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ABSTRACT

In economic environments, decision-makers can strategically delay irreversible investments to learn from the actions of others. This creates free-riding incentives and can lead to socially suboptimal outcomes. We experimentally examine if and how communication mitigates this free-riding problem in an investment-timing game. In our baseline investment-timing game, participants choose when to invest in a nonrival project with uncertain returns, in groups of two or four players. The earliest investor of the group bears the costs of investment while everyone in the group benefits if the project reveals high returns. If more investors invest at the same time, they share the costs. In the communication treatment, subjects can freely communicate before choosing the investment time. We find that in groups of two players, communication increases cooperation and leads to significantly earlier investments. In groups of four players, however, communication significantly reduces delay only in the first period of interaction, but not in the aggregate over all periods.

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1. Introduction

In many economic environments, decision-makers may strategically delay irreversible investments to learn from the actions of others leading to socially suboptimal outcomes. For example, firms can strategically delay the adoption of new technologies to learn about their profitability from early investors, which can lead to slower productivity growth (Krugman, 1994; Hoppe, 2002; Oster, 1982; Sumrall, 1982; Smith and Ulu, 2012).[1] Likewise, consumers may delay the consumption of new products and services to learn about the quality from friends (Liu et al., 2014), which can lead to inefficiently slow up-take of new products and services. Similarly farmers may delay using new types of crops to learn about their qualities from their peers (Conley and Udry, 2000), delaying better harvests.

One of the critical determinants of investment-timing decisions is the uncertainty about the profitability of the investment. For firms adopting new technologies, the demand is uncertain; for consumers picking up new products and services, the quality of the new products is uncertain; and for the farmers trying out new crops, the quality of the harvest is uncertain. Common to all these settings, the uncertainty could be resolved at no cost by observing the experience of an early investor. In the presence of such informational externalities and the non-rivalry of resources, learning opportunities from the experience of an early investor generate free-riding incentives to strategically delay investment timing. In other words, information on returns to the investment being public goods creates strategic free-riding incentives which may result in either late or no investment.

We experimentally study the investment-timing game, which is a variation of the volunteer's timing dilemma game (Weesie, 1993, Weesie and Franzen, 1998) with uncertain returns of investment. In the investment-timing game, players simultaneously choose their investment timings from a finite time horizon for a non-rival project. The project is equally likely to be of good or bad quality. The quality of the project can only be learned if at least one player invests in it. If the project turns out to be good, all players enjoy the benefits equally (i.e. the informational value of the news), while only the earliest investor bears the costs of investment. The benefits decrease in the earliest investment time (i.e. the delay) to reflect the fact that the longer the delay in investment is, the less time is left to utilize the benefits of the

[1] Strategic delays in new-technology adoption may be an important hurdle to economic growth (Fudenberg and Tirole, 1985).

projects, decreasing the value of information.[2] If the project turns out to be of bad quality, there are no benefits, while the earliest investor still bears the cost of investment. A single player undertaking the investment is sufficient to uncover the uncertainty of returns, i.e. additional investments bring no added value. If more than one player invests at the same time, they share the cost of investment equally.

Theoretically, the free-riding incentives will lead to late or no investments and thus socially suboptimal outcomes. One established way of enhancing cooperation in social dilemmas is to introduce communication among players (see the literature discussed in section 2). We hypothesize that communication helps to mitigate free-riding and reduce the average delays in investment times. In our experiment participants play the investment-timing game with or without communication opportunity (between-subject). After the communication stage is over, participants choose their investment times as described in the baseline game. We also vary group size (within-subject) for both the baseline investment-timing game and the investment-timing game with communication.

Our experimental results are the following. In the first period of our experiment, communication significantly reduces delay in investment times, by around 50% in both 2-person and 4-person groups. At the aggregate level, the average delay remains to be 40% lower in the presence of communication in 2-person groups. In 4-person groups, however, the effect of communication disappears at the aggregate level after the first period. The existence of free-riders in 4-person groups (who do not join the chat and typically report late investment times) reduces the efficacy of communication in comparison to 2-person groups.

Surprisingly, both with and without communication, the average delay in investment times is smaller in groups with 4 players than in groups with 2 players in both the first period and over all periods. Although this result is in contrast with our theoretical predictions, it is in line with the behavior observed in other volunteer's dilemma experiments (see section 2).

The remainder of our paper is organized as follows. We discuss the related literature in Section 2. In Section 3 we develop our model and present our theoretical predictions. In Section 4 we introduce our experimental design and hypothesis. In Section 5 we present our experimental results. Section 6 offers a concluding discussion.

[2] For example, the later firms/farmers try out a new technology/crops, the time period they can profit from this technology/crops is reduced by the amount of the delay of investment.

2. Related Literature

The empirical literature on social dilemmas is abundant; we will focus here on the most relevant studies for our study. The social dilemma literature in economics has three main categories: prisoners' dilemma, public good, and oligopoly games. Public-good games can be divided into linear public goods, in which the size of the public good increases with any contribution, and step-level public-good games, in which a fixed-size public good is provided if the contributions exceed a certain threshold. Typically, contributions in a step-level public good are unconditional and are lost when they are futile (the threshold is not reached) or unneeded (the threshold was even reached without that contribution). A special step-level public good is the volunteer's dilemma game (VDG) where the threshold is 1: the public good is provided if at least one volunteer contributes.

There are close parallels between our investment-timing game (ITG) and the VDG. In both games, the (size of the) public good is determined by only one player: the volunteer in VDG and the one with the earliest investment in ITG. The games also differ: in the VDG the decision is binary (to volunteer or not) while in the ITG the decision is on a continuum (when to invest). Moreover, in the VDG all volunteers must pay their contribution, while in the ITG only the players with the earliest investment pay, and players with the same investment time divide the costs.

Several experimental studies on the VDG examine the effect of group size. Theoretically, under the assumptions of rational players with homogeneous preferences, only mixed strategy equilibria exist, and interestingly, not only the individual probability of volunteering decreases with group size, but in equilibrium also the probability of at least one volunteer in the group decreases with group size (Diekmann, 1985). The empirical evidence is not in line with these predictions: typically, larger groups are more likely to have at least one volunteer (see, e.g., Goeree et al., 2017, Kopányi-Peuker, 2019, Campos-Mercades, 2021). This may be explained by heterogeneous preferences: if volunteering participants are more social than others, a larger group is more likely to include such a social participant so that it is more likely that someone volunteers. It can intuitively also be explained by noise: in a larger group, it will be more likely that a least one participant will mistakenly volunteer (see Goeree et al., 2017, for such explanation based on the quantal-response equilibrium). Otsubo and Rapoport (2008) experimentally test a dynamic version of VTD akin to our ITG with groups of three (and no cost sharing) and report that volunteering happens earlier than predicted by game theory. Our ITG is most closely related to the VDG in Weesie (1993, an asymmetric game without cost sharing) and Weesie and Franzen (1998, a symmetric game with cost sharing).[3] We adapt their setting by introducing uncertainty on returns of investments and the possibility of communication.

The experimental literature pays ample attention to the effect of communication on cooperation in social dilemmas like public-good games and oligopoly games. In general, communication enhances cooperation in public-good games (see Balliet, 2010, for an overview). Similarly, Gomez-Martinez et al. (2016) find a positive effect of communication on cooperation in a four-firm Cournot oligopoly. Fonseca and Normann (2012) find that the benefit of communication in a Bertrand oligopoly is decreasing in the group size. Typically, in communication treatments of social dilemma experiments, all members of the group automatically enter the discussion before making a choice. Our design deviates from this by letting the participants choose whether they want to communicate,[4] allowing for partial communication groups. Clemens and Rau (2022) find in such a 'partial cartel' experiment a positive effect of communication on cooperation in a Cournot oligopoly, but, in contrast to us, they do not study group size effects.

There is a relatively small theoretical literature on ITGs. This literature considers the strategic nature of irreversible investments in the presence of social learning when players can learn from each other's actions. Chamley and Gale (1994) and Gul and Lundholm (1995) theoretically study strategic delay with option models under pure informational externalities. Murto and Valimaki (2011, 2013) study the delay and information aggregation in a stopping game with private information. Kirpalani and Madsen (2022) model strategic delay in investment in the presence of information acquisition.

Various theoretical papers deal with delays in technology adoption (see, e.g., Farrell and Saloner, 1985, Farrell, 1987, Bolton and Farrell, 1990, and Fudenberg and Tirole, 1985). Decamps (2004) study investment timing in an attrition game, and Margaria (2020) study a stochastic war-of-attrition game to explore the interplay between informational and payoff

[3] Babcock et al (2017ab) and Doğan (2020) use related volunteering games to study gender differences in volunteering, with females volunteering more often than males in mixed gender groups.
[4] Such design choice is commonly followed in the industrial-organization literature to allow the researcher to study the effect of antitrust policy. See, e.g., the experimental literature on the effect of corporate leniency programs in antitrust, reviewed by Marvão and Spagnolo (2018).

externalities. In all these papers, delay in investments occurs for a variety of reasons including, but not limited to, the information structure and revelation, strategic complementarity or substitutability, or the second mover's advantage. In our paper, we focus on the fundamentals of strategic delay in investment timings by assuming that there is no rivalry, that the lessons are learned immediately and perfectly by everyone, and that the only strategic choice is the timing of investment.

3. Experimental Design and Procedures

Our experiment features a 2x2 design where we vary the availability of communication between subjects and vary the group size within subjects. This leads to the following 4 treatments: *NoComm2* (communication not possible, groups of 2 players)*, NoComm4* (communication not possible, groups of 4 players)*, Comm2* (communication possible, groups of 2 players)*, and Comm4* (communication possible, groups of 4 players).

We first describe our *NoComm* treatments. In the baseline investment timing game, there are n players labeled $i = 1, \dots, n$, who can invest in a nonrival project with uncertain returns. Each player i independently chooses their investment time t_i from the interval [0, 100], where $t_i = 0$ means immediate investment and $t_i = 100$ means no investment. The project is of good quality with probability q and of bad quality with probability $1 - q$. If the project is of bad quality, it yields zero returns. A good-quality project's returns equal $B(t_{min})$, where $t_{min} \equiv \min_{i=1,\dots,n} t_i$ denotes the delay (i.e. earliest investment time). The player with the earliest investment time pays the cost of the irreversible investment, $C(t_{min})$, while all players obtain the project's returns. More precisely, the payoff of player i choosing time t_i while the delay equals t_{min} is given by:

$$\pi_i(t_i, t_{min}) = \begin{cases} qB(t_{min}) - C(t_{min})/k & if\ t_i = t_{min} \\ qB(t_{min}) & if\ t_i > t_{min} \end{cases} \qquad (1)$$

where $k \equiv \#\{i: t_i = t_{min}\}$ is the number of players choosing the earliest investment time. In the experiment, we use the following parameters:

$$q = \frac{1}{2}, B(t_{min}) \equiv 100 - t_{min}, C(t_{min}) = B(t_{min})/4 = 25 - t_{min}/4.$$

In the *Comm* treatments, participants first face a communication stage before the investment-time decisions. In this communication stage, participants simultaneously choose whether they want to communicate with other participants in their group. Those who want to communicate form a communication group and enter a chat room for a free chat, and the ones who do not want to communicate are asked to decide independently on their investment times. Only the participants who are willing to communicate learn how many participants enter the chat room. The chat room is open for 3 minutes in the first five periods, and 1 minute in the following periods. Participants can leave the chat room at any point in time, and this information is shared with the others still in the chat room. After the chat room closes, all participants, including the ones outside the communication group, are asked to enter an investment time. If the investment times of participants in the communication group are the same, this choice is implemented for all participants in the communication group. If the investment times do not match, then all participants in the communication group receive this information, which indicates they could not agree on a common investment time, and they are asked to enter their individual decision times. The resulting payoffs for each participant, inside or outside the communication group, are calculated as in equation (1). An earnings calculator is provided on each decision screen to all participants. In this payoff calculator, participants can calculate their earnings in points for any combination of hypothetical choices (of theirs and their group members) and for any realization of the project quality (either good or bad quality).

To allow for learning, participants played a series of investment-timing games either with communication or without communication, as described above. In both *Comm* and *NoComm* treatments, participants play the corresponding game in groups of 2 in the odd-numbered periods and in groups of 4 in the even-numbered periods, for a total number of 40 periods.[5] After each period is played, participants are informed about their own payoffs, the choices and payoffs of the others in their group, and whether the project was of good or bad quality.

Our experiment consists of 10 sessions (five for each of the *Comm* and *NoComm* treatments), that were conducted at the CREED lab at the University of Amsterdam. All of the 160 participants in the experiment were recruited from the CREED subject pool. In each session, 16 participants interacted anonymously. In each period, participants were rematched within a matching group of 8 participants. All participants in each treatment were given the same instructions (see Appendix A). At the beginning of each period, participants are randomly re-matched with each other. The identity of the partners was not revealed to the participants. It was explained to the participants that their final earnings depended on their own choices and

[5] In four of the 10 sessions, we have missing data for period 40. To make treatment comparisons clean, we drop the last periods from all of our treatments and restrict our attention to periods 1–38 in our analysis.

the choices of the matched participants. The payoffs in the experiment were expressed in points. At the end of the experiment, the sum of a participant's earnings in points in all periods was converted into euros at the exchange rate of 120 points = 1 euro, and privately paid to participants. On average, participants earned 31.33 euros, which includes a show-up fee of 7 euros. Sessions lasted around 90 minutes.

4. Hypotheses

We formulate our hypotheses based on equilibrium analysis of the games played in the experimental treatments, assuming risk-neutral players. The formal analysis for the general variable values is presented in Appendix B.

The symmetric equilibrium of the baseline investment game *NoComm* is in mixed strategies (see Proposition B1 in Appendix B). This result becomes intuitive by using a proof-by-contradiction argument. Imagine all but one player playing the same pure strategy, i.e., choosing a particular investment time with certainty. Then, the remaining player is always better off by deviating and choosing a higher or a lower investment time, which contradicts the assumption that the pure strategy constitutes a symmetric Nash equilibrium.

Expanding the baseline investment game with a pre-play communication stage, as in our experiment, increases the set of outcomes the players can reach in a symmetric equilibrium. The investment-timing game (ITG) with communication has equilibria in which the players use the communication stage to establish the Pareto-efficient investment time 0 (see Proposition B2 in Appendix B). It is attractive for all players to join the communication stage because if one of them does not join, the other players play the symmetric Nash equilibrium of the baseline investment game. For the same reason, the players in the communication group have no reason do deviate from choosing investment time 0. In that equilibrium, a player is indifferent about the investment time, including investing at time 0. Therefore, a player's expected payoffs are $qB(0) - C(0)$, which is less than $qB(0) - C(0)/n$, i.e., a player's expected payoff in an n-person communication group investing at time 0.

The ITG with communication, *Comm*, has other symmetric subgame-perfect equilibria too for $n > 2$ (see Proposition B3 in Appendix B). In particular, symmetric mixed-strategy equilibria exist in which all players join the communication group with some probability $p \in (0,1)$. If at least two players join the communication group, the players joining invest at time

0, while players outside the communication group do not invest. If one or zero players join the communication group, all play according to the Nash equilibrium of the baseline game. For $n = 2$, such equilibrium fails to exist because a player's best response is to always join the communication group if the other player does so with probability $p \in (0,1)$. Because for $n = 4$, $p \approx 0.538 < 1$, with some probability, fewer than two players join the communication group, in which case the investment time is greater than zero.

Table 1 presents the equilibrium predictions regarding the expected delay in each of our four treatments. For group size 4, the mixed-strategy equilibrium is used in which all players enter the communication group with probability $p \approx 0.538$. We believe such equilibrium to be empirically more likely than the equilibrium where all players join the communication group because it lies between the extremes of full communication and no communication at all.

Table 1: Expected Delay in Equilibrium

	Group size 2	**Group size 4**
No communication	33.33	42.86
Communication	0	11.06

We formulate our research hypotheses based on the directional effects of the treatment conditions according to our equilibrium analysis. Comparing the expected equilibrium delays displayed in Table 1, we predict that the opportunity to communicate reduces the expected delay for both $n = 2$ and $n = 4$, leading to our first hypothesis:

Hypothesis 1 The delay is smaller with communication opportunity than without communication for both $n = 2$ and $n = 4$: (i) $D_{Comm2} < D_{NoComm2}$; (ii) $D_{Comm} < D_{NoCom}$.

Increasing the number of players from $n = 2$ to $n = 4$ pushes up the delay both with and without the opportunity to communicate. This prediction allows us to formulate the following hypothesis:

Hypothesis 2 The delay increases in the number of players both with and without communication: (i) $D_{COMM4} > D_{COMM2}$; (ii) $D_{NOCOMM4} > D_{NOCOMM2}$.

5. Results

5.1. Aggregate results

In this section, we first report the main results from our experiment and test our two key hypotheses. Table 2 displays the average delay in the first period and over all periods by treatment. We report the corresponding p-values of Mann-Whitney U-tests and Wilcoxon signed ranked test based on matching group averages.

Hypothesis 1 is that the availability of communication decreases the delay. This hypothesis is only partly confirmed. For the 2-person groups, we find a significant decrease in delay in the presence of communication (both in the first period and over all periods), but in the 4-person groups, the effect is only significant for the first period (see Table 2).

Hypothesis 2 is that the delay is increasing with group size. We find the opposite of hypothesis 2: the average delay is smaller in the groups of 4 than in the groups of 2, both in the presence and absence of communication. This finding squares well with the reported experimental evidence on the effect of group size on cooperation in volunteer's dilemma games (see section 2).

Table 2: Average delay by treatment

First period only	Group size 2	Group size 4	p-value (2-sided Wilcoxon)
No communication	29.85	22.35	0.260
Communication	14.13	9.5	0.185
p-value (2-sided Mann Whitney)	0.002	0.044	
All periods			
No communication	42.39	21.55	0.005
Communication	24.91	17.13	0.037
p-value (2-sided Mann Whitney)	0.001	0.200	

Note: *Statistical tests are on the level of matching groups (10 matching groups in both Comm and NoComm)*

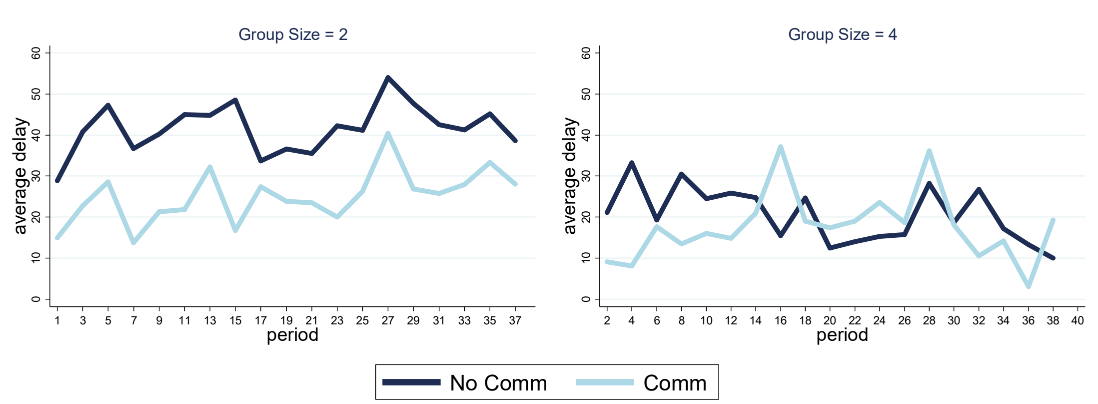
Next, we will take a closer look at comparisons between the treatments separately. First, we explore the effect of communication on delays in Section 4.2 and then report the effect of group size on delays in Section 4.3.

5.2. The Effect of Communication on Delays

In this subsection, we analyze the effect of communication on delays in more depth. Figure 1 illustrates the evolution of average delay over periods under *Comm* and *NoComm* treatments, for 2-person and 4-person groups respectively on the left- and right-hand panels. As can be seen in the left-hand panel of Figure 1, in 2-person groups, communication reduces delay by around 50% in all periods, while the right-hand panel shows, for 4-person groups, no clear difference between the treatments.

To formally quantify treatment differences, and to test their statistical significance, we estimate the effect of communication on delay, which is presented in Table 3. The econometric analysis is based on mixed-effect model regressions that capture the dependency among data points via random-effects parameters. Standard errors are corrected for clustering at the matching group level. Results based on 2-person groups and 4-person groups are reported in columns (1) and (2), and columns (3) and (4) respectively. The regression results confirm what is visualized in Figure 1. As can be seen in column (1), in 2-person groups communication reduces delay in *Comm* treatment is estimated to be 17.48 units lower than the delay in *NoComm* treatment, and the treatment effect is significant at the 1% level. If allowing for treatment effects on learning patterns across periods (column (2)), we see that the stronger

Figure 1: Evolution of Delay



decrease in delays is significant at the 1% level. As shown in column (3), in 4-person groups, the effect of communication on delays is much smaller in size (-4.41) and not statistically significant. Column (4) shows that once we control for the period and its interaction with the treatment dummy, the treatment difference becomes stronger and significant at the 10% level.

Table 3: The Effect of Communication on Delay

	Group-size 2		Group-size 4	
Variables	(1)	(2)	(3)	(4)
Comm	-17.479*** (3.650)	-22.246*** (6.498)	-4.411 (4.191)	-12.938* (6.353)
Period		0. 0667 (0. 181)		-0.361** (0.147)
Comm x Period		0.250 (0.243)		0.426** (0. 180)
Constant	42.389*** (2.877)	41.122*** (5.518)	21.546*** (2.997)	28.781*** (4.832)
Observations	3,040	3,040	3,040	3,040

Notes: *This table report results from mixed-effect regression with standard errors (in parenthesis) clustered at both individual and matching group levels. *** (**) [*] indicates that the estimated coefficient is significant at the 1% (5%) [10%] level. The dependent variable is delay in all specifications.*

In sum, on average communication significantly reduces delay in 2-person groups but not in 4-person groups. To understand the forces behind these results better, we will analyze 2-person groups and 4-person groups in more detail in the next two subsections.

Communication effects in small groups

In this section, we take a closer look at how communication works in 2-person groups. Although the treatment differences are in the direction of our predictions (see Table 1), the treatment effect is smaller than predicted. There is still a considerable delay in *Comm2* caused by less communication than predicted while *NoComm2* is largely in line with the predictions.

The symmetric Nash prediction in *Comm2* is that all players will engage in communication; they will decide on a 0-investment decision and thus share the costs. Behavior deviates from the predictions in two ways: not everyone communicates, and the participants communicating do not always agree, see Table 4. Only 68% of the participants decide for communication. Because communication only takes place if both members of the group decide so, actual communication happened only in 46% of the pairs. In 23% of these cases, participants do communicate but do not reach an agreement. Subjects that don't reach the agreement reach quite high delays, increasing the average delay. Therefore, we see higher delays than predicted in *Comm2* treatment.

Combining this finding with the behavior observed in *NoComm2* explains why our treatment effect is smaller in size than predicted by the theory.

Table 4: Communication decisions in *Comm2*

Actual chat	Size of Communication Group	N (%)	Average delay	Average investment decision*	Average earnings*
No 820 (54%)	One member decides against communication	694 (45.7%)	32.46	45.24 70.46	12.55 20.31
	Both members decide against communication	126 (8.3%)	57.12	74.36	13.16
Yes 700 (46%)	Both members decide for communication	700 (46%)			
	No agreement reached	158 (10.4%)	34.10	56.39	18.37
	Agreement reached	542 (35.6%)	5.07	5.07	22.43

* Separate for the participants who decide for/against communication

The question is, why did so many participants (31%) reject the possibility of a chat even though it is completely free? Based upon Table 4 we can post hoc calculate the expected earnings of a decision for or against communication: 18.34 and 18.46, respectively. So there seems to be no strong force in favor of deciding for communication. This is driven by the situation where one participant decides in favor and one against communication: the one in favor of communication typically reports the lower number (average of 46.02 versus 74.37) and thus the one against communication can freeride in many cases. This suggests that the chat decision almost works like signaling for behavior in the investment stage: the participant who declines communication signals a late investment decision, while the participant who wanted to communicate is likely to invest earlier. When both participants do not want to communicate, the average delay is relatively higher.

Communication effects in large groups

In this section, we examine how communication affects delays in 4-person groups. In *NoComm4* the delay is smaller than expected, and in *Comm4* it is larger than expected. In what follows we examine these two finding in detail.

First, we focus on the behavior in 4-player groups without communication, see Table 5. In *NoComm4* the average investment decision is 63.5, while the predicted symmetric Nash equilibrium is 75. The average delay (which is the minimum of the 4 investment decisions) is 21.3, while the predicted level is 43. These findings suggest the assumption of symmetry driving our theoretical predictions may not hold, leading to a much lower delay than predicted.

Second, we explore the behavior in 4-person groups with communication in detail. In *Comm4* the delay is larger than predicted, and that is especially so in the later periods. We argue that the reason why communication is not as effective as in 2-person groups is that although there is more communication than expected, communication is less effective in 4-person groups. In other words, in many cases, subjects fail to reach an agreement in 4-person groups after communicating.

To study the behavior after an agreement failure following communication, we look at the difference between the initial decision and the final decision of participants who failed to agree after the communication stage. It turns out that initial and final decisions are the same for 52% of those participants, while 44% of the participants submitted a higher final investment time than their initial investment times, contributing to the higher average delay in these groups. Moreover, 35% of the participants sticking to their initial investment time, have investment time choices less than 10, while 49% have more than 90. In sum, the less effectiveness of communication at the aggregate level in 4-person groups in comparison to 2-person groups is mainly driven by agreement failures in larger groups.

The chat data give some qualitative support on our results. Note, however, that the chats are only informative if the members do not immediately agree on an action. In discussions with 4 members, a higher number than 0 is not that often proposed for that reason, and if it is, it is pointed out by others that the loss would be quite small anyhow because the costs are divided by 4. The most interesting cases are in the 4-person treatment when only 2 or 3 members choose to communicate. These members note that one or more members are missing in the chat, and that these participants will likely choose a high number. Some groups decide that it is nevertheless best to choose a 0 delay, but some other groups don't accept free riding and decide on a very large number.[6]

Table 5: Communication decisions in *Comm4*

Actual chat	Size of Communication Group	N (%)	Average delay	Average investment decision*	Average earnings*
No	Three members decides against communication	144 (9.4%)	22.64	44.86 77.90	35.89 44.07
	All members decide against communication	12 (0.8%)	22.00	49.50	28.46
Yes	Four members decide for communication	380 (25%)			
	No agreement reached	176 (11.5)	23.5	61.82	46.06
	Agreement reached	204 (13.5)	1.28	1.28	55.46
	Three members decide for communication	520 (34.3%)			
	No agreement reached	284 (18.7%)	29.92	59.04 83.07	42.60 47.54
	Agreement reached	236 (15.6%)	4.36	4.56 77.44	58.53 65.61
	Two members decide for communication	464 (30.5%)			
	No agreement reached	196 (12.9%)	30.89	70.87 79.17	40.73 42.59
	Agreement reached	268 (17.6%)	9.50	14.52 79.57	43.22 51.53

* The upper [lower] number refers to participants who decide for [against] communication

Lastly, we investigate whether the choices to communicate or not serve as strategic signaling and affect the earnings of participants. To do so we estimate the effect of chat decisions on earnings in the communication treatment (see Table C3 in Appendix C). We control for the group size, by adding a dummy variable called Dummy 4, which is 1 for a group size of 4 and 0 for a group size of 2. We find that the earnings of players committing to chat

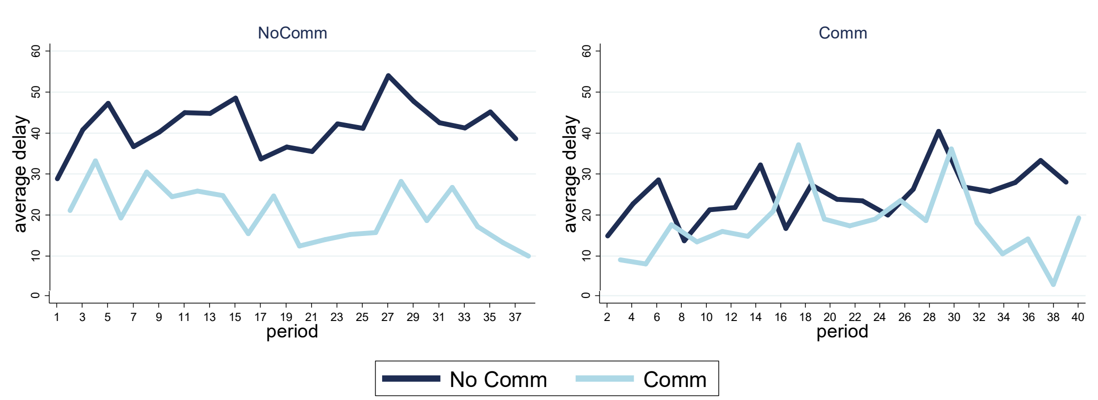
[6] In the Appendix D, we present a few examples of these chats to illustrate these findings better.

while other group members opting out are 10 points less than their group members, which is significant at the 1% level. This result is in line with our argument that participants used opting out of chat as a signaling mechanism to signal "hard to play with". These participants also submitted significantly higher investment times than those who committed to chat.

5.3. The Effect of Group Size on Delays

In this section, we analyze the effect of group size on delay in the presence and absence of communication. Figure 2 illustrates the evolution of average delay over periods for 2-person and 4-person groups for *NoComm* and *Comm* treatments respectively on the left- and right-hand panels. From the graph on the left in Figure 2, it becomes clear that an increase in group size leads to 50% smaller delays, increasing over periods, when there is no communication, while the difference disappears over the course of the experiment when communication is introduced.

Figure 2: Evolution of Delay



As shown in Table 6, presenting results from regressions where delay is regressed on a group size dummy, increasing group size significantly decreases the delay at the aggregate level. Column (2) shows that, when there is no communication, delay significantly decreases over time for 4-person groups but not so for 2-person groups.

In sum, on average group size significantly reduces delay in both 2-person and 4-person groups at the aggregate level. We will analyze this finding in detail in the following next section.

Group size effect in the no communication treatment

In this section, we concentrate on the effect of group size in *NoComm* treatments. The hypothesis that delay would be larger in larger groups is based on the assumption that the participants play according to symmetric mixed strategy equilibria. Our findings do not support this assumption. We will now elaborate in more detail how the individual investment times differ from these theoretic predictions.

In NoComm4 individual decisions are hypothesized to be distributed more skewed to the higher numbers, and the expected delay is about 43 (100 * 3/7, see example 2 in section 2). The observed average delay however is only 21.6. The observed average investment decision is 62.48. So, the participants decided on a higher number than expected in the small groups and lower than expected in the larger groups. This means that the effect of the group size on the delay can be primarily caused by the arithmetical effect that in larger groups the minimum number will be on average smaller.

Table 6: The Effect of Group size on Delay

	No Communication		Communication	
Variables	(1)	(2)	(3)	(4)
Dummy4	- 20.843*** (1.621)	- 12.341*** (2.625)	- 7.778** (3.052)	-3.032 (3.553)
Period		0. 0667 (0. 186)		-0.318 (0.167)
Dummy4 x Period		-0.428*** (0.101)		-0.253* (0. 123)
Constant	42.389*** (2.956)	41.122*** (5.670)	24.910*** (2.308)	18.876*** (3.524)
Observations	3,040	3,040	3,040	3,040

Notes: *This table report results from mixed-effect regression with standard errors (in parenthesis) clustered at both individual and matching group level. *** (**) [*] indicate that the estimated coefficient is significant at the 1% (5%) [10%] level. The dependent variable is delay in all specifications.*

A potential worry is that participants do not distinguish between the small and large groups (remember that group size was a within-subject treatment, with small groups in the odd and large groups in the even periods). This turns out not to be the case. If players would not distinguish between small and large groups, the correlation between the decision and the very recent decision one period ago (which had another group size) would be larger than the correlation between the decision and the decision 2 periods ago (which had the same group size). We find the correlations to be respectively 0.499 and 0.581.

We estimate the effect of group size on individual investment times using a mixed-effect model regression. We find that the group-size difference in the *NoComm* treatment is very small in size and not statistically significant. Controlling for the period and the interaction between the group size and period changes this result: the average investment timings are 3.3267 points larger in the *NoComm4* than in *NoComm2* (statistically significant at 5% level; see column 2 of table C1 in Appendix C). So, although the average investment times are comparable, we see a difference in trend over periods, which is a second indication that participants do distinguish the small and large groups in the experiment.

Note that experimental studies in the binary volunteer's dilemma (where players have a binary choice between volunteering or not) also do not confirm the symmetric equilibrium prediction that increasing the group size will decrease the probability of at least one volunteer (see, for example, Goeree et al., 2017, Kopányi-Peuker, 2019, Campos-Mercade, 2021). These studies conclude that the assumption of symmetry does not hold: some individuals are more likely to volunteer than others, and the probability that at least such a participant is in the group increases with group size.

Group size effect in the communication treatment

In the communication treatment, we also find a group size effect in the other direction than expected. The average delay in *Comm4* is not so far away from the prediction (predicted was 11, the realization is about 18), but in *Comm2* the prediction was 0 and the realization was about 25.

The chat scripts provide some qualitative support on our results in the *Comm2* treatment. In *Comm2* there often is a discussion about what number (delay) to choose, with one member proposing 0 and the other a higher number. The argument used for a higher number is typically that, if the project is a failure, the loss in that period would be lower. Since the risk is shared remains relatively higher in 2-person groups than that of in 4-person groups, participants choose higher numbers in 2 person groups even when they communicate.

In *Comm4* average delays are not far from the predictions, however, there are some interesting deviations. Table 5 shows the investment times, delays, and average earnings. On the one hand, there is more communication than predicted: 68% decide to communicate instead of the 54% predicted. This would lead to even smaller delays as predicted, if the communicators would, as assumed, always agree to a 0-investment time. Table 5 shows that if communication groups agree on an investment time, the delay is indeed quite small, but many groups do not agree. So, there are two opposing forces: there is more communication than predicted, but the communication is less effective than assumed. As in *Comm2*, non-communicators do on average free ride on communicators, but they earn little if they have the bad luck to be matched with three other non-communicators.

Summarizing, at the aggregate level we find significantly lower delays in larger groups than in smaller groups under both *Comm* and *NoComm* treatments. This result is in line with the finding from the literature and is attributed to the heterogeneity of players. Cooperative types are more likely to volunteer than others and the probability that at least such a participant is in the group increases with group size.

6. Conclusion

Using a laboratory experiment, we have examined if and how communication mitigates the strategic delay in investment timings. Our framework is an investment-timing game in which players decide when to invest in a project with uncertain returns. Only the earliest investor(s) pay the costs and the other players free ride. We hypothesize that introducing communication reduces strategic delay. We report that in the 2-person groups, communication indeed significantly reduces the strategic delay. In contrast, in 4-person groups, we find that communication helps subjects to reduce strategic delay significantly only in the first periods, but not in the aggregate over all periods. If all four persons decide to communicate, the delay is very small, but in cases where only two or three persons want to communicate, the delay can be considerable. The subgroup who decided to communicate (the insiders) rightly expects the other group members (the outsiders) to choose very high investment times, and often the insiders appear to be reluctant to accommodate these free-riding outsiders. It turns out that on average being an outsider is more profitable than being an insider.

Furthermore, we find that the delay is smaller in 4-person groups in comparison to that of 2-person groups. While this finding is in contrast to the game theoretic prediction, it is in line with behavior in other volunteer's dilemma experiments. We attribute this result to heterogeneity of players (i.e., violating the symmetry assumption). Some participants are more cooperative and are more likely to invest early than others. The probability that at least one such participant is in the group increases with the group size. This results in longer delays in 2-person groups in comparison to 4-person groups.

Our results are of interest to policymakers and competition lawyers. Firms involved in developing new products may be hindered by free-riding issues in settings where innovations are readily copied by competitors. Cooperation between firms regarding R&D is allowed in light of modern anti-cartel law under some conditions.[7] Our results point to cases where such a lenient approach to R&D collaboration is justified: in very concentrated industries allowing cooperation may help to speed up innovation, but in less concentrated industries it may not help at all.

Our results open new venues for future research in the following dimensions. In our experiment, by deciding *not* to communicate, players signal that they commit to free riding, which may have resulted in communication being ineffective in larger groups. Future research may reveal under what circumstances communication fails to help or even hurt cooperation. Moreover, we assumed that the project is non-rival to be able to isolate communication effects in a clean way. Future research may shed light on the question of the extent to which our results extrapolate to a setting where investment spillovers to competitors are less than perfect.

[7] For instance, Article 101 of the Treaty on the Functioning of the European Union allows firms to make an anti-competitive agreement if the agreement (i) "contributes to improving the production or distribution of goods or to promoting technical or economic progress", while (ii) "allowing consumers a fair share of the resulting benefit", and which does not (iii) "impose on the undertakings concerned restrictions which are not indispensable to the attainment of these objectives" and (iv) "afford such undertakings the possibility of eliminating competition in respect of a substantial part of the products in question."

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APPENDIX A: INSTRUCTIONS

Communication treatment

You are participating in an experiment on decision making. You are not allowed to talk or try to communicate with other participants during the experiment. If you have a question, please raise your hand.

Description of the Experiment

In this experiment you will be asked to make decisions in 40 periods. In each period, you will be randomly matched with (an)other participant(s): in odd periods you will be matched with 1 other participant so that you are in a group of 2. In even periods you will be matched with 3 other participant so that you are in a group of 4. The identity of the other participants you will be matched with will be unknown to you.

In each period, you and the other member(s) in your group (referred to as the "others") will be asked to decide at what time to make a costly investment. The time of investment can be any integer number between 0 and 100, where 0 means an immediate investment and 100 means no investment. You will take your decisions without seeing the decisions of others in your group.

The return to the costly investment will depend on the time of the earliest investment in your group and whether the investment succeeds or fails. The investment will succeed with probability 50% and fail with probability 50%. The computer will randomly determine whether the investment succeeds or fails. If the investment succeeds, the return to it will be 100 minus the *earliest investment time* in your group. If the investment fails, the return to it will be 0. All members of the group will *equally* benefit from the return of this investment. No additional return is accrued if two or more group members make the costly investment.

The group member with the *earliest* investment time will pay the cost of investment, which is 25 minus a quarter of his/her investment time, while all others will not bear any cost of investment. If there are more than one group member with the earliest time, they will share the cost equally. The cost of investment is the same whether the investment succeeds or fails.

For example, suppose that in a group of 4, the group members choose the following investment times: 20, 16, 53 and 98. The earliest investment time, chosen by the second group member, is equal to 16. As a result, the return to each group member will be $100 - 16 = 84$ if the investment succeeds or 0 if it fails. The cost of the investment will be $25 - \frac{16}{4} = 21$ and will only be paid by the second group member, irrespective of whether the investment succeeds or fails. In this scenario, the earnings of the group members with the investment times 20, 12, 53, 98 will respectively be 84, 63, 84, 84 if the investment succeeds and 0, -21, 0, 0 if the investment fails.

You can calculate your earnings in more detail for any group investment time choice of yours and your group members by using the EARNINGS CALCULATOR on your screen.

In each period, prior to the described decision situation, you will be asked whether you want to chat with your group members to try to coordinate your investment times. If at least two group members *choose to chat*, then chat will realize among you and the group members who had chosen to chat (referred to as the "chat group"). In this case, everyone in the chat group will first be asked to enter a suggestion for the common investment time. These suggestions will be shown to everyone in the chat group. Then the chat group members can chat with each other for a limited amount of time (3 minutes in periods 1-5, and 1 minute in periods 6-40). You may choose to leave the chat screen any time you wish, in which case you will not be able to see the rest of the conversation.

The group members who choose *not to chat* will directly be forwarded to the decision screen and make an individual decision. They will not be shown the suggestions made by the chat group members not any conversation between chat group members.

Once the time for chat is up, everyone in the chat group will automatically be forwarded to the decision screen. In this case, you will be asked to enter an investment time. If you and others in the chat group submits the same investment time and this turns out to be the earliest investment time in your group, then the cost of investment will automatically be shared by the members of your chat group. If at least one person from the chat group submits a different investment time than the rest, an agreement will not be reached among the chat group and all chat group members will be asked to submit their final investment time decisions.

For example, suppose that in a group of 4, three members of the group chooses to chat. The chat group members all submit the same investment time of 16. The fourth player submits investment time 20. Then the return will be 100-16=84 for all the four members if the investment succeeds, and 0 if it fails. The cost of investment will be $25 - \frac{16}{4} = 21$ and be shared by the three chat-subgroup members. Namely, all the three members who had the chat will pay 7 irrespective of whether the investment succeeds or fails. In this scenario, the earnings of the group members with the investment times 16, 16, 16, 20 will respectively be 77, 77, 77, 84 if the investment succeeds and -7, -7, -7, 0 if the investment fails.

Once everyone in your group submits their decisions, you will be directed to the results page and be provided with the following information on your screen: whether the investment succeeded or no, investment times, and earnings of everyone in your group.

After the 40 periods, we will ask you to complete a number of additional tasks.

At the end of the experiment, your earnings will be paid in cash by the experimenter. Your total earnings are the sum of your earnings in points over all periods of the experiment (including your earnings from the additional tasks). Your earnings in points will be converted into euros. The exchange rate is €15 for 1000 points.

No- Communication treatment

You are participating in an experiment on decision making. You are not allowed to talk or try to communicate with other participants during the experiment. If you have a question, please raise your hand.

Description of the Experiment

In this experiment you will be asked to make decisions in 40 periods. In each period, you will be randomly matched with (an)other participant(s): in odd periods you will be matched with 1 other participant so that you are in a group of 2. In even periods you will be matched with 3 other participant so that you are in a group of 4. The identity of the other participants you will be matched with will be unknown to you.

In each period, you and the other member(s) in your group (referred to as the "others") will be asked to decide at what time to make a costly investment. The time of investment can be any integer number between 0 and 100, where 0 means an immediate investment and 100 means no investment. You will take your decisions without seeing the decisions of others in your group.

The return to the costly investment will depend on the time of the earliest investment in your group and whether the investment succeeds or fails. The investment will succeed with probability 50% and fail with probability 50%. The computer will randomly determine whether the investment succeeds or fails. If the investment succeeds, the return to it will be 100 minus the *earliest investment time* in your group. If the investment fails, the return to it will be 0. All members of the group will *equally* benefit from the return of this investment. No additional return is accrued if two group members make the costly investment.

The group member with the *earliest* investment time will pay the cost of investment, which is 25 minus a quarter of his/her investment time, while all others will not bear any cost of investment. If there are more than one group member with the earliest time, they will share the cost equally. The cost of investment is the same whether the investment succeeds or fails.

For example, suppose that in a group of 4, the group members choose the following investment times: 20, 16, 53 and 98. The earliest investment time, chosen by the second group member, is equal to 16. As a result, the return to each group member will be $100 - 16 = 84$ if the investment succeeds or 0 if it fails. The cost of the investment will be $25 - \frac{16}{4} = 21$ and will only be paid by the second group member, irrespective of whether the investment succeeds or fails. In this scenario, the earnings of the group members with the investment times 20, 12, 53, 98 will respectively be 84, 63, 84, 84 if the investment succeeds and 0, -21, 0, 0 if the investment fails.

You can calculate your earnings in more detail for any group investment time choice of yours and your group members by using the EARNINGS CALCULATOR on your screen.

Once everyone in your group submits their decisions, you will be directed to the results page and be provided with the following information on your screen: whether the investment succeeded or no, investment times, and earnings of everyone in your group.

After the 40 periods, we will ask you to complete a number of additional tasks.

At the end of the experiment, your earnings will be paid in cash by the experimenter. Your total earnings are the sum of your earnings in points over all periods of the experiment (including your earnings from the additional tasks). Your earnings in points will be converted into euros. The exchange rate is €15 for 1000 points.

In the following, we present three representative screenshots from the experiment.

Figure A1: Decision Screen with two player groups

Figure A2: Decision Screen with four player groups

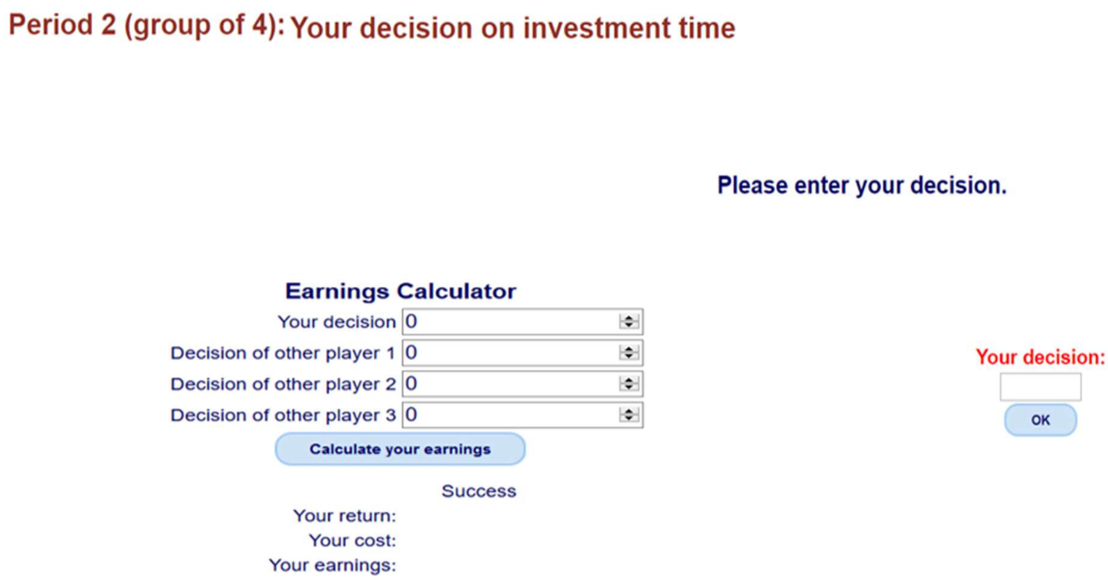
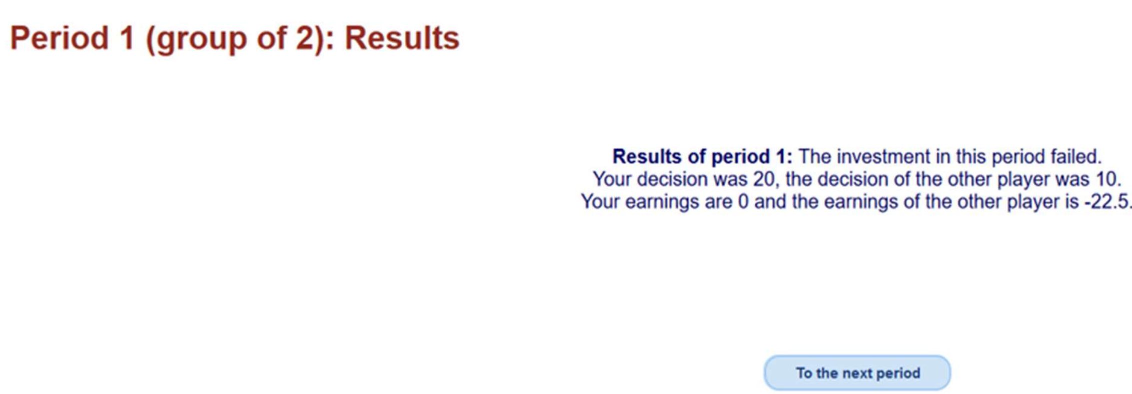


Figure A3: Feedback Screen with two player groups



APPENDIX B: EQUILIBRIUM ANALYSIS

This appendix offers an equilibrium analysis of the games played in the experiment. For each treatment, we restrict our attention to symmetric equilibria under the assumption that it is difficult for the participants to coordinate on asymmetric equilibria.

Proposition B1 *The baseline investment game has a symmetric risk-neutral Nash equilibrium in mixed strategies in which each player independently draws an investment time* $t \in [0{,}100]$ *according to the distribution function*

$$F(t) = 1 - \left(\frac{B(t)}{B(0)}\right)^{\frac{1}{n-1}} = \begin{cases} \dfrac{t}{100} & \text{if } n = 2 \\ 1 - \left(1 - \dfrac{t}{100}\right)^{\frac{1}{3}} & \text{if } n = 4 \end{cases}.$$

Proof Consider a symmetric mixed strategy in which a player invests at or before time t according to atomless probability function $F(t)$. To establish the equilibrium mixed strategy, assume that all players but player 1 play according to F. Let $G(t) \equiv 1 - ((1 - F(t))^{n-1}$ denote the distribution of the time that the first among the other players invests, where $g(t) \equiv G'(t)$. Player 1's expected utility when choosing time t equals

$$U(t) = \big(1 - G(t)\big)\big(qB(t) - C(t)\big) + \int_0^t qB(\tau)dG(\tau)$$
$$= \big(1 - G(t)\big)qB(t)/2 + \int_0^t qB(\tau)dG(\tau).$$

The first [second] term on the RHS refers to the event that player 1 has [does not have] the lowest investment time. In equilibrium, $U'(t) = 0$, which implies that

$$\big(1 - G(t)\big)B'(t)/2 + g(t)B(t)/2 = 0.$$

This differential equation has a unique solution for the boundary condition $G(100) = 1$:

$$G(t) = 1 - \frac{B(t)}{B(0)}.$$

The resulting mixed strategy equilibrium is defined by

$$F(t) = 1 - \big(1 - G(t)\big)^{\frac{1}{n-1}} = 1 - \left(\frac{B(t)}{B(0)}\right)^{\frac{1}{n-1}}. \blacksquare$$

We formally define the investment-timing game with communication as a three-stage game that proceeds as follows:

1. The players decide independently whether or not to enter a communication group. The number of players entering the communication group is made common knowledge.
2. All players independently submit an investment time. If the investment times of players in the communication group match, all players choices are implemented and the game ends. Otherwise, the game reaches stages 3.
3. The players in the communication group independently re-submit an investment time, replacing the initially submitted investment times.

Notice that we do not model the suggestions submitted before the chat nor the communication in the chat room. From a game-theoretical perspective, we can ignore both stages because any communication will boil down to meaningless cheap-talk in equilibrium.

Proposition B2 *The investment-timing game with communication has a symmetric risk-neutral subgame-perfect Nash equilibrium in which all players join the communication group with probability 1 and invest at time 0.*

Proof The equilibrium outcome displayed in the proposition is reached if all players play the following strategy:

1. Enter the communication group.

2. If all players have entered the communication group in stage 1, submit investment time 0. Otherwise, choose an investment time according to the mixed strategy in Proposition 1.

3. If at least one player in the communication group does not submit investment time 0, choose an investment time according to the mixed strategy in Proposition 1.

This strategy constitutes a symmetric risk-neutral subgame-perfect Nash equilibrium because a player deviating from it while all other players stick to it yields payoff $qB(0) - C(0)$, which is strictly less than $qB(0) - C(0)/n$, the player's payoff when playing this strategy.■

Proposition B3 *For* $n > 2$*, the investment-timing game with communication has a risk-neutral subgame-perfect Nash equilibrium in mixed strategies in which each player joins the communication group with probability* $p \in (0,1)$*, where* p *is implicitly defined by*

$$1 - \sum_{j=0}^{1} \binom{n}{j} p^j (1-p)^{n-j} = n(n-1)p^2(1-p)^{n-2}; \quad (2)$$

if a communication group of 2 or more players forms, the players in the communication group invests at time 0 and the players outside the communication group do not invest; otherwise, the players choose an investment time according to the mixed-strategy Nash equilibrium displayed in Proposition 1.

Proof If zero or one players join the communication group, the expected equilibrium payoffs equal $qB(0) - C(0)$, because the players play the equilibrium displayed in Proposition 1, in which a player is indifferent between picking any investment time t including $t = 0$. Let $p_k \equiv \binom{n-1}{k} p^k (1-p)^{n-1-k}$ represent the probability that k players other than player 1 join the communication group. In equilibrium, player 1 is indifferent between joining and not joining the communication group, which results in the equilibrium condition:

$$qB(0) - \sum_{k=1}^{n-1} p_k \frac{C(0)}{k+1} - p_0 C(0) = qB(0) - (p_0 + p_1)C(0)$$

The left-hand [right-hand] side represents player 1's expected payoffs when [not] joining the communication group. This condition can be rewritten as

$$\sum_{k=1}^{n-1} \frac{p_k}{(k+1)} = p_1$$

$$\Leftrightarrow \sum_{k=1}^{n-1} \frac{\binom{n-1}{k} p^k (1-p)^{n-1-k}}{(k+1)} = p_1$$

$$\Leftrightarrow \frac{1}{np} \sum_{j=2}^{n} \binom{n}{j} p^j (1-p)^{n-j} = (n-1)p(1-p)^{n-2}$$

$$\Leftrightarrow 1 - \sum_{j=0}^{1} \binom{n}{j} p^j (1-p)^{n-j} = n(n-1)p^2(1-p)^{n-2},$$

where the last equality follows by multiplying both sides of the penultimate equality by np, and using $\sum_{j=0}^{n} \binom{n}{j} p^j (1-p)^{n-j} = 1$, which follows directly from Newton's binomium. It is readily verified that equation (2) has an interior solution $0 < p < 1$.■

APPENDIX C: ADDITIONAL TABLES AND FIGURES

Table C1: The Effect of Group Size on Investment Timings in *NoComm*

Variables	(1)	(2)	(3)	(4)
Groupsize	-0. 7789 (1.4789)	3.3267** (1.6590)	3.6691** (1.8023)	1.502 (1.3506)
Round		0.5333* (0.3672)	0. 2846 (0. 2607)	
Groupsize x Round		-0. 4105*** (0.1505)	-0. 2071 (0. 1398)	
Delay_{t-1}			0.1331*** (0.0181)	0. 1335*** (0.0181)
Constant	63.2618 *** (2.6400)	54.6050*** (5.3073)	55.4627 *** (4.5018)	58.4343*** (2.5202)
Observations	3,040	3,040	2,880	2,880

Notes: *This table reports results from mixed-effect regressions with standard errors (in parenthesis) clustered at both individual and matching group level. *** (**) [*] indicate that the estimated coefficient is significant at the 1% (5%) [10%] level. The dependent variable is investment times timings in all specifications.*

Table C2: The Effect Chat Decision on Investment Timings

Variables	(1) n=2	(2) n=4
$\text{Chat Decision}_{t-1}$	0.137*** (0.044)	0. 239*** (0.029)
$\text{Chat Decision}_{t-2}$	0.238*** (0.019)	0.137*** (0.034)
period	- 0.006** (0.003)	-0.006*** (0.001)
Observations	1440	1440

Notes: *This table report marginal effects results from mixed-effect probit regression with standard errors (in parenthesis) clustered at both individual and matching group level. *** (**) [*] indicate that the estimated coefficient is significant at the 1% (5%) [10%] level. The dependent variable is chat decision in all specifications.*

Table C3: Regression Results on Earnings for Comm Treatment

Variables	(1)	(2)	(3)	(4)	(5)
Chat Decision	-11.2234*** (1.1016)	-7. 8176*** (1.2704)	-19.4120*** (3.5110)	-5.5868*** (1.0342)	-5.9281*** (0.7785)
Dummy4		24.8956*** (6.2036)		19.7637*** (4.9032)	
Constant	25.9492*** (2.2377)	20.4849*** (1.8308)	46.3658*** (4.3263)	27.4643*** (2.5515)	55.9502*** (4.8963)
Observations	838	838	1,164	1,164	520

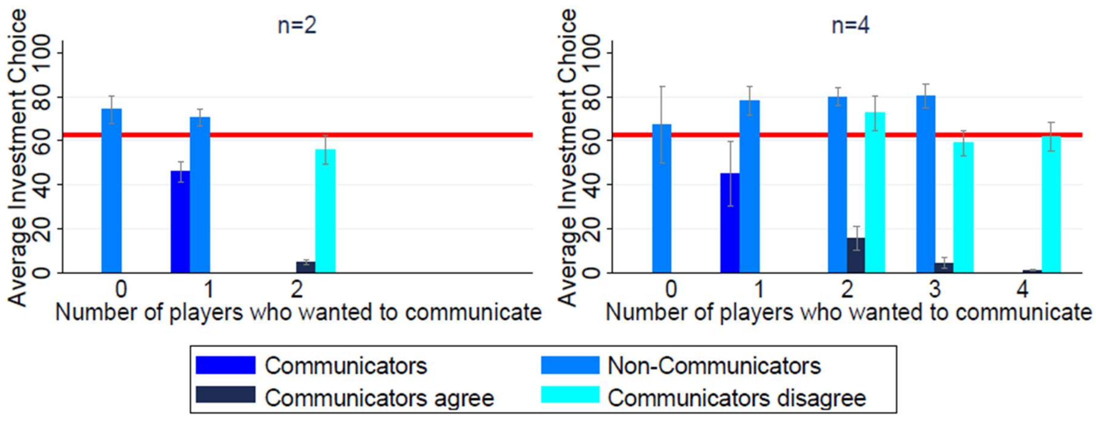
Notes: *This table report results from linear regression with standard errors (in parenthesis) clustered at the individual level. *** (**) [*] indicate that the estimated coefficient is significant at the 1% (5%) [10%] level. The dependent variable is a participant's earnings in all specifications. Specifications (1) and (2) are based on data when only one player wants to chat while the others do not, while (3) and (4) are based on data when two players chat, (5) is based on when three players chat. The Variable ChatDecision is a dummy variable that is defined to be 1 when the participant chooses to chat and 0 otherwise.*

Table C4: Regression Results on Investment Timings In Comm Treatment

Variables	(1)	(2)	(3)	(4)	(5)
Chat Decision	-30.7462*** (2.7063)	-29.3861*** (2.9464)	- 56.234*** (3.600)	-39.059*** (4.191)	-40.2323*** (4.9645)
Dummy4		5.3853* (3.0270)		23.0375*** (7.0989)	
Constant	72.5480*** (1.8487)	70.9805*** (2.1573)	78.878*** (3.0325)	55.9533*** (6.7346)	76.7068*** (4.6809)
Observations	838	838	1,164	1,164	520

Notes: *This table report results from mixed effects regression with standard errors (in parenthesis) clustered at the individual level. *** (**) [*] indicate that the estimated coefficient is significant at the 1% (5%) [10%] level. The dependent variable is a participant's earnings in all specifications. Specifications (1) and (2) are based on data when only one player wants to chat while the others do not, while (3) and (4) are based on data when two players chat, (5) is based on when three players chat. The Variable ChatDecision is a dummy variable that is defined to be 1 when the participant chooses to chat and 0 otherwise.*

Figure C1: Average Investment Times depending on Choosing to Chat or Not



Notes: *This figure shows the average investment timings depending on the number of players who wanted to communicate and whether the communication group agrees or dissolves.*

APPENDIX D: CHAT DATA

In the following we provide selected examples from our chat data to support our findings discussed in Section 4.2.

In the following we display two examples where participants discuss the *risk* of investment in a group of 2 players.

Example 1.

B: “hey”, A: “0 is better, heyyy”, B: “0 is risky tho”,

A: “if we both choose 0 we can get 87”,

B: “if it fails it is quite bad”,

A: “oh thats true”,

B: “if we both choose 10 we get 78”,

A: “so do you prefer 10, okay 10 is good for me”

Example 2.

B: “Why 44?”,

A: “potential loss”,

B: “ok, lets go for it”

In the following we present two examples of discussions of the 2 players (out of 4) who wanted to communicate. These participants typically discuss the free riders in their chat.

Example 1.

B: “well its clear”,

A: “fuck these freeriders”,

B: “0?”,

A: “let’s go 100”,

B: “sure??”,

A: “ahaha”,

B:“yeah”, A: “one of them will go under 100 for sure”

Example 2.

A: “ah”,

B: “hmm we re the only one”,

A: “I dont think we should do 0”,

B: screw them and lets go high”,

A: “lets do 40, yerah?”,

B: “40 is okay, im in”

A: “yeah?”

In the following, we report two examples of discussions of the 3 players (out of 4) who wanted to communicate.

Example 1.

C: “lets do 0”,

B: “0”,

A: “yes”

C: ”A?”

A: “hold on, d isn’t here”,

C: “haha perfect”,

B: “0”,

C: “even though d is not here, 0 is better for us”,

A: “ok”

Example 2.

C: ” please just do 0”,

A: “all 0?”,

B: “damn we’re missing one person, i agree but we don’t know what the fourth member is gonna choose”,

C: “you can see when someone plays dirty”,

A: “B also 0?”

C:“the fourth one will choose 99 i guess”,

B: ” yes let’s all do 0 and then we know if the other plays dirty”