eBay and Uber, function effectively, despite the possible selection bias of reported information and unwanted side effects embedded in the mechanism (Dellarocas, 2003).

The percentage of the subjects who acted according to their partners' reputations differed according to the information structure. Only around 3–5% of the subjects were estimated to have acted according to the Reps strategy when the reported information was not stored. In sharp contrast, with the reputational platform (under the Full condition), 30.6% (48.8%) of the subjects were estimated to have acted based on the Reps strategy when reporting was costly (cost-free). Hence a publicly available reputation platform plays a vital role in encouraging players to use reputational information. Nevertheless, the analysis revealed strong heterogeneity in the subjects' strategy choices, suggesting that care should be exercised when analysing subjects' cooperation behaviours under endogenous monitoring using theoretical models and simulations.

Although the experimental findings were clear, there are many exciting directions for future research. For instance, it would be meaningful to explore how the results obtained in the experiment are robust to the parameters of the experiment. For example, the continuation probability was set to 95% in this study. The impact of endogenous monitoring may depend on the probability, considering the prior research finding that subjects' decisions to cooperate may be strongly affected by the degree of people's patience (Dal Bó and Fréchette 2018). Likewise, the functioning of endogenous monitoring may depend on group size because the theoretical literature on repeated games discusses the effects of group size under random matching (Kandori 1992). Alternatively, both the way players engage in reporting and how they respond to reputational information may differ according to the flexibility of pairing, the content of information (e.g. action choices, feedback comments), and/or the verifiability of the information (trustful or cheap talk). Users on real online platforms can choose with whom they deal based on rating scores and (subjective) feedback comments. Such partner choices and detailed communication content may further boost the effectiveness of endogenous monitoring, as shown in the context of auctions (Brosig-Koch and Heinrich 2018). It is undoubtedly worthwhile exploring the role of endogenous monitoring in depth.

ACKNOWLEDGMENTS

This project was supported by a Grant-in-Aid from the Yoshida Hideo Memorial Foundation, and JSPS KAKENHI (grant number 23H00803). The authors thank John Hey for his hospitality in conducting the experiment at the University of York. The authors thank Mark Wilson (an IT manager at the University of York) for support in managing the computers and setup of the z-Tree software in the experimental sessions, and the editor, Daniel Gottlieb, and three anonymous reviewers for their valuable comments.

ENDNOTES

1. See Kandori (1992), Takahashi (2010) and Heller and Mohlin (2018) for theoretical work.
2. Public information about every past play of members in groups (Camera and Casari 2009; Kamei 2017), all past acts taken by the current partner toward the decision-maker through a unique identification number (Kamei 2017), or the colour-coded reputation mechanism similar to 'Standing' (Stahl 2013), help to improve cooperation. However, aggregated information may not always be enough to improve cooperation. For example, Bigoni *et al.* (2020) found that a numeric balance that summarizes past help given and received does not remove incentives to free-ride.
3. There is no treatment in which subjects can transmit reputational information for free in Camera and Casari (2018), therefore answering this question is impossible in their study.
4. It should be acknowledged that users have different and well-defined roles in real markets (e.g. drivers versus passengers in Uber). While some effects due to the asymmetric roles in a pair may be present, the present study aims to investigate the effects of endogenous monitoring *per se* without the effects of asymmetric different role assignments.
5. Prior research has suggested that most costly reporting may take the form of cooperator–defector reporting due to other-regarding preferences in a one-shot prisoner's dilemma where material benefit to the reporter is absent (Kamei and Putterman 2018); most reporting is truthful even when lying is possible in a trust game (Fonseca and Peters 2018); having a third party who can engage in reporting boosts trust and trustworthiness in a trust game, driven by the mere fact of being observed by others (Fehr and Sutter 2019); and information transmission through subjective ratings may not raise transfer and return rates in a trust game (Abraham *et al.* 2016). Regarding the finding of Fehr and Sutter (2019), see also Kamei (2018), who shows the impact of high visibility on altruistic acts. This channel is absent in the present study since a third party is not introduced (see the experimental design).

[6] Matching in transactions in some markets resembles exogenous (random) matching. Examples include Uber, which is characterized by blind passenger acceptance and cancellation penalty. Uber drivers must decide whether to accept a ride request without knowing the passenger's destination or fare; once the ride is accepted, cancellation leads to a penalty (e.g. Rosenblat and Stark 2016). Uber passengers are exogenously assigned drivers when they request rides; once drivers accept their requests, passengers are penalized if they cancel.

[7] An additional requirement is set such that the duration of interactions is up to two hours in total to avoid having an excessively lengthy experiment session (which could contaminate data due to the subjects' fatigue). However, most sessions (11 out of 16) went over all the six supergames.

[8] A larger group size was selected compared with Camera and Casari (2009) and Kamei (2017) where the group size was four, since this study considers large-scale economies (e.g. online platforms) where information does not automatically spread among community members without reporting. In response to this design choice, a Markov transition matrix and equilibrium conditions were derived as summarized in Section 3 and Online Appendix Subsection A.1.

[9] An integer between 1 and 100 is drawn randomly at the end of each round. If it is greater than or equal to 96, then subjects do not have the next round.

[10] This design setup is used also in Camera and Casari (2018) and Kamei and Putterman (2018).

[11] Resnick and Zeckhauser (2002) find that many users on real online platforms do not leave comments when having economic transactions there, consistent with the idea that reporting is costly.

[12] Fréchette and Yuksel (2017) show that subjects' behaviours under the block design do not differ from those under the standard random continuation rule, i.e. the method first used by Roth and Murnighan (1978).

[13] For example, suppose that the ten randomly drawn integers are 4, 34, 98, 56, 32, 93, 2, 45, 14 and 32 in sequence. In this situation, subjects' total payoffs in the supergame will be calculated based on the interaction outcomes until the third round in this block (the interaction outcomes from the fourth round will not be counted in calculating total payoff), and they will move on to the next supergame. If the ten integers are all less than 96, then subjects will move on to the next block in the same supergame.

[14] The percentages of female subjects were 52.8%, 59.4%, 61.4%, 67.2% and 50.0% in the N, C-Min, F-Min, C-Full and F-Full treatments, respectively. The percentages of economics students were 19.4%, 15.6%, 15.9%, 23.4% and 11.1% in the N, C-Min, F-Min, C-Full and F-Full treatments, respectively.

[15] The average per-subject payments were 14.69, 15.62, 17.24, 16.64 and 18.03 pounds sterling in the N, C-Min, F-Min, C-Full and F-Full treatments, respectively.

[16] See also Duffy and Ochs (2009).

[17] There is no requirement for the memory length of the reputational information in this proposition. According to his theoretical result, the memory length of 1 (Min condition), 6 (Camera and Casari 2018) or ∞ (Full condition) does not make any difference in subject cooperation behaviour for as long as reputational information is available.

[18] $g = (30 - 10)/(25 - 10) - 1 = 1/3$ and $l = -(5 - 10)/(25 - 10) = 1/3$.

[19] This equilibrium concept is more restrictive than the strict equilibrium discussed above. Equilibrium may also be constructed in other ways and by different strategies, but a full characterization of all possible equilibria is not possible and beyond the scope of this study because, as already noted, the number of possible strategies is infinite in an infinitely repeated setup.

[20] The distribution of subjects' strategy choices was estimated in the present paper using the approach taken by Dal Bó and Fréchette (2011). As discussed in Section 4, the grim trigger strategy was frequently adopted as the tit-for-tat strategy in the present environment (random matching).

[21] People's use of such discriminatory strategies is also an established phenomenon in finitely repeated dilemma games such as public goods games (Fischbacher and Gächter 2010; Kamei 2020b).

[22] The AD strategy—where the player selects defection unconditionally—is commonly observed even under partner matching. For example, Dal Bó and Fréchette (2011) estimated that the tit-for-tat and AD strategies together can account for 80% of all data. In our simulation, for simplicity, the AD players are assumed to always report when doing so is free, considering the high efficiency of reputational information seen in prior studies (Camera and Casari 2009; Stahl 2013; Kamei 2017). However, it is assumed that the AD players do not engage in reporting when it is costly since they can free-ride on others' reporting. Kamei and Putterman (2018), in a two-period prisoner's dilemma game environment, find that defectors are more selfish than cooperators in deciding whether to report; the former almost never engage in reporting when reporting is costly.

[23] The simulation assumes that in the N treatment, CC players stochastically select cooperation with a probability that their partners selected cooperation so far (see Online Appendix Subsection A.2.1). Such conditional decisions are common in repeated public goods games (Fischbacher and Gächter 2010). In the context of infinite repetition, the tit-for-tat and grim trigger strategies are the two most typical strategies that people can take, other than the AD strategy. These two strategies assume that players' action choices are affected by their experience, while the two strategies differ in terms of the degree of forgiveness.

[24] The average cooperation rate when the group size is four is 59.5% in Camera and Casari (2009) and 33.4% in Kamei (2017) under the continuation probability 95%, and 42.2% in Kamei (2020a) under the continuation probability 90% when no reputational information is available. It is worth noting that sustaining cooperation is theoretically more difficult when the group size is eight rather than four.

25 Simulations were performed based on two simplest assumptions for CC players. The first assumes that CC players select cooperation (defection) in round t if their current-round partners selected cooperation (defection) in round $t-1$ and the action was observable. According to this assumption, the history information was used as a coordination device, but their past interaction experiences were not considered. The second one assumes that CC players adjust action choices over time such that they would select cooperation in round t stochastically based on all their relevant prior interaction experiences. Specifically, players would mimic how previous partners who had history information selected cooperation toward themselves up to round $t-1$ (see the Online Appendix for details). CC players' behaviours in a laboratory can be considered somewhere in the middle of these two extreme assumptions.

26 The positive effects of costly reporting are nevertheless smaller compared with free reporting, since players' ability to discriminate peers is lower under costly than free reporting due to the smaller size of the reported information in the Min condition (see Online Appendix Figures A.2, A.3, A.6 and A.7).

27 In the context of an infinitely repeated prisoner's dilemma game with partner matching, Axelrod and Hamilton (1981) demonstrate that a simple tit-for-tat strategy works better than any strategy (e.g. sophisticated strategies based on the Markov process and Bayesian inference) in sustaining cooperation in computer simulations.

28 Effects of interaction lengths in the current supergame are minimized if observations in the first round or in the first block are used for the analysis, since subjects in all the treatments have gone through the first ten rounds of each supergame thanks to the block design.

29 A regression analysis confirms that the subjects' cooperation rates gradually declined over time within supergames in all treatments (see Online Appendix Table B.2).

30 Online Appendix Figure B.3 reports the average payoffs by treatment. Since it reveals qualitatively the same implications as seen from Figure 2, the discussions in Subsection 4.1 will be made based on the average cooperation rates.

31 To supplement the significance tests reported in Figure 2, another regression analysis was performed while adding session random effects (with an aim to control common shocks in sessions). The additional regressions generate qualitatively similar—somewhat stronger for some specifications—results (see Online Appendix Figure B.1).

32 Treatment differences were calculated as identified in Figure 2 when using only the data from supergames 1–3, and also when using only the data from supergames 4–6. As shown in Online Appendix Figure B.2, in each data subset, the difference in the average cooperation rate is significant between the N and F-Min treatments, regardless of which rounds of plays are used (the first round only, the first block only, or all rounds).

33 As shown in Online Appendix Figure B.2, the effect of costly reporting was not significant in the C-Min treatment, regardless of which data were considered (the first or second half of the experiment).

34 The increasing trend of cooperation in the C-Full treatment was significant. See the coefficient estimates for the supergame number variable in Online Appendix Table B.2.

35 Online Appendix Table B.4 reports the treatment differences in the average reporting rates by stage game outcome (e.g. cooperator–cooperator reporting).

36 Some subjects' decision not to report their partners' actions in the F-Min and F-Full treatments may have been caused by their limited cognitive ability, as discussed in Arruñada and Casari (2016) and Kamei (2020b).

37 To supplement Table 4, a regression analysis was performed to check the correlation between subjects' and their partners' cooperation rates, revealing similar conclusions as follows. First, the higher cooperation rate a subject had, the more likely the subject was to engage in reporting in each of the four reporting treatments. Second, the lower cooperation rate a subject had, the more likely the subject was to be costly reported by their match in the C-Full treatment. The detail is omitted to conserve space.

38 People's conditional behaviours are widely documented, for example in cooperation decisions (Fischbacher *et al.* 2001), direct punishment (Kamei 2014) and third-party punishment (Kamei 2020c).

39 As explained in Dal Bó and Fréchette (2011, p. 423), the gamma value in the structural estimation (SFEM) captures the size of noise. The gamma values estimated for all models shown in the present paper are strongly significant (see Online Appendix Tables B.7, B.8, B.9 and B.10). This means that the models predict our subjects' strategy choices significantly better than random choices in the dataset of the present experiment.

40 Dal Bó and Fréchette (2011) assume six strategies—AD, AC, GT, TFT, WSLS and T2—in their estimation.

41 A subject is assumed to cooperate in the first round of a given supergame unless he acts on the AD strategy.

42 As a preliminary analysis, a regression was conducted to investigate the relationship between subjects' decision to cooperate and their partner's reputational information (see Online Appendix Table B.6). The result finds that subjects on average selected cooperation conditionally upon their matched partners' reputations.

43 Online Appendix Figure B.6 and Table B.8 report the result when structural estimations are performed supergame by supergame. These show qualitatively similar results to Table 6 (while having additional insights).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Kamei, K. and Nesterov, A. (2024). Endogenous monitoring through voluntary reporting in an infinitely repeated prisoner's dilemma game: experimental evidence. *Economica*, 1–25. https://doi.org/10.1111/ecca.12539