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Author(s): Andrea Guido, Maxime Derex and Rustam Romaniuc

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NETWORK CONNECTIVITY AND REPEATED INTERACTIONS IN AN INFORMATION SHARING DILEMMA

ANDREA GUIDO[a], MAXIME DEREX[b] AND RUSTAM ROMANIUC[c]

The sharing of valuable information is at the root of both economic growth and societal welfare. However, individuals and organizations face a social dilemma when deciding whether to share information with others: while sharing can create positive externalities, it may also reduce one's competitive advantage. We present an incentivized game to study the effect of two social factors on individuals' willingness to share information: reputational concerns arising in repeated interactions and the number of social connections. Our results point to limits of repeated interactions as a factor to motivate sharing of valuable information — we find that reputation increases information sharing, but only when the number of connections is low. We discuss some behavioral mechanisms that could drive our results.

JEL Codes: D01, D23, O30.

Keywords: Cooperation, Social Dilemmas, Reputation, Networks, Information Sharing.

1. INTRODUCTION

The sharing of valuable information is at the root of both economic growth and societal welfare (Romer (1986, 1990)). However, the incentives that individuals and organizations face when deciding to share information with others are often comparable to those of collective action problems (Boyd et al. (2018); Hess and Ostrom (2007)): while sharing can generate social benefits (e.g., sharing the solution to create a vaccine against COVID-19), it may also reduce the sharer's advantage relative to others. Such a tension between cooperative and competitive forces leads to the fundamental problem of *information-sharing dilemmas* (Cabrera and Cabrera (2002)). If not mitigated, such social dilemmas may have negative economic consequences.[1]

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[a]Corresponding author. CEREN EA 7477, Burgundy School of Business, Université Bourgogne Franche-Comté, Dijon, France. andrea.guido@bsb-education.com

[b]Toulouse School of Economics, CNRS, University of Toulouse Capitole and Institute for Advanced Study in Toulouse maxime.derex@iast.fr

[c]Montpellier Business School, Montpellier, France. r.romaniuc@montpellier-bs.com

[1]Due to this incentive-compatibility problem, modern economies have devised formal arrangements, such as intellectual property rights or trade secrecy (Levin et al. (1987); Boldrin and Levine (2008); Frischmann (2012); Frischmann et al. (2014)). Yet, in many circumstances, formal arrangements are either infeasible or undesirable (e.g., Boldrin and Levine (2008)). For example, in the early phase of a novel project, informal ways to govern cooperation need to be adopted because "institutions of the market (property rights, price signals) are often poor at dealing with this combination of a highly distributed, tacit and uncertain resource"

Past work has highlighted the importance, at both intra- and inter-organizational levels, of establishing frequent (i.e., repeated) interactions and highly-connected networks for promoting information exchange (Acemoglu et al. (2016); Elsner et al. (2014); Moretti (2021); Reagans and Mcevily (2010); Sorenson (2018)). For example, many countries have adopted policies favoring the creation of large clusters of firms (Buera and Kaboski (2012); Moretti (2021)). At the organizational level, managerial trends point towards increasing connectedness in workplaces to improve coordination and interactions among units (Bernstein (2012); Cabrera and Cabrera (2002)). However, there is a general lack of causal evidence on the effect of these two factors on the willingness to share information. In this paper, we study experimentally how information sharing is affected by (i) the opportunity for repeated interactions, and (ii) the number of network connections among whom information may be shared.

Our research hypotheses are drawn from two related intuitions. First, increasing the probability of repeated interaction between individuals may increase their willingness to share valuable information thanks to the emergence of reputational concerns and reciprocity (Kreps et al. (1982)). This conjecture is corroborated by the well-known result in experimental economics that cooperation in other social dilemmas such as public goods games increases with the probability of interacting with the same partners in a near future (Ghidoni et al. (2019); Keser and van Winden (2000)). While we draw upon this strand of experimental literature, information-sharing has a different incentive structure than cooperation in a standard public goods game. Information sharing dilemmas are generally characterized by a trade-off between competition and cooperation (Cabrera and Cabrera (2002)), which is not present in standard public goods games. In this sense, our study aims at investigating whether the reputational concerns that explain cooperation in public goods games can also drive information sharing in a different type of social dilemma.

The second intuition is that the force of such reputational concerns may decrease when network connectivity is high. In situations where others can easily track who did what (as for example in a less connected network), reputation may be more salient, and reciprocal concerns may play a more important role (Harkins and Petty (1982); Liden et al. (2004); Williams et al. (1981)). However, reputation may play a minor role in a more connected network where it is more difficult to monitor others' actions and hold them accountable. This empirical conjecture has not received a thorough causal answer yet.

To recreate the tension typical of information-sharing dilemmas, we adapted an existing task used to study collective innovations (Derex and Boyd (2016)). Subjects in the experiment are assigned to a position in an exogenously-given network, and compete against each other to reach the highest cumulative score in a repeated computerized task. The subject with the highest score in the final ranking receives the highest prize, the second receives the second highest prize, and so on. The computerized task consists of combining several objects that appear on the screen. A subset of feasible combinations lead to the discovery of "bonuses", which are individual premiums that boost future scores of the

(Allen and Potts (2016), p. 1037). Further, there are many instances in which firms and individuals prefer to voluntarily share valuable information – an act that often is individually costly while benefiting others (Allen (1983); Benkler (2004, 2006); Boldrin and Levine (2002); David (1998); Kinsella (2013); Lerner and Tirole (2003, 2005)). Examples range from the user innovation commons, the emergence in the late sixteenth and early seventeenth centuries of the idea and practice of "open science", to the development of open source software projects (David (2008); Levine and Prietula (2014)).

individual finding them (mimicking the effect of newly discovered innovations). Subjects finding a bonus in a given round can share it within their network of linked counterparts. In this way, obtaining a bonus is similar to having access to valuable information that gives benefits to those holding it. However, while the total score at the network level is highest when everyone shares their discovered bonuses with others, sharing is individually costly as it reduces one's chances of being ranked higher in the final ranking.

We study the effect of the frequency of interactions on information sharing, and how this interacts with the number of connections, by experimentally manipulating i) subjects' matching protocol and ii) the number of linked counterparts each subject interacts with in the game. In the *Partner* condition, subjects interact with the same linked counterparts for the whole duration of the experiment, while in the *Stranger* condition, one's counterparts change after each round.[2] Under both matching protocols, we vary the number of one's direct connections in the network. In one condition ($K = 2$), each subject is connected with two other subjects, while in the other condition ($K = 4$), each subject is connected with four other subjects.

Our results show that repeated interactions with same counterparts favor information sharing due to the emergence of reciprocal exchanges. However, information-sharing is higher in the *Partner* condition compared to the *Stranger* matching only when connectivity is low (i.e., when one interacts with few counterparts). The relative advantage of the *Partner* condition over the *Stranger* one vanishes out when we increase the number of one's counterparts. These results indicate that reputation works well to motivate information sharing only with a low network connectivity.

While our design does not allow us to entirely shed light on the mechanisms driving our results, we put forward some plausible explanations. One explanation hinges on the fact that individuals feel less the burden of scrutiny by, and accountability to, others when making decisions in more-connected networks relative to less-connected ones. Other alternative explanations are based on retaliation and punishment in networks, and the breakdown of group identity when social contacts are numerous. Lastly, we are able to rule out an explanation based on the presence of pessimistic beliefs in larger networks given the absence of significant differences in information sharing rates in the first round of the game across all conditions.

The paper is structured as follows. Section 2 discusses the related literature. Section 3 introduces the experimental design. Section 4 discusses the behavioral hypotheses and experimental procedures. Section 5 reports the experimental results and Section 6 discusses the potential mechanisms. Finally, Section 7 concludes.

2. RELATED LITERATURE

Our work relates to two main literature strands. We primarily contribute to the empirical literature studying information sharing. A series of papers have emphasized the role of repeated interactions in encouraging firms and individuals to share information with competitors (Catalini (2018); Choudhury (2017); Sorenson (2018)). Similarly, workers in

[2]It is worth noting from the outset that our Stranger condition does not correspond to a perfect stranger matching, meaning that there is a non-null probability that same subjects will interact more than once over the 30 rounds of the game. On the difference between perfect and imperfect stranger matching in the context of public goods games, see Botelho et al. (2009) and Ghidoni et al. (2019) for an analysis applied to prisoner's dilemma games.

a firm become more prone to share information about best practices when management policies promote frequent interactions among employees (Cabrera and Cabrera (2002)). In this context, empirical work has also emphasized the importance of networks. There is evidence showing that firms tend to self-organize into networks to interact more often with preferred partners (Acemoglu et al. (2016); Moretti (2021); Uzzi (1997)) or with partners of their partners (Guillen (2000); Gulati and Gargiulo (1999)). In the Silicon Valley environment of the 1980s, the emergence of social, professional and commercial network connectivity eased the exchange of ideas across firms and made possible technological break-throws (Cooke et al. (1998); Saxenian (1990); Storper (1995)).

However, the existing literature is either based on case studies or use observational data which makes it difficult to disentangle the determinants of information sharing within a network of individuals or firms. In particular, network connectivity negatively covaries with population size in real populations (West et al. (2020, 2014)). Large-scale groups are likely to display lower social connectivity than small ones.[3] Consequently, it is difficult to disentangle the effect of social connectivity from that of group size using observational data. Additionally, existing non-experimental studies do not investigate how repeated interactions among agents affects their willingness to share valuable information with others. Our laboratory experiment allows us to identify the effect of network connectivity and the frequency of interactions on sharing decisions in an environment where people compete for a number of prizes – akin to market competition where firms can engage in some form of collaboration that benefits society at large but may be costly at the individual level.

Second, given the similarities between information sharing and cooperation, we contribute to the vast economic literature showing how reputational concerns promote cooperation in social dilemmas (Dal Bó (2005); Dal Bó and Fréchette (2011); Fudenberg and Maskin (1986); Kreps et al. (1982)). From a theoretical standpoint, cooperation may be a rational strategy when interactions are repeated because of reputation concerns (Kreps et al. (1982)). There is ample experimental evidence showing the benefits of repeated interactions in social dilemmas. In the context of public goods games, Keser and van Winden (2000) compare cooperation rates in partner and stranger matching. In the partner matching, subjects participate in a repeated public goods game where group composition is stable over time. On the contrary, in the stranger setting, group composition varies after each round. The authors find that cooperation is higher when subjects interact repeatedly when group composition is fixed compared to when group members change in each round. This is because reputational concerns are present in the former case but not in the latter. Similarly, Botelho et al. (2009) find that the higher the probability of interacting with the same individuals in a public goods game, the greater the probability of observing cooperation instead of defection in a group. This result has been shown to hold in the context of two-person prisoner's dilemma games. Ghidoni et al. (2019) find that cooperation is more frequent in games where subjects expect to encounter the same counterpart in the future compared to when the probability of meeting again is null.

There are three main aspects that differentiate our work from the experimental literature on partner versus stranger matching in social dilemmas. The first one is that existing stud-

[3]This is also a mathematical property of networks. If there is an upper limit to one's number of social contacts (what is often referred to as Dunbar's number ((Dunbar, 1998)), network density, i.e., the number of links in a network over the number of possible links feasible, decreases as the number of agents increases.

ies focus on the effect of partner and stranger matching in the context of closed groups while our experiment analyzes sharing decisions when subjects are connected within a network. This aspect becomes relevant as there is a growing literature studying cooperation in networks rather than groups because networks better mimic the complex social interdependencies that people have in real-life (Hauser et al. (2016); Rand et al. (2011)).

Second, the extant literature focuses on behavior in the context of public goods games where one's self-interest is not necessarily aligned with the group's interest. While studies on public goods are useful for understanding a myriad of non-market decisions, we believe that they do not fully capture market interactions where individuals and firms compete for a number of prizes (e.g., market shares) but also have the possibility to cooperate with each other. Our experiment implements an environment that allows us to capture such interactions.[4]

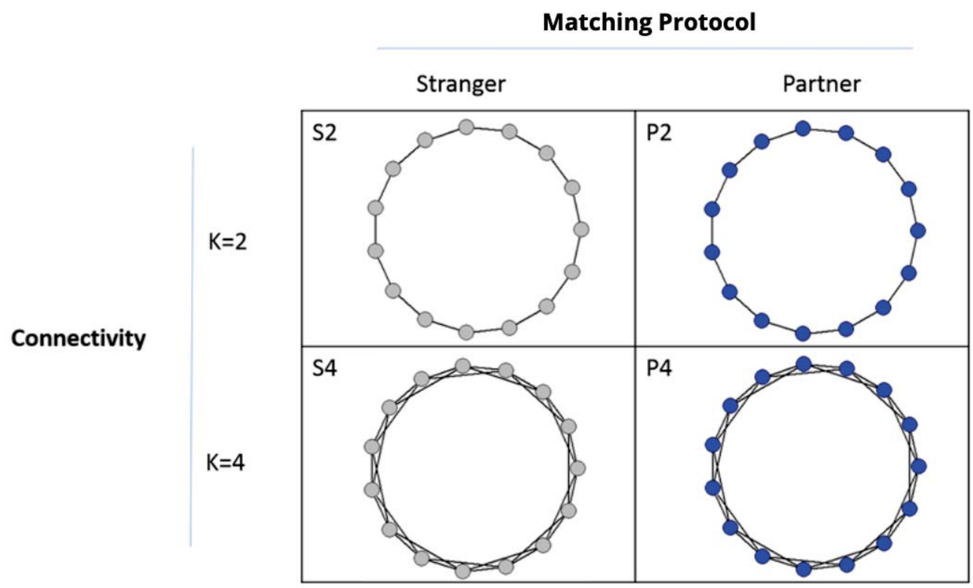
The third element that differentiates our work from the existing experimental literature on cooperation is that our experiment considers a hitherto neglected factor when comparing partner and stranger matching – the number of agents with whom one interacts. Previous studies comparing partners to strangers utilize standard group size (3 or 4 subjects in the same group) reporting that sustaining reciprocity becomes more challenging in larger groups (Nosenzo et al. (2015); Zelmer (2003)). To the best of our knowledge, only theoretical past work has shed light on the role of network connectivity, showing that free-riding is harder to be detected and sanctioned in highly-connected networks, which leads to the quick unravelling of cooperation (Boyd and Richerson (1988a,b)). Our experiment varies the number of connected individuals, thereby allowing us to compare partner and stranger matching when individual connections are high versus low.

3. EXPERIMENTAL DESIGN

To study the effect of network connectivity and repeated interactions on costly sharing decisions, we design a laboratory experiment in which subjects (15 in the whole session) compete against each other to find medical solutions to the spread of a virus. The choice of providing a context in the experiment is justified by the fact that subjects can more easily understand the experimental situation and increase engagement in the task. Our experimental design considers 4 between-subjects treatments varying in the number of connections (K) each subject has in the network (either 2 or 4) as well as the protocol implemented to match subjects in the network: *Partner* if one's counterparts are held fixed throughout the whole experiment or *Stranger* if one's counterparts are randomly shuf-

[4] Given that in our experiment subjects compete for a number of prizes, we should also note that our paper is related to the experimental literature investigating contests (e.g., Sheremeta (2018) provides a review of the literature on group contests). There are, however, important differences between research on group contests and our experiment. First, in group contests, participants expand costly effort with the objective to increase the probability of their group winning the contest. This creates an incentive for members of a group to cooperate with each other. Our experiment implements individual rather than group contest and cooperation does not take place within closed groups that may be in conflict with other groups. Instead, in our case, interactions take place within a large network where individuals compete with others for a number of prizes knowing that they can also choose to cooperate, thus reducing their own relative advantage (it is worth reminding here that except for the lowest ranked subject, every subject receives a prize but the size of the prize depends on one's position in the final ranking). The second major difference is that contrary to group contests, our game is not a negative-sum game. Subjects in our experiment generate positive externalities for others, in case they opt to cooperate, thereby increasing the size of the pie.

Figure 1: Summary of the experimental design.



fied in each round of the game. Specifically, in all experimental conditions implementing the *Stranger* matching protocol, i.e., conditions *S2* and *S4*, each subject is linked to 2 or 4 counterparts who randomly change in each repetition of the game. In all experimental conditions implementing the *Partner* protocol matching, such as *P2* and *P4*, subjects are connected with the same 2 or 4 counterparts throughout the whole experiment. As a consequence, our design involves a total of 4 treatments (*P2, P4, S2, S4*) summarized in Figure 1.

We now describe in more detail our experimental game. Subjects go through 30 rounds of the game which involves two decision stages. At the beginning of a round, each subject plays an individual task in which they select three objects out of sixteen available (see Figure 2). In each round, subjects are given 1 minute to make their choices.[5] Each possible combination in the game is associated with a unique score *a-priori* unknown to subjects. The distribution of scores is defined before the start of our experiments such that there is always one combination giving the highest score in a given round.[6] More formally, the score a subject receives in a given round t is defined as:

$$Score_{it} = (o_{1t} + o_{2t} + o_{3t}) * m_i$$

where $o_j,\ j \in \{1, 2, 3\}$ is the score associated with each of the objects chosen by subject i; the individual parameter m is a multiplier of the total score and is initially set to $m = 1$ for all individuals. A subset of such combinations (40% of the total) lead to the discovery

[5]In the game, subjects can drag and drop objects, change combinations within the 1 minute time limit, and can confirm their choice by pressing a confirm button.

[6]In our setup, a total of 516 possible combinations were feasible. Scores associated with each of these combinations are defined prior to the start of the experiment.

of “bonuses", that is, additional objects that increase a subject’s future scores in the game.[7] Specifically, finding a bonus increases a subject’s m by 10. Therefore, in all subsequent rounds, a subject’s future combination scores are multiplied by a higher factor. Under these incentives, sharing a bonus is akin to sharing of information in real contexts, as it would allow an organization to work more efficiently in the future.[8]

The second decision-stage of our game is conditional on whether a subject found a bonus in that particular round or not. When finding a bonus, a subject can decide to share it with all their linked counterparts. For example, if subject i has 2 linked counterparts (e.g., j and k) and decides to share the bonus found, then m_i, m_j and m_k increase of 10 from the subsequent round. Conversely, if i decides not to share, only their own m_i will be increased. Sharing decisions are made simultaneously among all subjects finding a bonus, without receiving any kind of feedback regarding their linked counterparts’ results from the first stage. Moreover, individuals cannot choose a subset of their linked counterparts to share the benefits of bonuses. Lastly, a subject can receive multiple bonuses at the same time if his counterparts find a bonus and decide to share. These, can be added to the subject’s own bonus, should he finds one in that round. Therefore, in a given round, depending on the network links one has, a subject can have a maximum increase in m by 30 (if $K = 2$) or 50 (if $K = 4$).

At the end of each round, after making their sharing decisions, all subjects receive aggregate feedback regarding how many among their linked counterparts found a bonus and their sharing decisions.[9] After receiving the feedback, subjects start a new round of the game. It is important to note that subjects were informed in the instructions that each combination yields an individual score and that some may result in a bonus that can be shared with others. Specifically, subjects were informed that a bonus will significantly impact their own earnings in rounds that follow and would have the same impact on others’ earnings if shared.

At the end of the experiment, subjects are ranked according to their final score (the sum of scores obtained over the 30 rounds) and obtain an individual monetary earning based on it and their position in the final ranking. Subjects were informed prior to the start of the game that the higher their final position in the ranking the higher will be their individual earnings. In particular, a subject ranked last gets no extra score, a subject ranked as penultimate gets 4% of their final accumulated score, and so on. The first ranked gets 56% of their final accumulated score as extra payment.

Put formally, at the end of the experiment, a subject earns:

$$Final\ Score_i = \sum_{t=1}^{30} Score_{it} * (1 + Rank\ bonus)$$

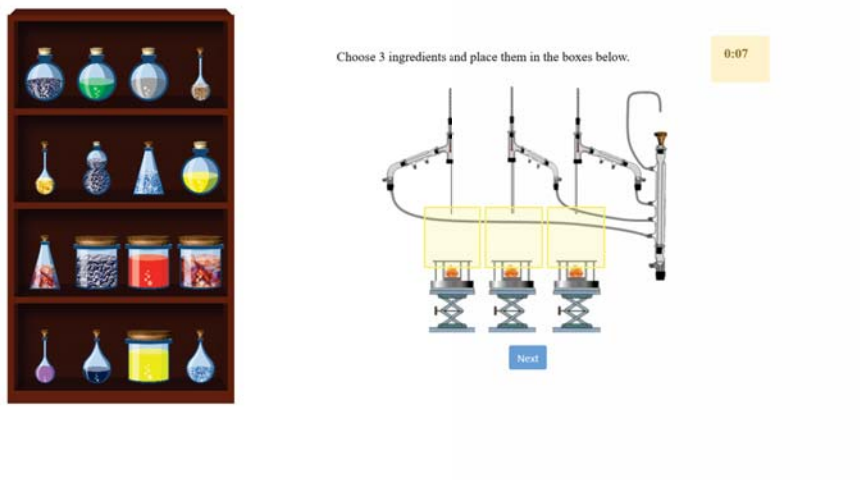
where $Rank\ bonus = (15 - Rank_i) * (0.04)$ and $Rank_i$ is the ranking of i.

[7]In the game, a bonus object is represented by a capsule that is added to each combination and increases their effectiveness. See Figure A4.

[8]The discovery of a bonus in our game resembles a technological shock that impacts a firm’s production efficiency.

[9]Information is given in such a way subjects cannot identify which linked counterparts found a bonus and shared it, but they can only know aggregate numbers in their network. We do so to eliminate possible reactions to the decision of some specific subject.

Figure 2: Screenshot of the combinatorial task.



Thus, subjects have an interest in maximizing their score in each round and to top the final ranking if they want to maximize their earnings. In designing our game, we paid attention to some relevant features. First, the search for new information that may turn into a valuable input requires exploring an unknown landscape of outcomes and opportunities whose results are often opaque. For these reasons, we designed a combinatorial task in which, in each round, subjects could explore a set of objects whose score was *a-priori* unknown to them. Second, our task requires subjects to exert effort in finding profitable combinations which determine their final earnings. Past experiments have shown that subjects have a higher sense of entitlement to earnings or earned endowments in real-effort tasks (e.g., see Carpenter and Huet-Vaughn (2019); Hoffman et al. (1994); Thaler and Johnson (1990)). Such an aspect is relevant for our study because people often feel entitled to their discoveries and are reluctant to share information given the effort and resources devoted in the discovery process. The fact that subjects' effort in the game did not affect their probability of finding a bonus does not raise concerns because this information was not revealed to subjects. Subjects acted on their beliefs that there is some rule in the way one needs to combine three objects in order to obtain a bonus. At the same time, there was no deception because we simply informed subjects that some combinations allow them to obtain a bonus without specifying whether there is a rule in the way objects need to be combined that would guarantee a bonus.

It is important to stress that we chose to exogenously fix the probability of finding bonuses, which is the same irrespective of subjects' choices in the task because it allows us to rule out individual factors, such as cognitive abilities, that would have resulted in different performances. Thus, the sharing decision in our experiment is not influenced by factors such as the number of bonuses found because all subjects have the same probability of finding a bonus in a given round. Furthermore, the sixteen objects were different in each round. Such a feature allows us to avoid that subjects focus and exploit a particular combination of objects. Lastly, given the probability of 40% in each round to find a bonus, our game is repeated for 30 rounds to obtain on average 12 sharing decisions for each subject, a number that is close to the number of rounds in many repeated public goods games, in particular the ones played on networks (see Rand et al. (2011)).

4. BEHAVIORAL HYPOTHESES AND EXPERIMENTAL PROCEDURES

4.1. *Behavioral Hypotheses*

Following our experimental design, we aim at addressing to two main research questions. We first aim to test whether repeated interactions encourage higher sharing of information. Past experiments studying cooperation in standard economic games, such as prisoner's dilemmas or public goods games, show that repeated interactions help alleviate the free-riding problem thanks to the emergence of reputation and reciprocal interactions (Andreoni and Miller (1993); Ghidoni et al. (2019); Keser and van Winden (2000)). Indeed, when interactions are repeated among same individuals, they may find cooperation to be a rational strategy to pursue (Kreps et al. (1982)). This evidence suggests that cooperation is dependent on the subjects' perception of future interaction. The tendency to cooperate is greater when subjects anticipate prolonged interaction with others as members of a group. We aim to extend these previous findings to the study of information sharing. For this reason, we expect that sharing of information under *Partner* networks will be higher than sharing observed under *Stranger* ones.

Hypothesis (H1): *Sharing of bonuses in Partner networks will be higher than sharing observed in Stranger networks.*

Secondly, we look at the interaction between repeated encounters and network connectivity. While our first research question addresses the emergence of reciprocal exchanges by comparing partner and stranger matching, our second question is whether the reputational concerns decrease in more connected networks. To the best of our knowledge, there is scarce evidence on the effect of network connectivity on information sharing in repeated interactions. Most of the extant work in this area is either observational or focuses on case studies (Cooke et al. (1998); Saxenian (1990); Storper (1995)). Some useful insights may come from the literature in experimental economics studying cooperation in standard settings, such as Prisoner's Dilemmas or Public Goods games. However, this literature presents two main limits. The first concerns the presence of scarce and mixed evidence on the effect of connectivity on cooperation (Gracia-Lázaro et al. (2012); Kirchkamp and Nagel (2007)) and the fact that results depend on the setting implemented (Semmann (2012); Traulsen et al. (2010)). The second main limitation is that most studies consider interactions in groups, rather than in networks, and experimentally vary the group size. For example, related meta-analytic evidence on the effect of group size suggests that a larger group size is detrimental to sustaining high level of cooperation in public goods games (Nosenzo et al. (2015); Zelmer (2003)). Yet, these works do not capture the tension between cooperation and competition. Moreover, our experimental environment differ in the fact that we do not consider groups, but networks, with the goal of manipulating connectivity, rather than group size.[10]

We put forward some possible mechanisms for why reciprocity can thrive in less-connected networks.[11] The first is based on the fact that actions in more-connected networks are less accountable among peers. In fact, when connectivity is high and individuals

[10]A notable exception is Rand et al. (2014) in the context of repeated Prisoner's Dilemma. Yet their framework does not capture both competition and cooperation that we intend to recreate in our design.

[11]For an evolutionary perspective, the reader is addressed to models of cooperation which have demonstrated that reciprocal concerns diminish as the number of interacting individuals increases (Boyd and Richerson (1988b); Nowak (2006)).

have many counterparts, individuals may feel less “under the spotlight" when making decisions, which results into lower social pressure (Harkins and Petty (1982); Harkins et al. (1980); Liden et al. (2004); Williams et al. (1981)).

Secondly, the greater the number of social connections, the more likely one is to meet free-riders. This can negatively impact reciprocity for a simple reason. When there exists no alternative way to punish free-riders than defecting on one’s connected peers, defection harms also other cooperators within the same network. Given that most of subjects in experiments are conditional cooperators, – individuals whose cooperation depends on others’ cooperation levels (Fischbacher et al. (2001)), punishing a free-rider with defection may even trigger further defection.

Thirdly, beliefs may play a role in this context. Early experimental evidence in the context of public goods games suggests that subjects believe that reciprocal interactions are more likely to take place in smaller groups than in larger ones (Brewer and Kramer (1986)). Recent evidence confirms these results by showing that participants in standard public goods games believe that larger groups are less cooperative since it is easier to interact with free-riders (Diederich et al. (2016)). If subjects bring such expectations to the laboratory, before interactions take place, reciprocity-based cooperation is less likely to emerge in larger networks.

Lastly, subjects may perceive group identity as a more salient feature in less-connected networks than in highly-connected ones. This channel is based on social identity theory which predicts that group identity salience is reduced in bigger groups (Charness and Chen (2020)). In this sense, higher connectivity can reduce the salience of group identity and increases the exposure to diverse individuals, which can weaken the preference for in-group members and the motivation to reciprocate with them (Ren et al. (2007).

While we are not able to identify which of these channels play a major role in our context, we conjecture that the sharing of bonuses is likely to be higher in less-connected networks given easier the peer-monitoring and greater social pressure to contribute. As such, we expect the difference in sharing between *Partner* and *Stranger* networks with $K = 4$ (P4 vs S4) to be smaller than that observed under conditions with connectivity $K = 2$ (P2 vs S2).

Hypothesis (H2): *The higher the connectivity in the network, the lower the difference between Partner and Stranger networks in terms of sharing.*

Our design allows us to to test H2 by performing a comparison that is in the spirit of difference-in-difference analyses between *Partner* and *Stranger* matching protocols with the same connectivity levels.

4.2. *Experimental Procedures*

Laboratory sessions were run at the Laboratory for Experimentation in Social Sciences and Behavioral Analysis (LESSAC) - Burgundy School of Business, in Dijon, France, using student subjects recruited through the LESSAC’s subject pool. Sessions were run over September-November 2020. In each session, 30 students were recruited and, upon their arrival, they were randomly assigned to cubicles. The experimenter then read out loud the instructions of the game.[12] All subjects were at least 18 years old and none

[12] Instructions and screenshots of the game translated into English are reported in the Appendix.

TABLE I
SHARING RATES PER TREATMENT AVERAGED ACROSS INDIVIDUALS.

	Partner	**Stranger**	**Difference**
$K = 2$	0.81 (0.21) N = 75	0.68 (0.31) N = 75	0.13 $p < .01$ $d = 0.48$
$K = 4$	0.69 (0.31) N = 75	0.64 (0.33) N = 75	0.05 $p = .30$ $d = 0.17$
Pooled Average	0.75 (0.27) N=150	0.66 (0.32) N=150	0.09 $p < .01$ $d = 0.30$

Notes: In brackets, standard deviations. N indicates the number of subjects. In column *Difference*, we report the difference between partner and stranger sharing rates, holding constant the same level of connectivity, along with the p-value of a pairwise t-test, and Cohen's *d*.

had previously participated in a social dilemma experiment. A subject's earnings at the end of the experiment depended entirely on their choices. There was no show-up fee, as we complied with the LESSAC's payment policy. A total of 300 subjects participated in the experiment in 20 independent networks, that is 5 networks for each treatment in our experimental design (i.e., 75 subjects in each treatment). The computerized game was coded using oTree (Chen et al. (2016)) and subjects went through a tutorial and an assessment quiz before starting the first round. Subjects needed to respond correctly to all the questions in the quiz in order to proceed. The average payment in the experiment was 18 euros and sessions lasted on average 90 minutes.

5. RESULTS

We now analyze subjects' sharing decisions. We focus on the percentage of total bonuses shared during the game by each subject (henceforth, sharing rates). Sharing rates in treatments implementing a partner matching are overall 9% higher than those implementing a stranger matching protocol (Table I; pairwise t-test, $p < 0.01$, Figure 3). The magnitude of the effect size associated with the comparison between *Partner* and *Stranger* is substantial (Cohen's *d* = 0.30).

Results are confirmed by estimates from regression models of individual-level sharing decisions (Table II). Overall, the probability of sharing is higher under *Partner* than in *Stranger* (*log-beta* = 0.433, Model (1)). Furthermore, when looking at its dynamic over game rounds, sharing rates steadily decline in *Stranger* matching protocol (variable *Round*, Models (2)-(3), *log-beta* equal to -0.011 and -0.022, respectively), while remain stable under *Partner* matching (interaction with dummy *Partner* in Model (3), *log-beta* = 0.025).

Figure 4 depicts the unraveling of sharing rates over rounds under *Stranger* matching protocol. Put together, these results show evidence in support of our first hypothesis: Repeated interactions promote sharing. The gap between *Stranger* and *Partner* networks becomes significant over repetitions.

We now move on to testing of our second hypothesis. Our aim is to estimate the in-

Figure 3: Sharing rates broken down by matching protocol (top panel) and connectivity (bottom panel).

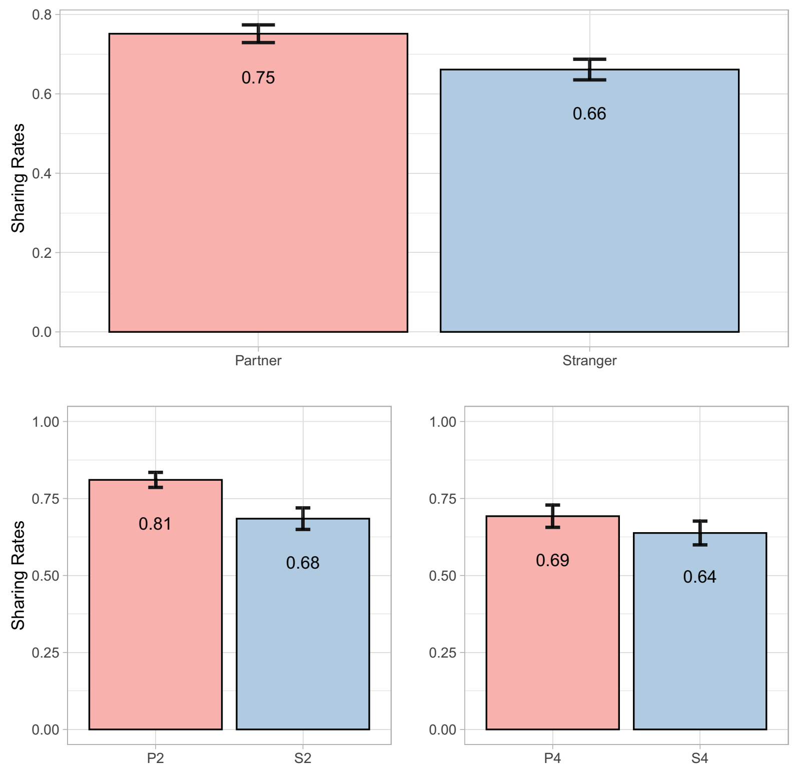


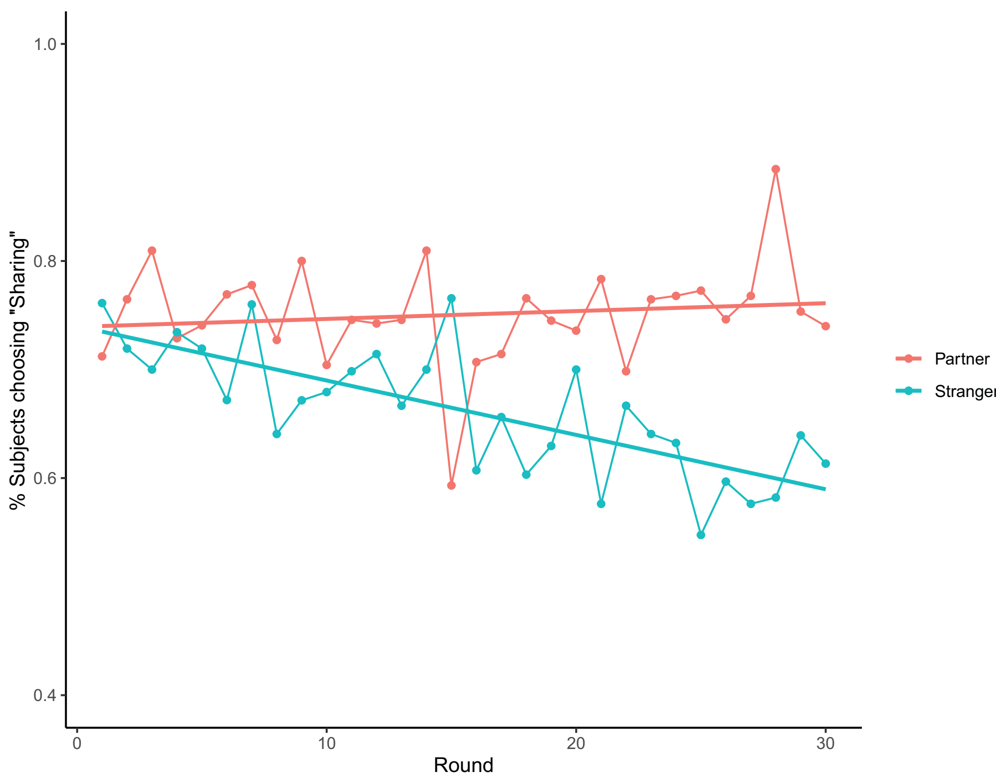
TABLE II

CLUSTERED-ERRORS LOGIT REGRESSION OF SHARING DECISIONS ACROSS PARTNER AND STRANGER MATCHING PROTOCOLS.

	Sharing decision		
	(1)	(2)	(3)
Partner Matching	0.433***	0.436***	0.031
	(0.074)	(0.074)	(0.141)
Round		−0.011***	−0.022***
		(0.004)	(0.005)
Round*Partner Matching			0.025***
			(0.008)
Constant	0.727***	0.903***	1.087***
	(0.067)	(0.092)	(0.107)
Observations	3,774	3,774	3,774
Log Likelihood	-2,268.738	-2,265.029	-2,260.336
Akaike Inf. Crit.	4,545.475	4,540.058	4,532.672

Notes: errors clustered at the network and round level. *p<0.1; **p<0.05; ***p<0.01.

Figure 4: Evolution over rounds of sharing rates under both *Partner* and *Stranger* matching.



terplay between repeated interactions and network connectivity. The gap in sharing rates between *Partner* and *Stranger* becomes wider and significant larger over round when connectivity is low (i.e, $K = 2$, $p < 0.01$, Cohen's $d = 0.48$, medium effect; Table I; Figure 3) while it shrinks under higher connectivity level (i.e., $K = 4$, $p = 0.30$, Cohen's $d = 0.17$, small effect; Table I; Figure 3). Sharing rates are similar at the beginning of the game across all treatments (chi-square test on contributions in round 1, p = 0.55). Yet, when looking at the last round of the game (round 30), sharing rates are significantly lower in S2 than in P2 conditions (chi-square test on sharing rates in round 30, p = 0.03) but statistically equivalent between P4 and S4 conditions (chi-square test on contributions in round 30, p = 0.13).

These results are confirmed by regression estimates of individual-level sharing decisions (Table III). Consistently with our pairwise tests, the probability of sharing is higher under *Partner* matching (variable *Partner*, Model (1), *log-beta* = 0.665, $p < 0.01$; Table III), yet the positive effect of repetition on sharing is substantially resized when connectivity increases (interaction *Partner Matching* * *K = 4*, Model (1), *log-beta* = -0.811, $p < 0.05$; Table III). Results hold even after including time-related variables. The probability of sharing decays over time under *Stranger* matching (variable *Round*, Model (3), *log-beta* = -0.022, $p < 0.01$; Table III), yet, consistently to the previous analyses, high levels of sharing are sustained over time under *Partner* (interaction $Round{*}PartnerMatching$, Model (3), *log-beta*= 0.025, $p < 0.01$; Table III).

These results support our second hypothesis: Higher connectivity reduces the positive effect of repeated interactions on sharing rates.

To better understand our results, we analyze the emergence of reciprocal exchanges under *Partner* matching protocol. Because repeated interactions over time allow for the

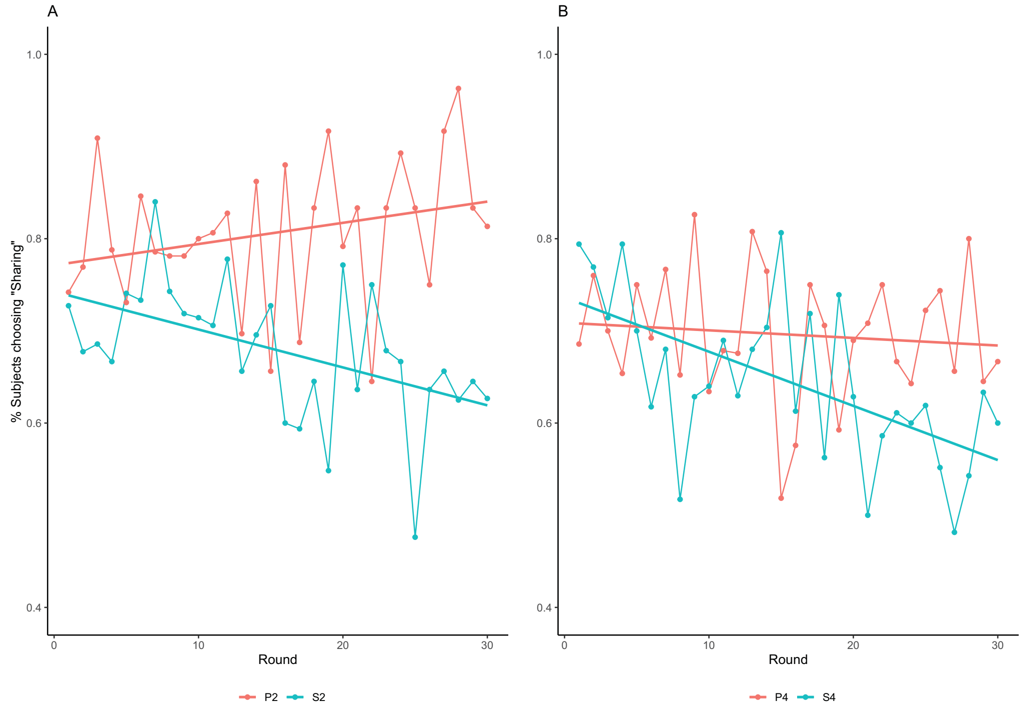
TABLE III

CLUSTERED-ERROR LOGIT REGRESSION OF SHARING DECISIONS ACROSS TREATMENTS.

	Sharing decision		
	(1)	(2)	(3)
Partner Matching	0.665^{***}	0.666^{***}	0.254
	(0.101)	(0.101)	(0.164)
K = 4	-0.168^{*}	-0.168^{*}	-0.169^{*}
	(0.100)	(0.098)	(0.098)
Round		-0.011^{***}	-0.022^{***}
		(0.004)	(0.005)
Partner Matching * K=4	-0.429^{***}	-0.427^{***}	-0.428^{***}
	(0.144)	(0.144)	(0.142)
Round*Partner Matching			0.025^{***}
			(0.008)
Constant	0.811^{***}	0.985^{***}	1.171^{***}
	(0.082)	(0.103)	(0.118)
Demographics	Yes	Yes	Yes
Observations	3,774	3,774	3,774
Log Likelihood	-2,251.844	-2,248.236	-2,243.387
Akaike Inf. Crit.	4,515.688	4,510.471	4,502.775

Notes: errors clustered at the network and round level. *p<0.1; **p<0.05; ***p<0.01.

Figure 5: Evolution over rounds of sharing rates under Partner and Stranger matching protocols, divided by network connectivity (Panel A, K=2; Panel B, K=4).



emergence of reciprocal exchanges, we investigate whether subjects behave reciprocally under treatments *P2* and *P4* and whether higher connectivity hampers the emergence of reciprocity. Table IV reports estimates from regression models of sharing decisions in a given round on the number of received bonuses from others in previous rounds of the game. Results from Model (1) show that receiving bonuses in previous rounds increases the probability of sharing in subsequent ones under *Stranger* (variable *N. Innovation received*, Model (1), *log-beta* = 0.636, $p < 0.01$) but the effect is stronger under *Partner* matching protocol (interaction *N. Innovation received* * *Partner*, Model (1), *log-beta*$= 0.602$, $p < 0.01$). When contrasting both *Partners* networks, higher network connectivity K hampers the emergence of reciprocal exchanges (variable *N. Innovation received* * *K=4*, Model (2), *log-beta*$=-0.459$, $p < 0.05$).

6. DISCUSSION

This study shows that information sharing is more likely when subjects interact repeatedly with the same network than when encounters take place at random. Reputational concerns triggered by repeated encounters favor the emergence of reciprocal relations: individuals view sharing information as a rational strategy to pursue because it triggers mutual generosity (Kreps et al. (1982)). This evidence is in line with past experiments implementing cooperation dilemmas (Ghidoni et al. (2019); Keser and van Winden (2000)) and empirical studies showing that firms often share information among a subset of competitors by establishing a network of reciprocal relations (Elsner et al. (2014); Reagans and Mcevily (2010)). We also find that reciprocity is harder to sustain when networks are more connected. By comparing *Partner* and *Stranger* experimental conditions in a difference-in-difference analysis, we find that the benefit of repeated interactions dimin-

TABLE IV
CLUSTERED-ROBUST LOGIT MODELS OF SHARING DECISIONS ACROSS CONDITIONS.

	Sharing$_{it}$	
	(1)	(2)
	Full Sample	Only *Partner*
N. Innovation received$_{t-1}$	0.636^{***}	1.531^{***}
	(0.175)	(0.249)
Partner	0.449^{***}	
	(0.073)	
Round	-0.055^{***}	-0.059^{***}
	(0.009)	(0.013)
N. Innovation received$_{t-1}$$*$Partner	0.602^{***}	
	(0.148)	
N. Innovation received$_{t-1}$ $* K$		-0.459^{**}
		(0.227)
Constant	1.615^{***}	2.211^{***}
	(0.161)	(0.233)
Demographics	Yes	Yes
Demographics	Yes	Yes
Observations	3,774	1,880
Log Likelihood	-2,241.135	-1,034.646
Akaike Inf. Crit.	4,496.270	2,081.291

Notes: errors clustered at the network and round level. *p<0.1; **p<0.05; ***p<0.01.

ishes when network connectivity increases. Such a moderating effect of connectivity can be due to several factors. The first deals with the fact that higher network connectivity decreases accountability, reducing social pressure. Subjects may feel less “under the spotlight" when deciding whether to share information in more-connected networks (Liden et al. (2004); Williams et al. (1981)).

Second, retaliation in more-connected networks is more costly, as it affects all of one’s linked counterparts. This may make it harder to sustain cooperation through the (implicit) threat of punishment.

A third possible mechanism we put forward in Section 4 relies on pessimistic beliefs, i.e., subjects may believe that reciprocity is harder to trigger in larger networks (Brewer and Kramer (1986); Diederich et al. (2016)). Lastly, we also suggested a mechanism based on group identity (Charness and Chen (2020)), which can become less salient in more connected networks if exposure to diverse individuals weakens the preference for in-groups.

It is hard to determine which mechanism drives our results with our data. However, the belief mechanism seems the least plausible to us, as first-round contributions are statistically indistinguishable between P2 and P4 networks (chi-square test on contributions in round 1, p = 0.55; see also Figure 5). If subjects had pessimistic beliefs about cooperation in more highly connected networks, we would observe lower sharing rates from the beginning of the experiment.

A possible criticism of our experimental design is the concern that subjects may have chosen triads at random. In this case, the criticism would go, they might share not out of reciprocity, but simply because they did not feel entitled to their discoveries. However, analysis of the choices made suggest that subjects did not make random choices in the combinatorial game. We find that some items in the game have a higher frequency to be chosen than others in a given round (chi-square test $p < 0.01$). This indicates that subjects in the game are likely not to make their choices completely at random but rather following some item feature (colors, shape, etc.).[13]

7. CONCLUSION

The success of individuals and organizations hinges upon the exchange of information gathered from the environment (Elsner et al. (2014); Henrich (2016)). However, at the root of information sharing lies a tension between collective and individual interests, typical of collective action problems (Boyd et al. (2018); Hess and Ostrom (2007)). While the action of sharing can create positive externalities to others, it reduces one’s competitive (for instance, market) advantage. The misalignment between cooperative and competitive forces can be an obstacle to socially beneficial sharing.

Motivated by the similarities between information sharing dilemmas and collective action problems (Hess and Ostrom (2007)), we shed light on the reputational and network connectivity mechanisms to facilitate information sharing (Cabrera and Cabrera (2002); Elsner et al. (2014); Ghidoni et al. (2019); Keser and van Winden (2000)). We designed a laboratory-incentivized experiment to study the role of these two factors in a novel information-sharing task. Our 2X2 design allows us to identify the effect of repeated encounters in both more- and less-connected networks.

[13]This interpretation is supported further by the subjects’ comments during debriefing session, where they indicated that their combinations were chosen based on patterns of shapes and colors.

The main lesson from our experimental results is that repeated interactions favor information sharing when connectivity is low. Reciprocity arising in repeated interactions vanishes as network connectivity increases; subjects are more inclined to respond reciprocally when connected to fewer counterparts. Although our design does not allow us to disentangle competing explanations, we have proposed some mechanisms based on punishment and conditional cooperation (Fischbacher et al. (2001)), group identity (Charness and Chen (2020)) and social pressure when making decisions (Liden et al. (2004); Williams et al. (1981)).

Some recent work has put forward the importance of network interventions aiming both at i) increasing network connections and reducing barriers that impede the flow of new information (through, for example, the creation of open-access resources, Evans and Reimer (2009); Sorenson and Fleming (2004)) and ii) spurring long-lasting relations among actors (Catalini (2018)). Our study provides experimental evidence on how these two factors, objects of public policies, may interact antagonistically in affecting sharing decisions. Furthermore, the advantage of using controlled experiments allowed us to address issues that cannot be tackled using field experiments. In particular, real-world network connectivity positively covaries with population size, making it impossible to disentangle the effect of former from that of the latter factor.

Our work also relates to the literature studying the effect of network structures on cooperation. Recent evidence shows that less-connected static networks favor the emergence of cooperation in repeated social dilemmas, such as the N-person prisoner's dilemma (Rand et al. (2014)). However, the existing experimental evidence provides mixed results (Gracia-Lázaro et al. (2012); Kirchkamp and Nagel (2007)) and often results depend on the game settings (Semmann (2012); Traulsen et al. (2010)). In contrast to these contributions, we study a novel situation, the sharing of information, in a setting where subjects face decisions that better reflect the trade-offs confronted by competing firms or individuals.

Our work has several limitations. First, we do not examine the mechanisms underlying the moderating effect of network connectivity. Future work should propose a thorough test of the mechanisms explaining these results. Second, different forms of networks, as well as degrees of connectivity should be tested. This would provide a more robust check of our findings. Lastly, our innovation game focuses on the sharing of profitable discoveries, leaving aside the process of innovation itself. To increase external validity, further work should study the factors that not only favor sharing, but also facilitate the the whole process of discovery. We leave these and other related questions for future work.

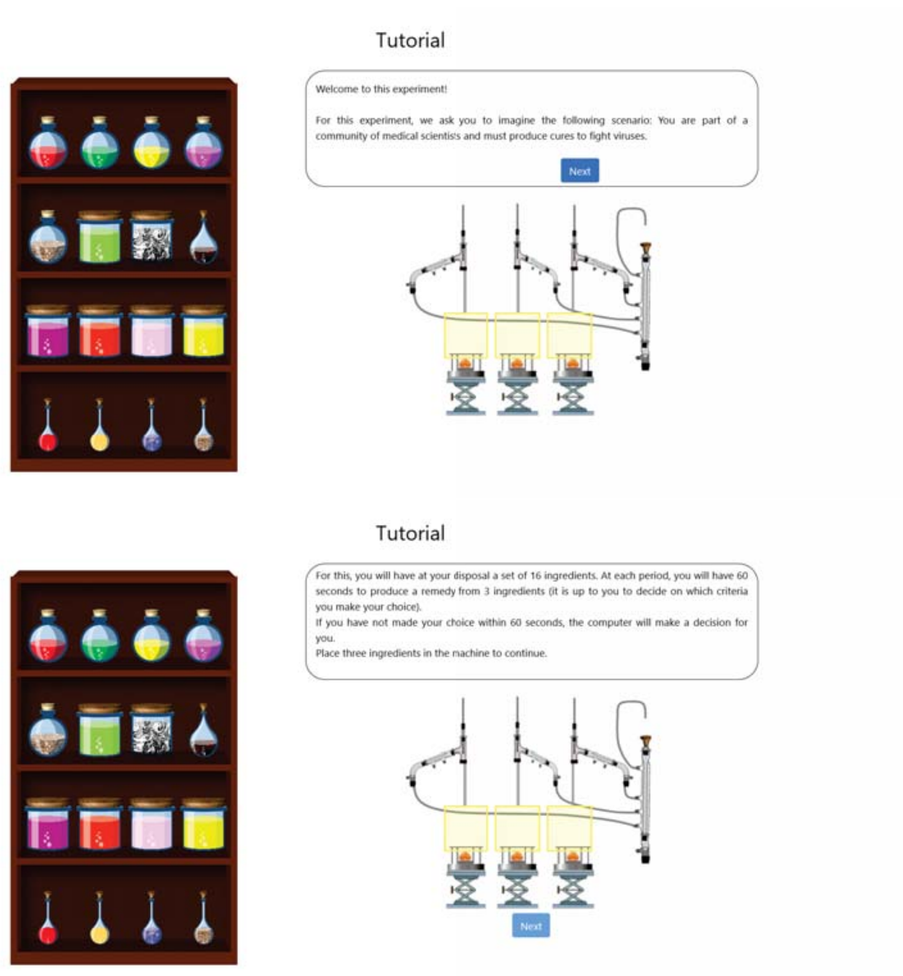
APPENDIX

A1. SCREENSHOT AND INSTRUCTIONS OF THE COMBINATORIAL TASK

Prior to the start of the paid rounds, subjects face a guided tutorial illustrating the combinatorial task at hand, the information given in each round, and decisions to take in each game stage. Subjects read instructions displayed on the screen (Figures A1-A3). During the combinatorial task, each participant has to pick three out of the 16 objects (ingredients) and place them into the yellow boxes so as to produce combinations for that round. Once the participant has dropped the three objects, he/she can confirm the choice by pressing the button right below. In each round, the set of 16 objects changes.

When individuals find an bonus, a new object is added to the figure on the right (see Figure A4). Such new item increases of 1 the parameter m in the payoff function of the

Figure A1: Screenshot of the game tutorial. In these two screens, subjects learn how to produce combinations by dragging and dropping three ingredient out of the 16 available.



subject. According to the treatment, subjects receive a different feedback page reporting the results of the sharing stage (Figure A3.1-A3.2).

Figure A2: Screenshot of the game tutorial. In these screens, subjects are informed about their individual score obtained in each round, their cumulative scores, and the ranking. Subjects learn that their final payments at the end of the experiment is based on both their cumulative score and ranking.

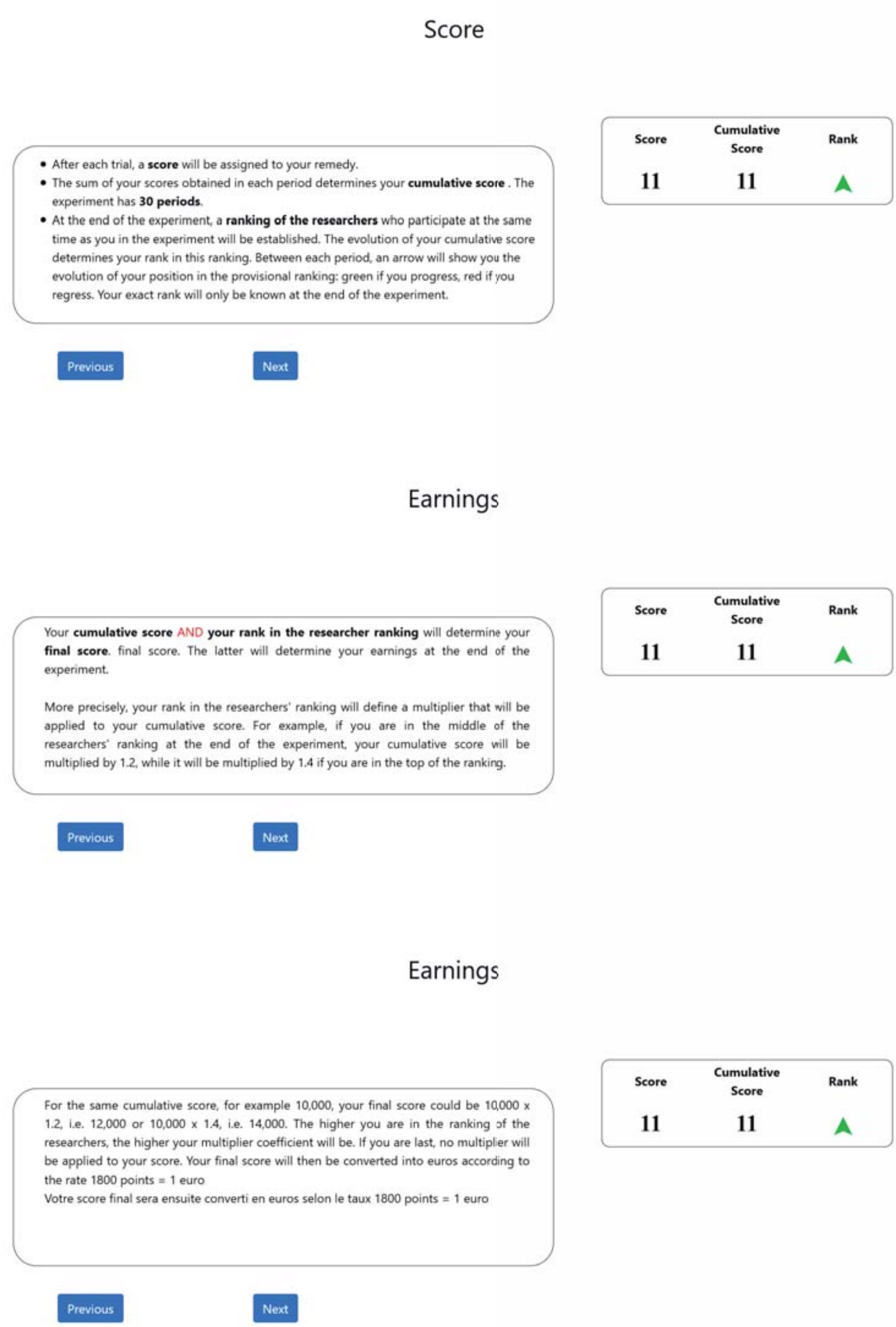
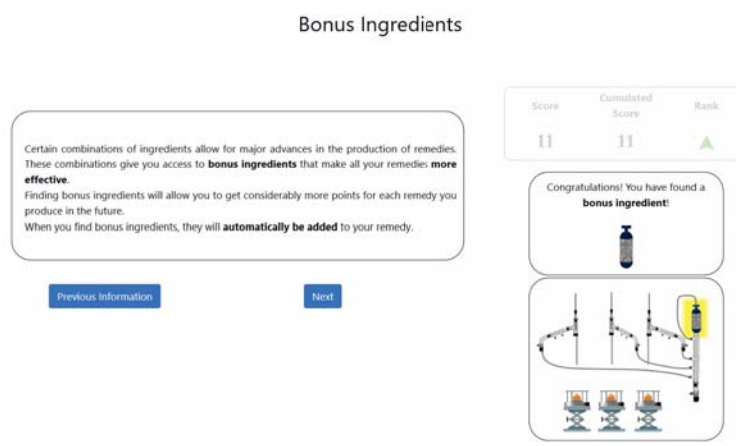


Figure A3: Screenshot of the game tutorial. In these screens, subjects are told that a subset of all possible combinations lead to the discovery of additional ingredients that increase the effectiveness of future combinations. Lastly, subjects learn about the possibility of sharing the benefits from the discovery of bonuses with their connected partners. The number of partners displayed (either 2 or 4) as well as the message reminding subjects that they are either connected with the same or different counterparts (depending on the matching protocol) changes based on the treatment considered.



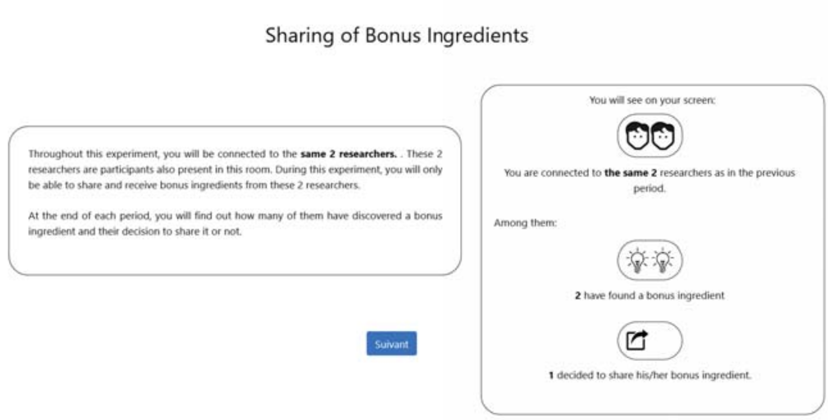


Figure A4: Screenshot of the new item added.

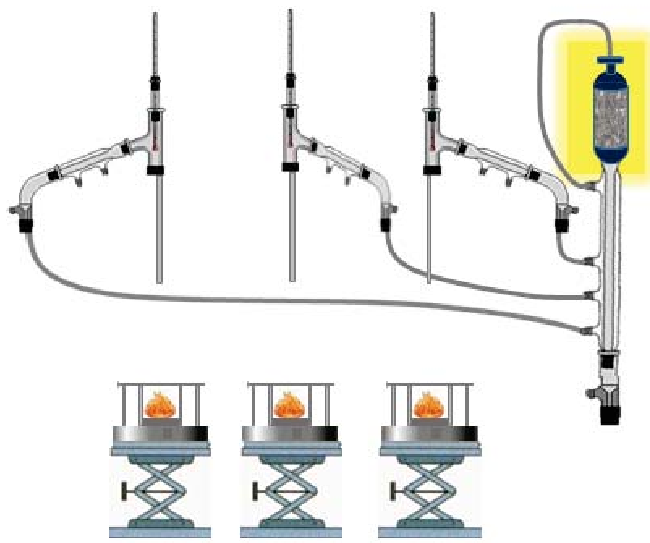
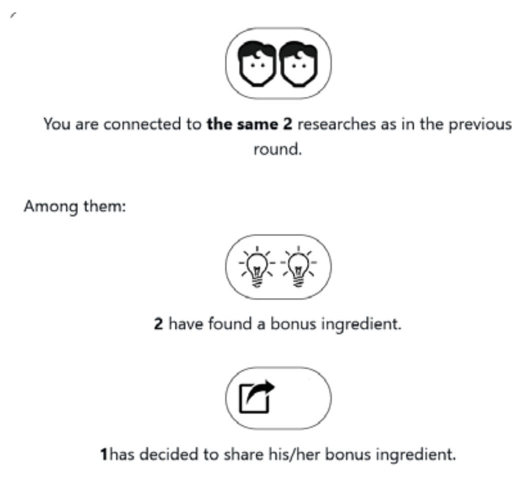
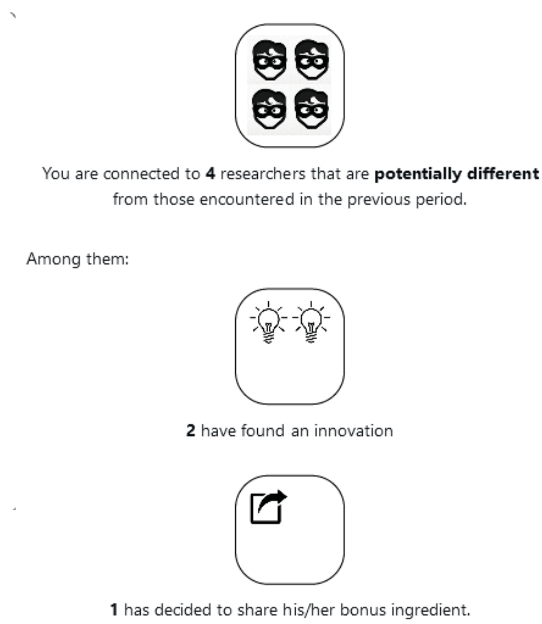


Figure A5: Screenshots of the Sharing Result stage. The first row from the top reminds the subject i) the number of neighbors ii) whether they are the same in each round or they change. The second row informs how many of the connected partners have found an innovation. The last figure at the bottom reports the number of shared innovations among those found by their linked partners

(a) A3.1 Condition P2.



(b) A3.2 Condition S4.



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