Can Communication Mitigate Strategic Delays in Investment Timing?*

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ABSTRACT

In economic environments, decision-makers may strategically delay irreversible investments to learn from the actions of others creating socially suboptimal outcomes. We investigate if and how communication mitigates the strategic delay in investment timings. Players choose when to invest in a nonrival project with uncertain returns. The earliest investor bears the costs of investment and all players learn whether the project is of good or bad quality. Informational externalities create free-riding incentives resulting in strategic delays in investment timings. Our theoretical analysis suggests that introducing communication into this setting reduces strategic delay. We implement our model in a laboratory experiment utilizing a 2x2 design, where we vary the availability of communication and the number of agents. We find that communication significantly reduces the strategic delay and leads to earlier investment timings in the two-player case. In the case of four players, communication helps subjects to coordinate and reduce strategic delay significantly in the first period of the experiment, while coordination failures emerge in the following periods sweeping away the beneficial effect of communication at the aggregate level.

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1. Introduction

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

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 early investors. In the presence of such informational externalities and the non-rivalry of resources, learning opportunities from the experience of others generate incentives to strategically delay investment timing, generating socially suboptimal outcomes.[1] In this paper, we investigate if and how introducing communication opportunities among decision-makers can mitigate the strategic delay of investments and, in turn, address resulting inefficiencies.

In our model, players have the opportunity to invest in a non-rival project with uncertain returns. The project is of good quality with probability q and of bad quality with probability $1 - q$. In the case of good quality, the returns to the project are decreasing over time, capturing the fact that the longer the delay in investment times the less time the players can enjoy the project's fruits. In the case of bad quality, the project yields zero returns. Players choose their investment timings simultaneously. The player making the earliest investment incurs the costs of unveiling the uncertainty, and all players utilize the benefits equally. A single agent

[1] Strategic delays in innovation adoption has been a central problem in economic growth. Tirole and Fudenberg (1985) suggests addressing delays in new technology adoption helps with answering the key question of economic growth: "How to close the delay between the generation and the exploitation of new technologies?"

undertaking the investment is sufficient to uncover the uncertainty of returns, i.e. additional investments bring no added value.[2]

We introduce a communication stage to our baseline setting. In this communication stage, each agent decides whether or not to communicate with the others. Communication takes place among the agents who agree to communicate. Agents opting out of communication do not take any further action at this stage. Following this communication stage, players choose their investment timings simultaneously. If communicating players agree on a common investment time, they share the costs of investment equally among each other in case they turn out to be the earliest investors. If they fail to agree, they individually decide on their investment times, like the non-communicating players, and the player with the earliest investment time incurs the cost while all players benefit from the lessons of the investment.

We analyze the symmetric equilibria of the investment timing game. The baseline game does not have a symmetric equilibrium in pure strategies. We show that in the symmetric mixed strategy equilibrium, the expected delay in the investment timing game with communication is strictly smaller than the delay in the game without communication. The intuition is that the introduction of communication into the investment timing game leads to a different outcome than the game without communication only if communication takes place, in which case the delay is equal to 0 in equilibrium. We also find that, without communication, the average delay is increasing in the number of players. With communication, the average delay is minimized with two players.

We test the results from our theoretical model in a laboratory experiment, in which subjects play the investment timing game with and without communication in groups of 2 and 4 players. To allow for learning, subjects play each game 20 times with randomly re-matched partners. In the communication treatments, subjects are first asked whether they want to communicate with others or not. The ones who agree to communicate are forwarded to a chat screen, where they can have free chats with each other. The ones who did not agree to communicate are directed to stage 2. After stage 1 ends for communicators, all players are asked to decide on their investment timings simultaneously in stage 2.

[2] Our central interest is examining the free-riding incentives stemming from social learning, which we isolate by assuming that the only costs players incur is the cost of resolving the uncertainty on the returns of investment. For example, the first firm adopting a new technology pays the cost of investment while all other firms receive the same return, i.e. costs of planting the new technology is assumed to be normalized.

We find that in the first round of our experiment, communication significantly reduces delay in investment times, by around 50% in both 2-player and 4-player groups. At the aggregate level, the effect of communication remains significant for 2-player groups while it disappears for 4-player groups. For groups of 2 players, the average delay is roughly 40% smaller in the communication treatment than in the no communication treatment. We find that the communication opportunity mitigates delay in two ways: coordination on immediate investments when communication takes place and coordination on the asymmetric outcome when communication does not take place. We find that communication does not take place with around half of the pairs. In such pairs, we observe that the subjects who opt out of communication choose significantly later investment times than those who are willing to communicate. These pairs coordinate on the asymmetric outcome of leaders and followers. In the other half of our pairs, with whom communication takes place, 80% coordinate on almost immediate investment times and the 20% fail to coordinate yet still decide on earlier investment times in comparison to the no communication treatment.

For groups of 4, we fail to find a significant effect of the opportunity to communicate. We attribute this result to coordination failures. While communication takes place around 90% of the time, almost half of the communicating groups fail to coordinate on a common investment time. In this case, subjects choose their investment times individually where we observe similar average investment times to the no communication treatment. On average, the failure of coordination (which happens with around half of the communicating groups) offsets the gain from communication (which happens with the other half of the communicating groups). Thus, the coordination failures sweep away the beneficial effect of communication at the aggregate level.[3]

The remainder of our paper is organized as follows. We discuss the related literature in Section 1.1. In Section 2 we develop our model and present our theoretical predictions. In Section 3 we introduce our experimental design and hypothesis. In Section 4 we present our experimental results. Section 5 offers a concluding discussion.

1.1. Related Literature

Our paper builds on two strands of literature studying strategic investment timings and communication. In the literature of investment timing games, multiple players decide when to

[3] This finding squares well with the reported experimental evidence on the effect of group size on coordination, see for example, Huck et al. (2004).

make an irreversible investment in a project with uncertain returns under informational externalities. This literature mainly focuses on the strategic nature of irreversible investments in the presence of social learning, namely when players can learn from each others' actions. Chamley and Gale (1994) and Gul and Lundholm (1992) 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.

There is also a stream of papers studying the delay in technology adoption (see, Farell and Saloner 1985, Farrell 1987, Bolton and Farrell 1990, Fudenberg and Tirole 1985). Decamps (2004) study a similar problem of investment timing in an attrition game, Margaria (2019) study a stochastic war attrition game to explore the interplay between informational and payoff externalities. In all these papers, delay in investmenrs occurs for a variety of reasons including but not limited to the information structure and revealation, strategic complementarities or substitutibilities, or second mover's advantage.

In this paper, we focus on the fundamentals of strategic delay in investment timings by assuming that there is no rivalary, that the lessons are learnt immediately and perfectly by everyone, where the only strategic choice is the timing of investment. Our investment timing games are closely connected to the games of volunteer's dilemma, in particular to Weesie (1993) and Weesie et al. (1998). To this setting, we introduce communication to explore if and how players communication affects strategic delay by offering a coordination device among players. Communuaction has been studied as a coordination device in a variety of settings from public good games to minimum-effort games. It has been long recognized that communication can help coordination (Farrell 1987, 1988; Farell and Rabin 1996). Cooper et al. (1989) shows that communication increases coordination in the Battle-of-the-Sexes game. He et al. (2019) show that while communication is very effective in the Battle-of-the-Sexes game, it is much less so in Chicken game. Isaac and Walker (1988) and Ledyard (1995) shows the efficiency enhancing effect of communication in public good games.

2. The Model and Theoretical Predictions

In this section, we introduce the investment timing game. In the investment timing game, players have the opportunity to invest in a nonrival project with uncertain returns. Consider n risk-neutral players labeled $i = 1, \ldots, n$. We first consider the investment timing game without communication, which we call the baseline game, and then the investment timing game with communication. Each player i simultaneously decides, at what time $t_i \in [0, \infty)$ to invest in the project, if she invests at all. The decision not to invest is marked by $t_i = \infty$, and the immediate investment decision is marked by $t_i = 0$. In other words, each player's strategy set is $[0, \infty]$.

The project is nonrival and is of good quality with probability q and of bad quality with probability $1 - q$. The prior probability q is common knowledge to all players. If the project of bad quality, it does not yield any returns, while if the project of good quality yields a return decreasing in the delay $t_{min} \equiv \min_{i=1,\ldots,n} t_i$.

The expected utility of player i equals

$$u_i(t_i, t_{min}) = \begin{cases} qB(t_{min}) - C(t_{min}) & \text{if } t_i = t_{min} \\ qB(t_{min}) & \text{if } t_i > t_{min} \end{cases}$$

where $B(t_{min})$ denotes the returns if investment takes place at a time t_{min} and the project is good, and $C(t_{min})$ is the cost of a player who chooses the lowest investment time. Let $\bar{t} \equiv min\{t: B(t) = 0\}$. We assume that B is differentiable over the domain $[0, \bar{t})$ with $B(0) = 1$, $B'(t) < 0$ for all $t \in [0, \infty)$. The costs are assumed to be proportional to the expected returns, i.e., $C(t) = \alpha q B(t)$ for some $\alpha \in (0,1)$.[4]

A key feature of our model is that projects are non-rival, all agents benefit equally from the lessons from an investment undertaken by any of the players. Only the agent making the first investment incurs the costs of the investment, while returns are declining over time because the longer it takes for the investment to take place, the less time the player can enjoy its fruits. For instance, if the per period expected returns equal b, the discounted returns when the investment is done at time t equals $B(t) = b \int_t^\infty e^{-\delta\tau} d\tau = \delta b e^{-\delta t}$. Similarly, if the investment costs c, the discounted costs of an investment undertaken at time t is equal to $C(t) = ce^{-\delta t}$. Notice that $C(t)$ is indeed proportional to $B(t)$.

As the game is perfectly symmetric, we focus on symmetric equilibria. It is readily verified that a symmetric Nash equilibrium in pure strategies does not exist. Now, 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

[4] Weesie (1993) assumes that costs are time invariant.

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

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

$$= (1-\alpha)\big(1 - G(t)\big)qB(t) + \int_0^t qB(\tau)dG(\tau).$$

The first [second] term on the RHS refers to the event that player 1 is [not] the first to invest. In equilibrium, $U'(t) = 0$, which implies that

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

This differential equation has a unique solution:

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

The resulting mixed strategy equilibrium is defined by

$$F(t) = 1 - \big(1 - G(t)\big)^{\frac{1}{n-1}} = 1 - B(t)^{\frac{1-\alpha}{\alpha(n-1)}}.$$

Notice that $\lim_{t \to \bar{t}} F(t) = 1$, which implies that the probability that none of the players invests equals zero.

Lemma 1 *The baseline game has a symmetric Nash equilibrium in mixed strategies in which each player independently draws an investment time according to the distribution function*

$$F(t) = 1 - B(t)^{\frac{1-\alpha}{\alpha(n-1)}}.$$

Example 1 *If* $n = 2$, $B(t) = max\,\{0, 1-t\}$, *and* $\alpha = 1/2$, *then* $F(t) = t$. *In other words, both players draw the time that they invest from a uniform distribution on the interval [0,1]. The expected delay is 1/3.*

In the investment timing game with communication, the players can communicate before making an investment decision. More precisely, they interact in the following two-stage game:

1. The players decide independently whether or not they want to communicate with other players. We write $K_i = 1$ if player i communicates and $K_i = 0$ if she does not join.

2. The group of communicating players and the players who are not communicating independently decide at what time to invest, if investing at all.[5] Let t_K denote the time the communication group invests and let $t_i = t_K$ if $K_i = 1$.

Analogously to the baseline game, the delay is given by $t_{min} \equiv \min\left\{\min_{i:K_i=0} t_i\,, t_K\right\}$. The payoffs are as follows.

$$u_i(t_i, t_{min}) = \begin{cases} qB(t_{min}) - C(t_{min}) & \text{if } t_i = t_{min} \text{ and } K_i = 0 \\ qB(t_{min}) - C(t_{min})/k & \text{if } t_i = t_{min} \text{ and } K_i = 1 \\ qB(t_{min}) & \text{if } t_i > t_{min} \end{cases}$$

where k is the number of players communicating, i.e., $k \equiv \#\{i: K_i = 1\}$. Notice that the players communicating share the investment costs if they are the first to invest.

It is easy to see that the resulting game has multiple equilibria. Let us focus for the moment on equilibria in which $t_K = 0$ and $t_i = \bar{t}$ for all i for whom $K_i = 0$, i.e., the communicating group invests at time zero, and the other players never invest. The following result establishes that only one-player communication group can emerge in equilibrium.

Lemma 2 *Suppose in stage 2 of the investment timing game with communication,* $t_K = 0$ *and* $t_i = \bar{t}$ *for all* $i: K_i = 0$. *Then, there is no pure-strategy equilibrium in which more than one player joins the communication group.*

The proof is simple. If at least one of the other players joins the communication group, the expected payoffs of a player entering the communication group are equal to $qB(0) - C(0)/k$ while not entering yields $qB(0) > qB(0) - C(0)/k$. Clearly, any communication group will collapse because players that do not join the communication group can free ride on the group's decision to invest at time 0.

Notice that a two-player communication group can emerge in equilibrium if the players play the symmetric Nash equilibrium of the baseline game in case only one player enters the communication group. Because of the mixed strategy equilibrium, in the symmetric Nash equilibrium, all players are 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 $qB(0) -$

[5] We do not model how the members of the communication group coordinate on when to invest. They might do so by majority voting or randomly assigning a dictator among themselves who decides on their behalf. As long as all members of the communication group share the investment costs equally, the coordination device is not relevant for the equilibrium analysis.

$C(0)/2$, i.e., a player's expected pay-off in a two-person communication group that invests at time 0.

Lemma 3 *For $n = 2$, the investment timing game with communication has a symmetric equilibrium in which both players join the communication group with probability 1 and invest at time 0.*

For $n > 2$, it might be hard for players to coordinate on an equilibrium where two players join the communication group, because of its asymmetric nature. Let us, therefore, focus on symmetric mixed-strategy equilibria in which all players join the communication group with some probability p. Suppose that communication groups consisting of at least two players invest at time 0 while players outside the communication group never invest. Suppose also that, if one or zero players join the communication group, all play according to the Nash equilibrium of the baseline game displayed in Lemma 1. Because a player in this equilibrium is indifferent between picking any investment time t including $t = 0$, the expected equilibrium payoffs equal $qB(0) - C(0)$. 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.

Lemma 4 *For $n > 2$, the investment timing game with communication has a mixed-strategy Nash equilibrium in which each firm joins the communication group with probability p, where p is implicitly defined by*

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

if a communication group of 2 or more players forms, the communication group invests at $t_K = 0$ and the players i outside the communication group invest at $t_i = \bar{t}$; otherwise, the players choose an investment time according to the mixed-strategy Nash equilibrium displayed in Lemma 1.

It is readily verified that an interior solution $0 < p < 1$ exists. Remarkably, the equilibrium probability p of joining the communication group is independent of B and C. The intuition is that the expected equilibrium returns for members inside and outside the communication group is always $qB(0)$. Similarly, the expected costs are always a multiple of $C(0)$, which drops out when solving for the p that renders the players indifferent between entering or not entering the communication group, a necessary condition for the mixed-strategy equilibrium.

Example 2 *If $n = 4$, the investment timing game with communication has a symmetric mixed-strategy equilibrium in which each player joins the communication group with probability $\frac{8-\sqrt{10}}{9} \approx 0.538$. A communication group with at least two players emerges in equilibrium with approximately 0.742 probability.*

The average delay in the investment timing game with communication ($E\{t_{min}^{Comm}\}$) is lower than in the baseline game ($E\{t_{min}^{NoComm}\}$) if players play according to the equilibria displayed in Lemmas 4 and 1 respectively:

Proposition 1 *In equilibrium, $E\{t_{min}^{Comm}\} < E\{t_{min}^{NoComm}\}$.*

This result is readily established because the two games only differ in terms of the outcome if a communication group of two or more players forms in the investment timing game with communication, in which case the delay equals 0 and is hence almost surely lower than the delay in the baseline game.

What is the effect of increasing the number of players on the expected investment delay? Note that in the baseline game, the distribution of investment time is:

$$H(t) = P\{t_{min} \leq t\} = 1 - \left(1 - F(t)\right)^n = 1 - B(t)^{\frac{1-\alpha}{\alpha}\frac{n}{n-1}},$$

which is decreasing in n. In other words, investment time in the case of n players first-order stochastically dominates investment time in the case of $n+1$ players. This implies that as the number of players increases, the expected investment delay increases.

Example 3 *If* $B(t) = 2max\,\{0,1-t\}$, $q = 1/2$, *and* $\alpha = 1/2$,

$$H(t) = 1 - (1-t)^{\frac{n}{n-1}}.$$

The expected delay equals

$$E\{t_{min}\} = \int_0^1 t dH(t) = \int_0^1 (1 - H(t))dt = \int_0^1 (1-t)^{\frac{n}{n-1}} dt = \frac{n-1}{2n-1},$$

which is decreasing in n.

For the investment timing game with communication, it is hard to express the effect of the number of players on the average delay for general n because the probability of joining a communication group is implicitly defined (see (1)). What we can establish is that for $n = 2$, the average delay is longer than for $n > 2$ if the players play according to the Nash equilibria displayed in Lemmas 3 and 4 respectively. The (obvious) reason is that in the case of $n = 2$, the players always communicate, resulting in a certain delay of 0, while for $n > 2$, communication between at least two players occurs with probability strictly less than 1, so that the expected delay is strictly greater than 0.

Proposition 2 $E\{t_{min}^{Comm}\}$ is greater in the case of $n > 2$ than in the case of $n = 2$.

3. Experimental Design and Hypothesis

3.1. Experimental Design

Our experiment features a 2x2 design where we vary the availability of communication opportunity between subjects and vary the group size of 2 and 4 within subjects leading to the following four treatments:

- *NoComm2:* Communication not possible, groups of 2 players
- *NoComm4:* Communication not possible, groups of 4 players
- *Comm2:* Communication possible, groups of 2 players
- *Comm4:* Communication possible, groups of 4 players

In the *NoComm* treatments, participants play the baseline investment timing game while in the *Comm* treatment they first go through the communication stage before making their investment time decision.

In the *NoComm* treatments, subjects choose their investment times, a number t_i from the interval [0, 100], where $t_i = 0$ means immediate investment and $t_i = 100$ means no investment. The investment opportunity is non-rival and has uncertain returns. It is of good quality with probability $q = 0.5$ and of bad quality with probability $1 - q = 0.5$. The return of the investment is 100 minus the delay (i.e. earliest investment time) with 0.5 probaility, and 0 with 0.5 probability. The subject with the earliest investment time in his matched group, pays the cost of the irreversible investment given by $C(t_{min}) = \frac{1}{4}B(t_{min}) = \frac{1}{4}(100 - t_{min})$, while all subjects in the matched group utilize the returns equally. The resulting payoff of subject i choosing time t_i while the delay equals t_{min} is given by:

$$u_i(t_i, t_{min}) = \begin{cases} 25 - \frac{t_{min}}{4} & if\ t_i = t_{min}, \\ 50 - \frac{t_{min}}{2} & if\ t_i > t_{min}\,. \end{cases}$$

In the *Comm* treatments, subjects first face a communication stage prior to the investment time decisions. In this communication stage, subjects simultaneously choose whether they want to communicate with other subjects in their group. Those who want to communicate are forwarded to a chat screen, the ones who does not want to communicate are directly forwarded to the second stage where investment times are chosen.

In the communication stage, subjects first submit an initial suggestion for the investment time decision simultanously. This suggestion is not binding, but only aimed to initiate the discussion in the chat. Subjects then enter the chat screen for a free chat, which lasted 3 minutes in the first five periods, and 1 minute in the following periods. Subjects can leave the chat screen at any point in time, and this information is shared with the othres in the chat room. After the time finishes, subjects are asked to enter an investment time. If the decision times of subjects in the communication group are the same, this choice is implemented as their communication group decision. If the decision times do not match, then subjects in the communication group receives this information, meaning they could not agree on a common investment time and are asked to enter their individual decision times. Subjects who are not in the communication group are also asked to enter their investment time decisions. The payoff of subject i choosing time t_i is determined by the following payoff function:

$$u_i(t_i, t_{min}) = \begin{cases} B(t_{min}) - C(t_{min}) & \text{if } t_i = t_{min} \text{ and } K_i = 0 \\ B(t_{min}) - C(t_{min})/k & \text{if } t_i = t_{min} \text{ and } K_i = 1 \\ B(t_{min}) & \text{if } t_i > t_{min} \end{cases}$$

where k is the number of subjects in the communication group, i.e., $k \equiv \#\{i: K_i = 1\}$ and the delay is given by $t_{min} \equiv \min\left\{\min_{i:K_i=0} t_i\, , t_K\right\}$.

To allow for learning, subjects played a series of investment timing games either with communication or without communication, as described above. In each treatment, subjects 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. After each period is played, subjects are informed about the choices and payoffs of the others in their group, their own payoffs and whether the investment project is of good or bad quality.

3.2. Experimental Procedures

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. 160 students participated in the experiment. Participants were recruited from the CREED subject pool. In each session, 16 subjects interacted anonymously for 40 periods that lasted around 90 minutes.[6] In each period, subjets are rematched within a matching group of 8 subjects.

All participants in each treatment were given the same instructions (see Appendix). At the beginning of each period, subjects are randomly re-matched with each other. The identity of the partners was not revealed to subjects. It was explained to the subjects that their final earnings depended on their own choices and the choices of the matched participants. The subjects were asked to choose a number between 0 and 100 in each period. Subjects were provided an earnings calculator on the computer screen enabling them to calculate their earnings in points for any combination of hypothetical choices and any realization of the project quality.

The payoffs in the experiment were expressed in points. At the end of the experiment, the sum of a subject's earnings in points in all rounds of all matches were converted into Euro at the exchange rate of 120 points= 1 euro, and privately paid to subjects. The average earning in the experiment was 31.33 Euro.

3.3. Hypothesis

We formulate our hypotheses based on the theoretical analysis in Section II. For each treatment, we restrict our attention to the symmetric equilibria presented in the theory section substituting the parametrization used in our experiment (see Examples 1–3). Table 1 presents the equilibrium predictions regarding the expected delay in each treatment. Comparing the equilibrium expected delays, we predict that the opportunity to communicate reduces the expected delay by about 30 for both $n = 2$ and $n = 4$, leading to our first hypothesis.

Table 1: Expected Delay in Equilibrium

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

[6] 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.

Hypothesis 1 The delay is smaller with communication opportunity than without communication opportunity for both $n = 2$ and $n = 4$: (i) $D_{Comm} < D_{NoCom}$; (ii) $D_{Comm4} < D_{NoComm4}$.

Moreover, increasing the number of players from $n = 2$ to $n = 4$ pushes up the delay both with and without the opportunity to coordinate by about 10. 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) $D_{COMM} > D_{COMM2}$; (ii) $D_{NOCOMM4} > D_{NOCOMM2}$.

4. Results

4.1. 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 of 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: 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 coordination (Huck et al. (2004), Kopányi-Peuker (2019)).

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.

Table 2: 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	**Group size 2**	**Group size 4**	**p-value (2-sided Wilcoxon)**
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 communication and 10 in no communication)*

4.2. The Effect of Communication on Delays

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 that there is no longer a clear difference between the treatments.

To formally quantify treatment differences, and to test their statistical significance, we estimate the effect of communication on delay, 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 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 10% level.

Figure 1: Evolution of Delay

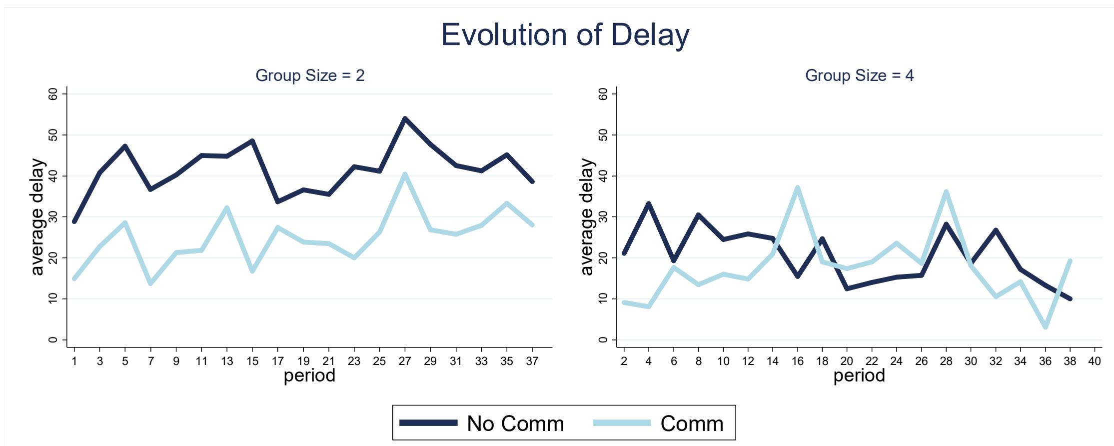


Table 3: The Effect Communication on Delay

	Group-size 2		Group-size 4	
Variables	(1)	(2)	(3)	(4)
Comm	-17.479***	-22.246***	-4.411	-12.938*
	(3.650)	(6.498)	(4.191)	(6.353)
Period		0. 0667		-0.361**
		(0. 181)		(0.147)
Comm x Period		0.250		0.426**
		(0.243)		(0. 180)
Constant	42.389***	41.122***	21.546***	28.781***
	(2.877)	(5.518)	(2.997)	(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 level. *** (**) [*] indicate that the estimated coefficient is significant at the 1% (5%) [10%] level. The dependent variable is delay in all specifications.*

Now we take a closer look at the effect of communication in 2-person and 4-person groups respectively.

Communication effect in small groups

In 2-person groups, although the treatment differences are in the direction of our predictions (see Table 1), there is still a considerable delay in *Comm2* caused by less communication than predicted and free riding of non-communicators. *NoComm2* is largely in line with the predictions.

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 decides for/against communication

The symmetric Nash prediction is that all players will engage in communication; they will decide on a 0-investment decision and thus share the costs. Table 4 shows that, against the theory, 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 45% of the pairs. In 22% of these cases no agreement was reached. The question is, why did so many participants (32%) reject the possibility of a chat? 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 free ride in many cases. This suggests that the chat-decision works like a coordination device for behavior in the investment stage: the participant who declines communication signals a late investment decision, and that the participant who wanted to communicated is likely to bear the whole cost of investment. When both participants don't want to communicate, the earnings are relatively low.

In *NoComm2* treatment, individual decisions are supposed to be uniformly distributed on [0,100], so with an average individual decision of 50 and an expected delay of 33 (see example 1 in section 2). We find an average delay that is larger (42.4, see table 2) and average individual decisions are 63.26.

Communication effect in large groups

We hypothesized that communication would decrease delay, also in the large groups. Over all periods, we find that the difference is in the right direction, but not statistically significant. In *NoComm4* the delay is smaller than expected, and in *Comm4* it is larger than expected. In *NoComm4* the average investment decision is 63.5 (the symmetric Nash equilibrium predicted 75) and the delay (which is the minimum of the 4 investment decisions) is 21.3 (predicted was 43), which suggests the assumption of symmetry may not hold.

In *Comm4* the delay is larger than predicted, and that is especially so in the later periods. There is more communication than expected, but communication is less effective (in many cases no agreement is reached). To study the behavior after an agreement failure, 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 decision than their initial decisions. Out of this 52%, 35% has investment time choices less than 10, while 49 has more than 90.

Lastly, we investigate whether the choices to communicate or not serve as strategic signaling and affect the earnings of participants. To so do we estimate the effect of chat decision on earnings in the communication treatment. 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 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.

Table 5: Communication decisions in *Comm4*

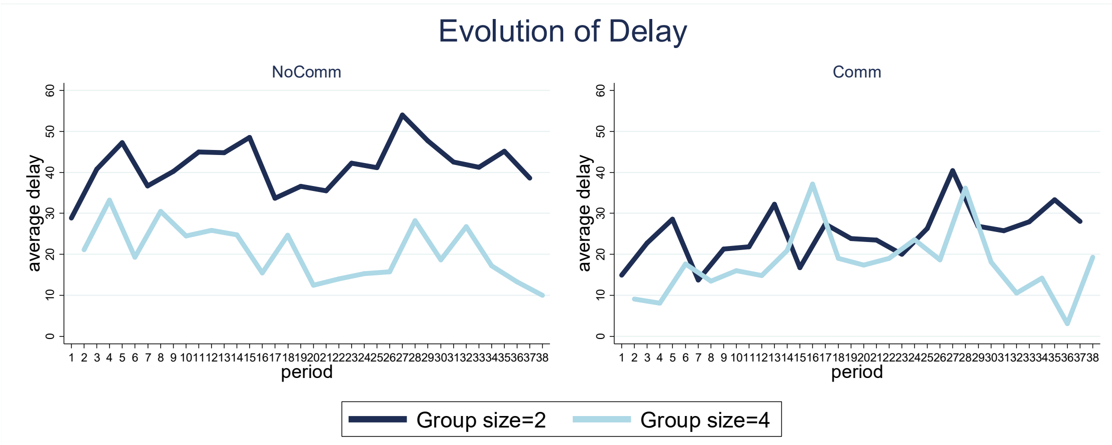
Actual chat	Size of Communication Group	N (%)	Average delay	Average investment decision*	Average earnings*
No	Three members decides against communication	144 (9.4%)	22.64	44.86 77.90	35.89 44.07
	All members decide against communication	12 (0.8%)	22.00	49.50	28.46
Yes	Four members decide for communication	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 decides for [against] communication

4.3. 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 when communication is introduced.

Figure 2: Evolution of Delay



As shown in Table 6, presenting results from regressions where delay is regressed on a groupsize 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.

Group size effect in the no communication treatment

The hypothesis that delay would be larger in larger groups is based upon the assumption that the players play according to symmetric mixed strategy equilibria. That is not what we find. We will now look how the individual investment times differ from these game 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 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 Groupsize 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 don't 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 B1 in appendix B). So, although the average investment times are comparable, we see a different 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 not confirm the symmetric equilibrium prediction that increasing the group size will decrease the probability of at least one volunteer (see, for example, Kopányi-Peuker, 2019). 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 player 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, realization about 18), but in *Comm2* the prediction was 0 and the realization was about 25. We will first discuss the behavior in *Comm2*.

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% decides to communicate instead of the 54% predicted (see example 4). 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 that many groups do not agree. So, there are two counter 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.

5. 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 where the players can free ride on earlier investments by others. Theoretically, we find that introducing communication reduces strategic delay. In the lab, we find that in the two-player case, communication significantly indeed reduces the strategic delay. In contrast, in the case of four players, we only find for the first period that communication helps subjects to coordinate and reduce strategic delay significantly, while coordination failures emerge in the following periods sweeping away the beneficial effect of communication at the aggregate level. We see two reasons why communication is not very effective in the four-player case: (i) there is much less free riding than predicted by theory, resulting in low delays, even without communication; (ii) the communication in and of itself creates free riding problems because it turns out to be more attractive to be an outsider than an insider of the communication group.

Our results have several interesting implications both academically and for policy making. We contribute to the broad literature on communication, which generally shows that communication helps players to reach better outcomes in a large range of settings including the prisoner's dilemma and other social dilemmas (see Balliet, 2010, for a meta analysis), trust games (Charness and Dufwenberg, 2006), and oligopoly games (Fonseca and Normann, 2012; Gomez-Martinez et al., 2016). Our paper adds to this in that we have identified when communication works and when it does not in the particular setting of investment timing games. Other papers also point to the limitations of communication, including He et al. (2019) in the context of coordination games and Fonseca and Normann (2012) in the context of oligopolies. Papers on free riding (e.g. public good games). Our finding of communication yielding disappointing results in the four-player case links to the literature on partial cartels where free riding of outsiders is also an imminent threat to cartel stability (Bos and Harrington, 2010; Gomez-Martinez, 2017).

Our results also speak to the policy makers, competition lawyers in particular. Cooperation between firms regarding R&D is allowed in the light of anti-cartel law under a number of conditions. Our results point to cases where such lenient approach to R&D collaboration is justified: Firms involved in developing new products may be hindered by free riding issues in settings where innovations are readily copied by competitors. Our experiment shows that allowing for cooperation between firms may speed up innovation, in particular in very concentrated industries.

We envision the following avenues for future research. In our experiment, players signal by deciding *not* to communicate 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. 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 to what extent our results extrapolate to a setting where investment spill-overs to competitors are less than perfect. Finally, our results are obtain for homogeneous players, which leaves open the question what the impact of player heterogeneity might be.

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APPENDIX

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.

Table B1: The Effect 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 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 investment times timings in all specifications.*

Table B2: The Effect ChatDecision on Investment Timings

Variables	(1) n=2	(2) n=4
Chat Decision$_{t-1}$	0.137*** (0.044)	0. 239*** (0.029)
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.* T-1 period

Table B3: 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

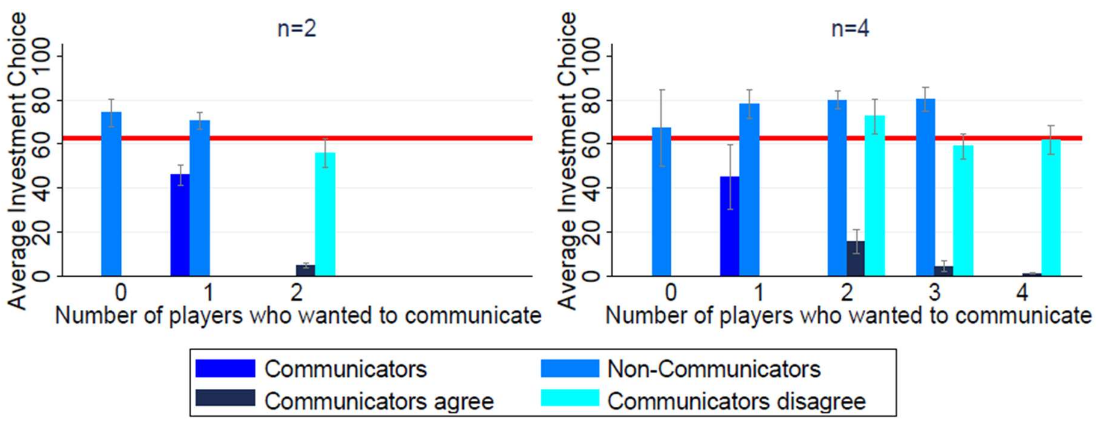
Notes: *This table report results from linear regression with standard errors (in parenthesis) clustered at the individual level. *** (**) [*] indicate that the estimated coefficient is significant at the 1% (5%) [10%] level. The dependent variable is a participant's earnings in all specifications. Specifications (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 B4: 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 B2: 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.*