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Cooperation in knowledge sharing and R&D investment[☆]

Felix C. Meickmann[*]

Department of Economics, University of Cologne, Germany

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ABSTRACT

This paper reports a laboratory experiment that provides insights on cooperation in R&D investment when knowledge sharing decisions are endogenous. Specifically, there are two types of treatments: one in which participants decide on whether to share knowledge before they make their investment decisions and one where the knowledge sharing constellation is exogenously given, both with and without non-binding communication. The results show that there are behavioral spillovers between the decisions on knowledge sharing and investment. When exogenously set, the degree of symmetric knowledge sharing does not affect cooperation. Communication increases cooperation more when participants can decide on knowledge sharing.

1. Introduction

Over the last decades, the role of knowledge transfer in cooperative and non-cooperative research and development (henceforth R&D) has been studied extensively in a vast body of theoretical and empirical literature. R&D is considered to be essential for innovation as well as productivity and economic growth in general.[1] There is also consensus that inter-firm cooperation in R&D can raise social welfare.[2] As such, governments try to encourage firms to conduct joint R&D activities and to form so-called Research Joint Ventures by exempting cooperation measures from competition law.[3] One key com-

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* Correspondence to: University of Cologne, Staatswissenschaftliches Seminar, Albertus-Magnus-Platz, Köln 50923, Germany.
E-mail address: felix.meickmann@uni-koeln.de

[1] On the general returns of R&D see Hall et al. (2010). For the importance of R&D for economic growth see Aghion and Howitt (1998), Grossman and Helpman (1994) and Romer (1990).

[2] Theoretical studies comparing cooperative and non-cooperative R&D include d'Aspremont and Jacquemin (1988); De Bondt and Veugelers (1991); Kamien et al. (1992); Katz (1986); Spence (1984) and Suzumura (1992).

[3] E.g., EC Treaty Art. 81 (3).

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ponent of such cooperation is the transfer of knowledge between firms. There is, however, a discrepancy between standard theoretical predictions and empirical findings on the effect of knowledge transfers on investments into R&D. Standard theoretical models predict that investments into R&D are smaller the greater the degree of knowledge transfer.[4] A large number of empirical studies have not found such a correlation or even have documented an inverse relationship by reporting more cooperation, corresponding to higher R&D investments, when higher levels of knowledge transfers are present.[5] One possible explanation of the divergence of the empirical findings from the theoretical predictions are behavioral spillovers between an active decision on knowledge sharing and a subsequent decision on R&D investments.[6] That is, cooperation in knowledge sharing is followed by cooperation in R&D investment, and non-cooperation in knowledge sharing is followed by non-cooperation in R&D investment. This study sets out to experimentally test whether there exist behavioral spillovers between an active decision on knowledge sharing and a subsequent investment decision.

Suppose that investments into R&D reduce the investing firm's production cost.[7] The extent to which one firm's investment into R&D reduces another firm's cost is determined by the amount of knowledge that is transferred from the investing firm to the other. As a result, the transfer of knowledge is related to two distinct effects: an efficiency effect and an incentive effect.[8] On the one hand, if knowledge is transferred from one firm to another, the recipient firm needs to invest less into R&D to reach a certain level of innovation. Thus, the efficiency of the industry increases. On the other hand, high outgoing knowledge reduces the return of innovation since the recipient firm can imitate without cost, thus decreasing the incentive to conduct R&D. Therefore, the degree of knowledge transfer is not only decisive for the efficiency of R&D processes but also the strategic environment in which investments into R&D are made. As such, it determines the individually, industrially and socially optimal levels of R&D investment, which in most cases differ from each other. For example, when all knowledge is mutually shared, the individually optimal level of R&D investment is lower than the industrially optimal level of R&D investment, which is lower than the socially optimal level of R&D investment. Alternatively, when no knowledge is shared at all, the individually optimal level of R&D investment equals the socially optimal level and is higher than the industrially optimal level of R&D investment.[9]

Meanwhile, the transfer of knowledge between firms is regularly determined by their active decisions of whether to share knowledge with the respective other firms.[10] These decisions can take place prior to investments into R&D and be observable and irreversible in the short run. As such, they may lead to asymmetric knowledge sharing that cannot be resolved for some time. To fix the idea, consider the following examples for two firms, say firm A and firm B. First, imagine firm A includes a non-compete clause in its labor contracts whereas firm B does not. At the time the firms find out about the respective other firm's behavior, the existing contracts cannot be modified ad-hoc. Therefore, when investing into R&D, firm B has to take into account that knowledge can freely flow to firm A via movement of workforce but not vice versa. Alternatively, picture the firms setting up a joint data room, based on a necessarily incomplete contract, where both firms store research data to be used mutually. Let's say firm A deliberately makes only data available that is not appropriable for firm B while firm B shares data that can be used by firm A. Consequently, when deciding upon R&D investments, firm B has to consider that firm A may imitate the results of upcoming research on the basis of the already transferred knowledge without cost.[11]

Experiment. The aim of the experiment reported in this paper is to investigate the effect of an active decision on knowledge sharing on the subsequent R&D investment decision. In particular, behavioral spillovers shall be considered.

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[4] See e.g., d'Aspremont and Jacquemin (1988) and Kamien et al. (1992).

[5] See e.g., Becker and Dietz (2004); Cassiman and Veugelers (2002); Hernan et al. (2003); Kaiser (2002) and Veugelers (1997).

[6] In contrast, the theoretical literature attributes the discrepancy regularly to the increased attractiveness of cooperation in R&D investment when a high degree of knowledge transfer is present, irrespective of how the high degree of knowledge transfer was arrived at. For an isolated experimental investigation of the role of the degree of knowledge transfer, see Suetens (2005).

[7] The assumption that R&D reduces production costs is made by d'Aspremont and Jacquemin (1988) and the literature following them (see De Bondt, 1997 or Sena, 2004 for an overview of this literature). The same holds for the assumption that investments into R&D are additive if knowledge is shared. The experiment in this paper is based on a model derived from the framework by d'Aspremont and Jacquemin (1988). Therefore, both assumptions are adopted.

[8] See e.g., Amir et al. (2003); Knott et al. (2009); Spence (1984).

[9] When all knowledge is mutually shared, the individually dominant strategy is to make comparatively low investments into R&D due to a decrease in the individual return on innovation (as previously discussed with regards to the incentive effect). At the industry level, however, a higher investment into R&D by both firms would be more profitable (see the aforementioned efficiency effect). An even higher investment would lower production cost further and ultimately increase production quantities which is beneficial for social welfare. Without any knowledge sharing, relatively low investments into R&D, resulting in relatively higher production costs and lower production quantities, are optimal from an industry perspective. The individually dominant strategy involves higher R&D investments which result in lower production costs and greater production quantities, thereby improving social welfare. At this point, however, the cost of further investment into R&D would exceed its benefits.

[10] Initially, only exogenously provided and symmetric knowledge transfer constellations were considered. Amir et al. (2003, p.185) considered this as "rather disturbing". Several more recent studies point to the strategic relevance and the welfare implications of actively shared knowledge (e.g., Dawid and Hellmann, 2020; Gersbach and Schmutzler, 2003a; Katsoutacos and Ulph, 1998; Kesteloot and Veugelers, 1995; Lambertini et al., 2004; Poyago-Theotoky, 1999) and potentially asymmetric constellations (e.g., Amir et al., 2003; Atallah, 2005; Knott et al., 2009; Salant and Shaffer, 1998). Here, specific circumstances can exist under which an optimal solution requires one-sided knowledge transfer with one firm conducting all R&D activity. However, in most situations the main result of the previous literature carries over, that is, symmetric full knowledge sharing and cooperation in R&D investment is optimal (i.e., on the industry level and socially). Meanwhile, individually, not sharing knowledge and not cooperating in R&D investment is the dominant strategy in almost any scenario.

[11] Other real-world examples in which decisions on knowledge sharing are made individually before investments in R&D take place, and which may lead to asymmetric knowledge sharing constellations in the short run, include the establishment of joint R&D facilities, espionage, general location choices and research path decisions. See also Amir et al. (2003); Kesteloot and Veugelers (1995) and Veugelers (1997).

The experimental design is based on a three stage game derived from the standard R&D framework by d'Aspremont and Jacquemin (1988). In the first stage, firms individually choose how much knowledge they want to share. In the second stage, both firms are informed about their competitor's knowledge sharing decision and choose their R&D investment level. In the third stage, firms engage in Cournot competition. Theoretical equilibria and the joint profit maximizing solutions for this model are provided under simplifying restrictions for the complete game and the resulting subgames. The experimental implementation looks like this: First, firms face the binary decision of whether to share knowledge.[12] The choices of the two firms determine in which one out of four possible knowledge sharing constellations the R&D investment decision is made afterwards. In the second stage, both firms are informed about their competitor's knowledge sharing decision (and thus the knowledge sharing constellation) and choose their R&D investment level. The Cournot competition stage is integrated into the second stage via presenting the participants the payoffs corresponding to their investment levels, assuming Cournot-Nash-equilibrium play in the third stage.[13] As such, participants have to act in the knowledge sharing stage and the investment stage. In total, eight neutrally framed treatments were run. Specifically, there were two treatments with exogenously provided full knowledge sharing, two without knowledge sharing, two with exogenously provided asymmetric knowledge sharing and two in which participants individually chose between full and no knowledge sharing. In one of each, unstructured non-binding communication was allowed. All treatments lasted for 15 rounds and at the beginning of each session, participants were randomly assigned to groups of two with fixed partner matching.[14]

Results. The main findings are: (1) with an endogenous knowledge sharing decision, behavioral spillovers are very frequent, that is, duopolies that cooperate in knowledge sharing cooperate in R&D investment and duopolies that do not mutually share knowledge do not. When both parties share knowledge, they cooperate substantially more often in the R&D investment stage when the knowledge sharing decision is endogenous, regardless of whether communication is available or not. With an endogenous knowledge sharing decision and in the absence of mutual knowledge sharing, no cooperation in the R&D investment stage emerges. (2) Meanwhile, cooperation rates are not affected by the degree of knowledge sharing when exogenously set and symmetric. With exogenously provided asymmetric knowledge sharing constellations, there is virtually no cooperation in the sense of joint profit maximization – irrespective of the availability of communication. (3) In all other treatments, communication increases cooperation; in the treatment with endogenously chosen knowledge sharing parameters even to a cooperation rate close to 100 percent. (4) In the treatments with an exogenously provided asymmetric knowledge sharing constellation, participants do not cooperate towards a joint profit maximizing solution but coordinate on a more egalitarian outcome. (5) Furthermore, in the treatments without communication, a high rate of participants choose neither the cooperative level of investment nor the non-cooperative Nash-equilibrium level when knowledge sharing is absent. (6) There is evidence that with endogenously chosen knowledge sharing parameters these choices are motivated by inequality aversion. Also, the decisions made under exogenously provided asymmetric knowledge sharing can be better explained by assuming inequality aversion. With exogenously provided symmetric knowledge sharing parameters, analogous decisions cannot be explained by inequality aversion.

Literature. This study is related to three branches of the literature. First, while there exists a large body of experimental literature on Cournot competition and more generally on oligopoly behavior, literature on non-cooperative R&D and knowledge sharing is scarce.[15] Suetens (2005) reports an experiment to investigate the relationship between knowledge transfer parameters and R&D investment decisions. However, in contrast to this paper, her study provides symmetrical knowledge transfer parameters exogenously. In particular, the impact of non-binding communication and binding contracts is considered under symmetrical full knowledge transfer and no knowledge transfer. Her findings suggest that cooperation in the absence of knowledge transfer can only be induced using binding contracts; whereas with knowledge transfer, non-binding communication leads to a substantial increase of cooperative behavior. More recently, Roelofs et al. (2017) report an experiment with endogenous knowledge sharing decisions in an environment in which firms are subject to asymmetric cost structures and that allows for side payments. In contrast to this study, only symmetric knowledge sharing constellations are possible; that is, if one of the parties decides not to share knowledge, the other party automatically does not engage in knowledge sharing as well, irrespective of their actual decision on whether to share any knowledge. Hence, deciding to share knowledge does not bear the risk of ending up sharing knowledge without receiving knowledge. This is a realistic setting for many cases and as such the results of the study are important to assess the effect of endogenous knowledge sharing decisions on R&D investments. The authors find that, although the participants exhibited a strong willingness to share knowledge, their behavior was by and large consistent with the theoretical (non-cooperative) equilibrium predictions. However, despite the broad applicability of the setting presented by Roelofs et al. (2017), there exist numerous situations – such as the aforementioned – in which an endogenous decision on knowledge sharing can result in (temporarily) asymmet-

[12] As such, the structure is comparable to Amir et al. (2003) and Kesteloot and Veugelers (1995) but not to Gersbach and Schmutzler (2003b), Lambertini et al. (2004) or Poyago-Theotoky (1999) where the knowledge sharing parameter is determined after R&D investment levels have been chosen.

[13] The assumption of Cournot-Nash-equilibrium play in the third stage allows for the isolation of behavioral spillovers in the two previous stages and thus for a cleaner comparison. It further reduces confounding factors and the complexity of the game for the participants of the experiment. For a similar approach see e.g., Suetens (2005).

[14] Repeated interactions of the identical parties are the most realistic scenario for the situation at hand. Fixed partner matching also is very common in experiments investigating cooperative behavior, see e.g., Anderhub et al. (2003), Benndorf and Odenkirchen (2021), Horstmann et al. (2018), Müller (2006), Suetens (2005) or Suetens (2008).

[15] For an overview of the experimental literature on oligopoly behavior see e.g., Potters and Suetens (2013) or Engel (2007).

ric knowledge sharing constellations. Due to the risk of one-sided knowledge sharing, the strategic environment in those situations differs fundamentally from a situation in which asymmetric knowledge sharing constellations are ruled out per se. Hence, the results presented by Roelofs et al. (2017) cannot be directly transferred to what is investigated in this study.

Further, this study is related to literature that reports experiments which investigate behavioral spillovers between multiple stages of a game and apply the R&D framework by d'Aspremont and Jacquemin (1988), but, contrary to this study, focus on the relationship between R&D cooperation and collusion in pricing behavior on a subsequent product market. Suetens (2008) runs treatments with and without knowledge sharing that is exogenously set and with and without the possibility to agree on binding R&D contracts. She finds that cooperation in the R&D investment stage facilitates price collusion when such binding contracts are made. In a related study, Nicklisch (2012) adapts the R&D model by d'Aspremont and Jacquemin (1988) to analyze how collusive decisions on advertising expenditures (resembling R&D investments) translate to collusive pricing behavior. The reported findings are consistent with those obtained by Suetens (2008): The degrees of cooperation and collusion in multiple decisions are strongly correlated. Another study that applies the R&D framework is presented by Cason and Gangadharan (2013) who use a competitive double auction environment and find, contrary to Suetens (2008) and Nicklisch (2012), no evidence that cooperation in R&D facilitates collusive pricing.[16] Other studies investigating the relationship between behavior in multiple stages of a game or sequentially played games also report results that are generally indicative of a strong spillover effect (e.g., Cason et al., 2012; Cooper and Kühn, 2014; Normann and Wenzel, 2018).

Finally, this paper adds to the literature on costless non-binding communication in oligopoly experiments which is considered to be "cheap talk" (Farrell and Rabin, 1996). From a theoretical point of view, cheap talk should not have any effect on strategic behavior. However, cheap talk may suffice to reduce uncertainty about other parties' actions or motives (Crawford, 1998). Fonseca and Normann (2012) investigate the impact of communication on Bertrand oligopolies with varying numbers of firms. They find that communication substantially facilitates collusion and allows subjects to yield greater profits. Waichman et al. (2014) analyze the impact of communication on Cournot competition, comparing standardized and free communication with students and managers as participants and also report that communication generally increases collusion.

Organization of the paper. The rest of this paper is organized as follows. In the next section, the model is specified, the parameter setting is derived and theoretical benchmarks are provided. Section 3 describes the design of the experiment. Section 4 presents the results and Section 5 discusses and concludes.

2. Model and theoretical predictions

As a version of the d'Aspremont and Jacquemin (1988) framework, a three stage game for two players is considered. In the first stage, firms simultaneously set their knowledge sharing parameter (s_i, s_j), i.e., the amount of knowledge the firm shares with its competitor. In the second stage, firms are informed about the knowledge sharing decision of the other firm and decide on their R&D investment (x_i, x_j). In the last stage, firms engage in Cournot competition by choosing output quantities (q_i, q_j).

The industry consists of two firms producing a homogeneous good in a market with linear demand

$$P(q_i, q_j) = a - (q_i + q_j) \tag{1}$$

where q_i denotes the production quantity of firm i with $i = 1, 2$, $i \neq j$, and a represents the market size. Firms have to incur initial marginal costs c. The non-negative R&D investment (x_i, x_j) combined with the knowledge sharing parameter (s_i, s_j) in $\{0, 1\}$ leads to a reduction of the firm's cost. The resulting effective marginal costs are $c_i = c - x_i - s_j x_j$ and $c_j = c - x_j - s_i x_i$, respectively. Assume that $a > 2c > 0$. Introducing the R&D cost parameter γ, the costs of conducting cost reducing R&D are represented by $\frac{\gamma}{2}x_i^2$. To ensure interior solutions, assume that $\gamma \geq \frac{4}{3}$.[17] Hence, firm i's profit is given by

$$\pi_i = [P - c_i]q_i - \frac{\gamma}{2}x_i^2. \tag{2}$$

Solving for the Nash-Cournot-equilibrium leads to

$$q_i = \frac{1}{3}[(a - c) + (2 - s_i)x_i + (2s_j - 1)x_j]. \tag{3}$$

Thus, the second stage profit function is

$$\pi_i(x_i, s_i, x_j, s_j) = \frac{1}{9}[(a - c) + (2 - s_i)x_i + (2s_j - 1)x_j]^2 - \frac{\gamma}{2}x_i^2. \tag{4}$$

[16] Cason and Gangadharan (2013) argue that the reason why they do not find cooperative behavioral spillovers might be due to the use of double auctions. Double auctions usually lead to competitive prices and high efficiency.

[17] See Amir and Wooders (1999).

Table 1
Theoretical Benchmarks.

	x_i^{NC}	x_j^{NC}	x_i^C	x_j^C	π_i^{NC}	π_j^{NC}	π_i^C	π_j^C	W^{NC}	W^C	x_i^W	x_j^W
$s_i = s_j = 0$	3.7	3.7	1.7	1.7	23.5	23.5	27.8	27.8	124.9	117.5	3.7	3.7
$s_i = s_j = 1$	1.9	1.9	5.0	5.0	35.1	35.1	41.6	41.6	149.0	222.0	5	5
$s_i = 0, s_j = 1$	5.3	1.1	3.8	4.2	47.7	11.5	63.8	6.6	137.6	169.3	5	5

The joint profit of the two firms is hence

$$\begin{aligned}\pi(x_i, x_j) = &\frac{1}{9}[(a-c) + (2-s_i)x_i + (2s_j - 1)x_j]^2 \\ &+ \frac{1}{9}[(a-c) + (2-s_j)x_j + (2s_i - 1)x_i]^2 \\ &- \frac{\gamma}{2}x_i^2 - \frac{\gamma}{2}x_j^2.\end{aligned} \tag{5}$$

For the cooperative case, looking for the joint profit maximizing solution, the maximizing solution of the whole game induces $s_i = s_j = 1$. To see this, note that the derivative of π with respect to s_i is $\frac{4}{9}[a-c+(2-s_j)x_j+(2s_i-1)x_i]x_i - \frac{2}{9}[a-c+(2-s_i)x_i+(2s_j-1)x_j]x_i \geq 0$ for any $x_i > 0$. Hence, π is increasing in s_i, such that the joint profit maximizing solution is given, whenever $s_i = 1$. Taking the knowledge sharing parameter as given, one can solve for the following non-cooperative subgame equilibria[18]

$$x_i^{NC}, x_j^{NC} = \begin{cases} \dfrac{4(a-c)}{9\gamma-4}, \dfrac{4(a-c)}{9\gamma-4}, & \text{if } s_i = s_j = 0, \\ \dfrac{2(a-c)}{9\gamma-4}, \dfrac{2(a-c)}{9\gamma-4}, & \text{if } s_i = s_j = 1, \\ \dfrac{12\gamma(a-c)}{8+27\gamma^2-30\gamma}, \dfrac{2(3\gamma-4)(a-c)}{8+27\gamma^2-30\gamma}, & \text{if } s_i = 0 \text{ and } s_j = 1. \end{cases} \tag{6}$$

Furthermore, for the given specifications, one can solve for the joint profit maximizing cooperative R&D level[19]

$$x_i^C, x_j^C = \begin{cases} \dfrac{2(a-c)}{9\gamma-2}, \dfrac{2(a-c)}{9\gamma-2}, & \text{if } s_i = s_j = 0, \\ \dfrac{4(a-c)}{9\gamma-8}, \dfrac{4(a-c)}{9\gamma-8}, & \text{if } s_i = s_j = 1, \\ \dfrac{2\gamma(a-c)}{9\gamma^2-14\gamma+4}, \dfrac{4(\gamma-1)(a-c)}{9\gamma^2-14\gamma+4}, & \text{if } s_i = 0 \text{ and } s_j = 1. \end{cases} \tag{7}$$

For the experiment, the following parameters were chosen: $\gamma = 2.23$, $a = 25$, $c = 10$.[20] Table 1 provides the according theoretical benchmarks for non-cooperative R&D equilibrium investment levels (x_i^{NC}, x_j^{NC}) and cooperative R&D joint profit maximizing investment levels (x_i^C, x_j^C) as well as the resulting profits (π), levels of social welfare (W) and the social welfare maximizing investment levels (x_i^W, x_j^W) under the restriction that $x_i + s_j * x_j \leq c$, where social welfare is $W = \frac{(a-P)*(q_i+q_j)}{2} + \pi_i + \pi_j$, with the first term of the equation representing consumer welfare.[21] Recall that, when the knowledge sharing decision is endogenous, the subgame perfect Nash-equilibrium implies $s_i = s_j = 0$ with the respective equilibrium investment levels. Analogously, the joint profit maximizing solution can be achieved with $s_i = s_j = 1$ and the corresponding R&D investments.

From Table 1 it can be seen that the following relations hold with respect to individual profits (for i)

$$\pi^C_{s_i=0,s_j=1} > \pi^{NC}_{s_i=0,s_j=1} > \pi^C_{s_i=s_j=1} > \pi^{NC}_{s_i=s_j=1} > \pi^C_{s_i=s_j=0} > \pi^{NC}_{s_i=s_j=0} > \pi^{NC}_{s_i=1,s_j=0} > \pi^C_{s_i=1,s_j=0}.$$

[18] Second order conditions require that $\gamma > \frac{8}{9}$.

[19] Second order conditions require $\gamma > \frac{10}{9}$.

[20] The parameters were chosen such that they satisfy the stability criterion by Henriques (1990), the symmetry criterion by Salant and Shaffer (1998) and the condition for the optimality of a symmetric full knowledge sharing and cooperative R&D investment solution by Amir et al. (2003). For the case at hand, these can be translated to $\gamma > 2$. Symmetric equilibria and joint profit maximizing solutions in $s_i = s_j = 1$ and $s_i = s_j = 0$ enhance the comparability between the decisions in these knowledge sharing constellations. The parameters were selected to allow a representation of the different R&D investment levels in an evenly spaced standard game matrix with as little deviation as possible from the exact predictions. Therefore, the non-cooperative subgame equilibria and the cooperative joint profit maximizing solutions must be close to full integers while differing sufficiently from each other. By fulfilling the criteria mentioned above and producing numerical outcomes that are not significantly divergent from those in related experiments, such as Suetens (2005), it can be concluded that the chosen parameters should not exert a disproportionately larger influence on the results compared to other possible parameter values.

[21] Although participants cannot choose social welfare directly, under the present assumptions their decisions determine output quantities and thus consumer welfare. Hence, social welfare is a relevant measure that has to be considered too.

Table 2
Benchmarks in the Game.

	x_i^{NC}	x_j^{NC}	x_i^C	x_j^C	π_i^{NC}	π_j^{NC}	π_i^C	π_j^C	x_i^W	x_j^W
$s_i = s_j = 0$	4	4	2	2	22	22	28	28	4	4
$s_i = s_j = 1$	2	2	5	5	36	36	42	42	5	5
$s_i = 0, s_j = 1$	5	1	4	4	47	12	63	7	5	5

With respect to industry profits it holds that

$$\pi^C_{s_i=s_j=1} > \pi^C_{s_i \neq s_j} > \pi^{NC}_{s_i=s_j=1} > \pi^{NC}_{s_i \neq s_j} > \pi^C_{s_i=s_j=0} > \pi^{NC}_{s_i=s_j=0}.$$

With respect to social welfare the relation is

$$W^C_{s_i=s_j=1} > W^C_{s_i \neq s_j} > W^{NC}_{s_i=s_j=1} > W^{NC}_{s_i \neq s_j} > W^{NC}_{s_i=s_j=0} > W^C_{s_i=s_j=0}.$$

3. Experimental design, participants and procedures

Design

The aim of the experiment is to evaluate the levels of knowledge sharing and subsequent R&D investment when the knowledge sharing decision is endogenized (i.e., made by the participants themselves) in comparison to situations in which the degree of knowledge sharing is determined exogenously. In particular, it shall be identified whether and, if so, to what extent behavioral spillovers exist under endogenous knowledge sharing. Furthermore, the influence of non-binding unstructured communication in this environment shall be investigated.

The experiment consists of three stages: The knowledge sharing stage, the investment stage and the Cournot competition stage. The latter was not actively played in any of the treatments but integrated into the payoffs presented in the R&D investment stage. For this, the Nash-Cournot output equilibrium is computed as a function of the firms' R&D expenditure and the knowledge sharing parameters. In total, eight treatments were conducted: a baseline treatment without communication and an endogenous knowledge sharing decision, three treatments with exogenously set knowledge sharing parameters (i.e., $s_i = s_j = 0,\ s_i = s_j = 1$ and $s_i = 0,\ s_j = 1$), a cheap-talk treatment with a fourth stage allowing non-binding communication and an endogenous knowledge sharing decision, and three treatments with communication and exogenously set knowledge sharing parameters (i.e., $s_i = s_j = 0,\ s_i = s_j = 1$ and $s_i = 0,\ s_j = 1$). In the cheap-talk treatments, unstructured communication between the two parties of each duopoly was allowed via a chat screen. All treatments consisted of 15 decision rounds with partner matching, which was known to the participants. Conditional on the decisions made in each round, the payoff was calculated in line with the respective payoff scheme and credited to the participant's account. After the 15 rounds were finished, the current account was paid to the participants. The experiment was designed with neutral framing (see e.g., Abbink and Hennig-Schmidt, 2006) to reduce potential confounding factors.[22] Since the subgame perfect Nash-equilibrium and the joint profit maximizing solutions are located at mutually not sharing knowledge (i.e., $s_i = s_j = 0$) and mutually sharing full knowledge (i.e., $s_i = s_j = 1$), respectively, the game was restricted to a corresponding binary choice in order to arrive at clear results in terms of the scope of the present study. Additionally, the possible R&D investment levels were limited to a choice of five ($x_i \in \{1, 2, 3, 4, 5\}$)[23] to reduce the complexity of the game while still allowing for a number of constellations that are neither a Nash-equilibrium nor a joint profit maximizing solution. To prevent participants from trying to infer any particular fixed relation between the knowledge sharing constellation, the investment levels, and the payoffs, the knowledge sharing decision between $s_i = 0$ and $s_i = 1$ was simply referred to as a decision between X and Y. The different levels of R&D investment were called A, B, C, D and E. No additional context was provided. Finally, the reduction of a continuous into a discrete strategy space induces the occurrence of multiple equilibria (Holt, 1985; Huck et al., 2001). To overcome this issue, 18 out of the 200 values were manipulated by reducing the payoff by one Taler.[24] Table 2 provides the resulting benchmarks for the strategy space in the game.

[22] Neutral framing is considered the best practice to mitigate experimenter demand effects (De Quidt et al., 2019). Another effect of contextualized frames and labels, as opposed to neutral frames, that is particularly important for cooperation is that they tend to influence participants' beliefs about other participants' behavior and intentions (see e.g., Batson and Moran, 1999; Dufwenberg et al., 2011; Ellingsen et al., 2012; Kay and Ross, 2003; Liberman et al., 2004). Such frames and labels may even represent "coordination devices" (Ellingsen et al., 2012, p. 117). A disadvantage of the use of neutral framing is that much of the previous literature on R&D investments uses at least some context and thus, the comparability of results might be limited. This said, in duopoly experiments more generally, the use of neutral framing is more frequent. Overall, the benefits of using neutral framing should outweigh its downsides.

[23] These levels include the rounded values of the calculated Nash-equilibria and joint profit maximizing solutions.

[24] The transfer of a continuous strategy space into a discrete one involves rounding numbers (in the specific case at hand to full integers) which can result in additional equilibria in the discrete strategy space that are not existent in the continuous one. In response, those equilibria were dissolved by reducing one of the rounded values in such equilibria by one Taler. The adjusted rounded values were closest to the lower value in decimals. As an example: if an equilibrium with $\pi_i = 19$ and $\pi_j = 19$ occurred from rounding $\pi_i = 18.52$ and $\pi_j = 18.94$, $\pi_i = 18.52$ was reduced to $\pi_i = 18$.

Table 3
Treatments.

Treatment	Knowledge Sharing Decision	Communication	Participants
BLEND	Endogenous	No	32
BLEX00	Exogenous, no knowledge sharing	No	30
BLEX11	Exogenous, full knowledge sharing	No	30
BLEX01	Exogenous, asymmetric knowledge sharing	No	32
CTEND	Endogenous	Yes	32
CTEX00	Exogenous, no knowledge sharing	Yes	30
CTEX11	Exogenous, full knowledge sharing	Yes	32
CTEX01	Exogenous, asymmetric knowledge sharing	Yes	32

Baseline treatment with endogenous knowledge sharing choice - BLEND

There were two stages. No communication was allowed. In the first stage, participants individually had to decide whether to choose $s_i = 0$ (no outgoing knowledge sharing) or $s_i = 1$ (full outgoing knowledge sharing). In the experiment, $s_i = 0$ was represented by X and $s_i = 1$ was represented by Y. After both participants made their choice, their decision was revealed to the matched partner. In the second stage, the participants had to choose their R&D investment level $x_i \in \{1, 2, 3, 4, 5\}$, represented by A, B, C, D and E. Following, these decisions were revealed to the other player too.

Baseline treatment with exogenously set knowledge sharing parameter - BLEX00

Knowledge sharing parameters were exogenously set to $s_i = s_j = 0$. Hence, the knowledge sharing stage is omitted. No communication was allowed. The remainder parallels the BLEND treatment.

Baseline treatment with exogenously set knowledge sharing parameter - BLEX11

This treatment is identical to the BLEX00 treatment, except that now knowledge sharing parameters were exogenously set to $s_i = s_j = 1$.

Baseline treatment with exogenously set knowledge sharing parameter - BLEX01

This treatment is identical to the BLEX00 treatment, except that now knowledge sharing parameters were exogenously set to $s_i = 0$ and $s_j = 1$. The individual knowledge sharing parameters were determined randomly and were fixed over all rounds.

Cheap-Talk treatment with endogenous knowledge sharing choice - CTEND

There were three stages. In the first stage of every round, participants were able to conduct unstructured communication via a chat-window. The time to chat was limited to 60 seconds in the first round and to 40 seconds in the following rounds. A single message was limited to 250 characters. In the second and third stage - like in the two stages of the endogenous baseline treatment - participants had to choose $s_i = 0$ (represented by X) or $s_i = 1$ (represented by Y), respectively, and their R&D investment level $x_i \in \{1, 2, 3, 4, 5\}$ (represented by A, B, C, D and E). Their choices were revealed afterwards to the respective other party.

Cheap-Talk treatment with exogenously set knowledge sharing parameter - CTEX00

Knowledge sharing parameters were exogenously set to $s_i = s_j = 0$ and the knowledge sharing stage was omitted. The remainder parallels the CTEND treatment.

Cheap-Talk treatment with exogenously set knowledge sharing parameter - CTEX11

This treatment is identical to the CTEX00 treatment, except that now knowledge sharing parameters were exogenously set to $s_i = s_j = 1$.

Cheap-Talk treatment with exogenously set knowledge sharing parameter - CTEX01

This treatment is identical to the CTEX00 treatment, except that now knowledge sharing parameters were exogenously set to $s_i = 0$ and $s_j = 1$. The individual knowledge sharing parameters were determined randomly and were fixed over all rounds.

Consider Table 3 for an overview of the treatments.

In every treatment, participants were handed out a payoff scheme that was valid for all 15 rounds.[25] The payoff scheme consists of either one (when knowledge sharing parameters were exogenously set) or four matrices (one matrix for each possible combination of endogenously chosen knowledge sharing parameters), showing the possible outcomes for the subject themselves and the matched partner, contingent on the chosen R&D investment and the chosen knowledge sharing parameter.[26]

[25] The payoff scheme is located in the Online Appendix C.

[26] The design of the study involved a challenge in terms of presenting the payoff information to participants. While all four payoff tables were presented in the treatments with endogenously chosen knowledge sharing parameters, only one table was presented in the treatments with exogenously set knowledge sharing parameters. This asymmetry may raise concerns about potential effects on the results. However, other forms of presentation, such as presenting all four tables in the treatment with exogenously set knowledge sharing parameters, could have resulted in confusion among participants. They would have been exposed to irrelevant information, which could have led to unintended choices and outcomes. On the other hand, presenting only the table corresponding to the particular knowledge sharing choices made during the experiment in the treatments with endogenously chosen knowledge sharing parameters would have prevented participants from considering the outcomes of different strategies beforehand. Further, it might have led participants to wonder whether everyone is shown the same tables. Therefore, the chosen design was deemed the least confounding. The use of profit tables instead of calculators also served to make the impact of each decision on the payoff clearer and reduce the complexity and length of the experiment. According to a study by Requate and Waichman (2011), using a profit table instead of a calculator is not expected to affect duopoly decisions.

Table 4
Average Market Outcomes.

Know. Sharing	Treatment	Investment	Profit	Welfare	N	rel. freq.
				Rounds 1–15		
$s_i = s_j = 0$	BLEND	3.84 (1.11)	22.33 (5.00)	123.66 (1.37)	232	48.33%
	BLEX	3.16 (1.23)	24.42 (4.77)	122.38 (2.31)	450	-
	CTEND	4.50 (0.71)	19.64 (2.10)	123.79 (0.00)	2	0.44%
	CTEX	2.15 (0.84)	27.07 (3.18)	119.61 (2.57)	480	-
$s_i = s_j = 1$	BLEND	4.58 (0.11)	40.58 (4.90)	211.44 (21.40)	120	25.00%
	BLEX	3.10 (1.41)	37.63 (6.21)	176.44 (27.78)	450	-
	CTEND	4.95 (0.38)	41.46 (1.56)	220.83 (8.13)	432	90.00%
	CTEX	4.64 (0.89)	40.90 (3.44)	213.46 (19.10)	450	-
$s_i \neq s_j$	BLEND	3.02 (1.76)	30.99 (18.86)	140.49 (10.14)	128	26.67%
	BLEX	2.64 (1.63)	31.14 (17.01)	138.02 (11.53)	480	-
	CTEND	4.44 (1.36)	33.99 (35.48)	144.07 (15.60)	16	9.56%
	CTEX	2.25 (1.46)	31.48 (15.52)	137.29 (13.18)	480	-
				Rounds 7–15		
$s_i = s_j = 0$	BLEND	3.91 (1.09)	22.09 (4.85)	123.74 (1.13)	160	55.56%
	BLEX	3.20 (1.22)	24.37 (4.67)	122.37 (2.14)	270	-
	CTEND	4.50 (0.71)	19.50 (2.12)	123.79 (0.00)	2	0.74%
	CTEX	2.15 (0.85)	27.31 (3.28)	119.59 (2.52)	288	-
$s_i = s_j = 1$	BLEND	4.83 (0.69)	41.58 (3.07)	217.89 (14.47)	72	25.00%
	BLEX	3.14 (1.43)	37.83 (6.05)	177.31 (28.68)	270	-
	CTEND	5.00 (0.00)	42.00 (2.97)	222.03 (00.00)	268	99.26%
	CTEX	4.71 (0.80)	41.42 (2.97)	215.02 (17.20)	270	-
$s_i \neq s_j$	BLEND	2.95 (0.89)	30.66 (3.75)	139.24 (7.90)	56	20.42%
	BLEX	2.58 (1.60)	31.14 (16.66)	137.44 (11.23)	288	-
	CTEND	-	-	-	-	-
	CTEX	2.28 (1.50)	31.50 (15.62)	137.78 (13.14)	288	-

Note: Standard deviations in parentheses.

Participants, Payments and Procedures

The experiment was conducted at the Cologne Laboratory for Economic Research (CLER) at University of Cologne, the experimental laboratory of the Duesseldorf Institute for Competition Economics (DICE) at Heinrich-Heine University Duesseldorf and the Laboratory for Economics Research (LaER) at University of Osnabrueck, with a total of 250 participants. Table 3 presents the distribution of participants among the different treatments. All participants were pre-registered volunteers and students from a wide variety of fields of study. They were recruited using ORSEE (Greiner, 2015) and randomly assigned to treatments. The experiments were programmed and conducted with zTree (Fischbacher, 2007). Sessions lasted approximately 70 minutes and the participants were paid on average EUR 9.86 plus EUR 4 show-up fee.

Each participant was randomly assigned to a partner. At the beginning of each session, instructions were handed out to the participants, read out aloud, and questions could be asked privately.[27] During the whole session, participants were not allowed to communicate other than via the chat window in the cheap-talk treatments. To ensure the understanding of the game and the payoff-scheme, participants had to answer control questions before the game was started and they were not able to continue before giving the correct answer.

4. Experimental results

In what follows, the analysis will focus on and the reported results will refer to rounds 7 to 15, if not stated otherwise. The participants had gained some experience in the first six rounds, so their behavior tended to be more stable in rounds 7–15.[28] Stable data is particularly important to attain reliable results since statistics mostly report averages across rounds per duopoly. This is done because individual observations in a duopoly and across rounds are not independent of one another. However, for transparency, the data for all rounds are provided as well in the tables and in square brackets for the non-parametric tests.

Table 4 provides an overview of the market outcomes of the R&D investment decisions for all treatments and the different knowledge sharing constellations based on individual decisions. For each knowledge sharing constellation and irrespec-

[27] Instructions are located in the Online Appendix B.

[28] Fig. 1 shows that general cooperation rates in the baseline treatments are more stable after round six. Fig. 2 shows that knowledge sharing decisions in the CTEND treatment were almost completely stable after round six.

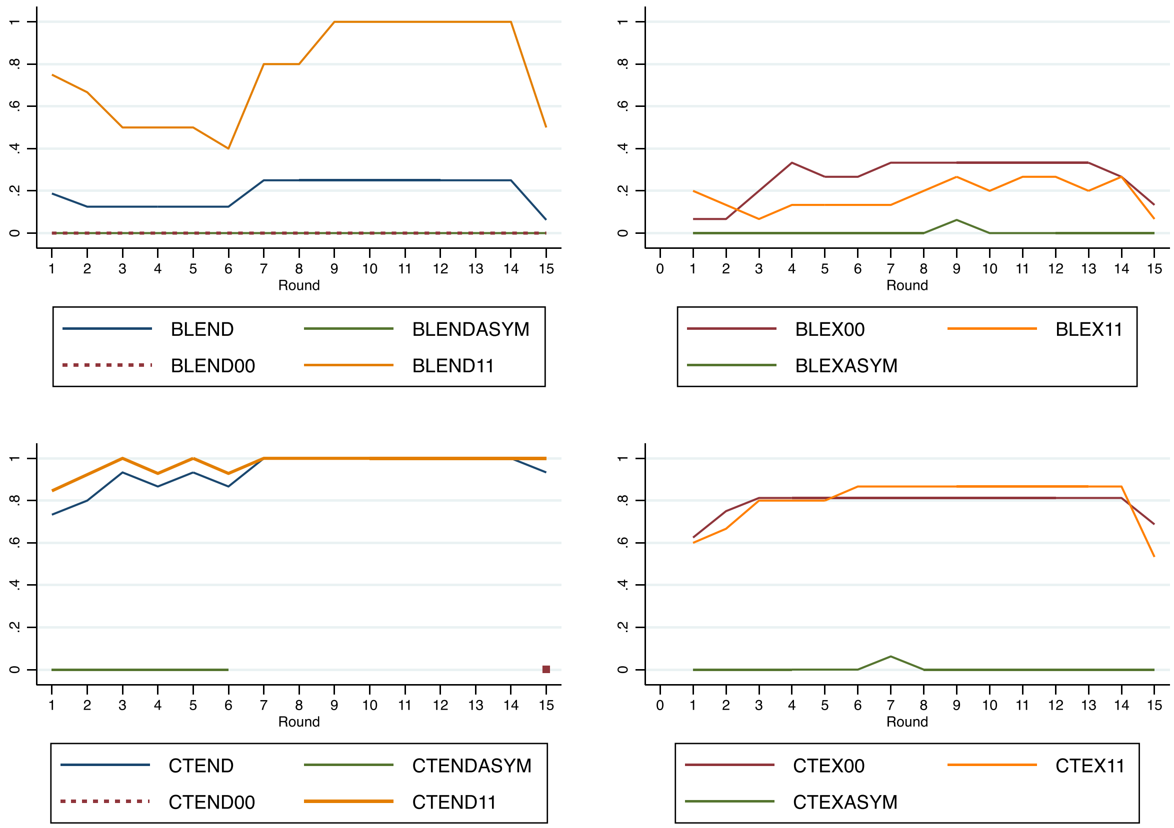

Fig. 1. Evolution of Cooperation Rates over Time.

tive of the availability of communication, R&D investments were higher in treatments where knowledge sharing parameters were chosen than in treatments where these were exogenously set. This is also the case for social welfare.

R&D Investment

The main objective of this paper is to investigate the effect of an active knowledge sharing decision on R&D investments and in particular its impact on cooperation. Cooperation is defined as mutually chosen joint profit maximizing R&D investment levels in the respective knowledge sharing constellation. Thus, the cooperation rate is the percentage of duopolies that cooperated out of all duopolies in the specific treatment and knowledge sharing constellation.

Fig. 1 shows the evolution of the cooperation rates on duopoly level in all treatments. The two graphs on the left show the cooperation rates for the treatments involving an active knowledge sharing decision, including data disaggregated by the knowledge sharing constellation the investment decision was made in. The two graphs on the right show the data of the six treatments with exogenously set knowledge sharing constellations. Note that cooperative behavior was rather stable (excluding end effects) in all treatments from round 7 onward.[29] An exception is the BLEX11 treatment where one can observe slight volatility in the cooperation rates across all rounds. A special feature of the CTEND treatment can be seen in the bottom graph on the left, namely that no duopoly was affected by end effects in the case of mutual knowledge sharing.

Next, turn to Table 5 which shows average cooperation rates on duopoly level in percent. Recall, that an independent observation is the average across rounds per duopoly. First, the data are presented disaggregated by knowledge sharing constellations, which are reported before each treatment's name, and then, from column twelve on, the data are pooled by

[29] In the treatments with an endogenous knowledge sharing constellation, cooperating duopolies stabilized as well, maintaining their knowledge sharing and investment decisions. In contrast, the duopolies who mutually chose not to share knowledge with each other rarely changed their knowledge sharing decision, but around 50 percent of them changed their investment decision in each round. In duopolies with asymmetric knowledge sharing by choice, most of the participants who initially chose to share knowledge changed their decision, while most of the participants who did not share knowledge stuck with their decision. In treatments with exogenously determined knowledge sharing constellations, around 50 percent of participants changed their investment decision in each round in the BLEX00 treatment and around 40 percent did so in the BLEX11 treatment and the BLEX01 treatment. With communication and exogenously determined knowledge sharing constellations, around 10 percent of the participants changed their investment decisions over all rounds, changes, however, were less frequent between rounds 6 and 14.

Table 5
Duopolies Cooperating in the R&D Investment Stage.

Know. Sharing	Treatment	Cooperation Rate	
		Rounds 1–15	**Rounds 7–15**
$s_i = s_j = 0$	BLEND	0.00%	0.00%
	BLEX	26.22%	30.37%
	CTEND	0.00%	0.00%
	CTEX	78.75	79.86%
$s_i = s_j = 1$	BLEND	45.76%	64.81%
	BLEX	17.78%	20.74%
	CTEND	97.78%	100.00%
	CTEX	80.00%	82.96%
$s_i \neq s_j$	BLEND	0.00%	0.00%
	BLEX	0.04%	0.07%
	CTEND	0.00%	-
	CTEX	0.04%	0.07%
Pooled Data	BLEND	19.17%	22.92%
	BLEX	14.49%	16.91%
	CTEND	93.78%	99.26%
	CTEX	52.48%	53.90%

Note: Percentages are averages over all/7-15 rounds per duopoly in the respective knowledge sharing constellation. These differ from relative frequencies of cooperative behavior in the disaggregated BLEND and CTEND treatment.

treatment(type). Statistical testing reveals that the differences in cooperation rates in R&D investment between constellations with mutual knowledge sharing and without knowledge sharing are significant at the 1 percent level in both treatments (i.e., with and without communication) with an active decision on knowledge sharing (BLEND00 vs. BLEND11: $p = .0013$ [$p = .0045$], two-tailed Mann-Whitney-*U*-test (henceforth, MWU), n=19 [n=22]; CTEND00 vs. CTEND11: $p = .0001$ [$p = .0170$], two-tailed MWU, n=16 [n=16]).[30] Meanwhile, the null-hypothesis of independence from knowledge sharing constellation cannot be rejected confidently for the treatments with exogenously determined symmetric knowledge sharing constellations (BLEX00 vs. BLEX11: $p = .9439$ [$p = .6967$], two-tailed MWU, n=30 [n=30]; CTEX00 vs. CTEX11: $p = .5542$ [$p = .4393$], two-tailed MWU, n=31 [n=31]).

Result I: *With an active decision on knowledge sharing, cooperation rates are higher in cases with mutual knowledge sharing than in cases without knowledge sharing. When the knowledge sharing constellation was determined exogenously, there is no difference between the cooperation rates in situations with mutual knowledge sharing and those without knowledge sharing.*

The difference between the cooperation rates of the BLEND treatment and the pooled BLEX treatments is relatively small and non-parametric testing does not reject the null hypothesis of independence from treatment (BLEND vs. BLEX: $p = .9836$ [$p = .8803$], two-tailed MWU, n=62 [n=62]). With both participants sharing knowledge, cooperation rates in the BLEND treatment are over three times that of the analogue BLEX treatment. This finding is supported by a non-parametric test (BLEND11 vs. BLEX11: $p = .0687$ [$p = .4312$][31], two-tailed MWU, n=21 [n=23]). The average cooperation rate in the treatments with unstructured non-binding communication and exogenously provided knowledge sharing parameters is 79 percent lower than the average cooperation rate in the treatments with unstructured non-binding communication and endogenously chosen knowledge sharing parameters. This difference is statistically significant at the 1 percent level (CTEND vs. CTEX: $p = .0003$ [$p = .0038$], two-tailed MWU, n=62 [n=62]). When there was an active decision to mutually share knowledge, the average cooperation rate is 20.5 percent higher compared to when mutual knowledge sharing was set by default. The null hypothesis of independence from treatment can be rejected with significance at the 1 percent level (CTEND11 vs. CTEX11: $p = .0032$ [$p = .0044$], two-tailed MWU, n=30 [n=30]).

Result II: *When knowledge was shared mutually, duopolies cooperated more in R&D investment when they made an active decision compared to a situation in which mutual knowledge sharing was set exogenously. This result holds irrespective of whether communication was available.*

[30] Statistical tests are reported with the name of the treatment followed by the knowledge sharing constellation. The total number of duopolies underlying some statistical tests differ from the total number of duopolies because of duopolies that did not mutually share knowledge in the BLEND or CTEND treatment in rounds 7–15. The numbers reported in square brackets correspond to the p-values and number of observations for all rounds.

[31] Note that the cooperation rates under mutual knowledge sharing in the BLEND treatment are over all periods 2.6 times that of the BLEX11 treatment. Hence, the relative difference is quite stable. The fact that the difference is statistically not significant when conducting a two-tailed MWU test over all periods with one observation per duopoly should thus be treated cautiously. In particular, since in this comparison, the single decision of a duopoly that interacted once in this knowledge sharing constellation is weighted as much as the decisions of a duopoly that interacted in this knowledge sharing constellation for 15 periods. Further, the likelihood of fewer interactions in this knowledge sharing constellation is higher for duopolies that do not cooperate in R&D investment. To adjust for these limitations, a logistic regression was conducted (see Online Appendix A, Table 1). The marginal effects of a logistic regression report that the likelihood of a duopoly to cooperate is 58.9 percent higher in BLEND11 compared to BLEX11. This effect is statistically significant at the 1 percent level ($p < .001$).

Without knowledge sharing in stage one, there was no cooperation in the R&D investment stage in the BLEND treatment whilst in the BLEX00 treatment 30.37 percent of duopoly decisions were joint profit maximizing. This difference is statistically significant at the 5 percent level (BLEND00 vs. BLEX00: $p = .0249$ [$p = .0203$], two-tailed MWU, n=28 [n=29]). Whenever asymmetric knowledge sharing was present, cooperation in R&D investment was virtually non-existent, irrespective of whether the asymmetry arose from an active decision or was set exogenously. The null-hypothesis of independence from treatment cannot be rejected confidently (BLEND01 vs. BLEX01: $p = .2365$ [$p = .1821$], two-tailed MWU, n=54 [n=60]; CTEND01 vs. CTEX01:[32] p=0.5347, two-tailed MWU, n=38). Note, however, that under asymmetric knowledge sharing, the joint profit maximizing investment levels imply payoffs that are heavily skewed in favor of the participant not sharing knowledge.[33]

Result III: *Without knowledge sharing and without communication, there was more cooperation in R&D investment whenever the mutual absence of knowledge sharing was determined exogenously compared to when it was determined endogenously. Whenever only one party of the duopoly was not sharing knowledge, virtually no cooperation in R&D investment can be observed in any of the treatments.*

Compared to the baseline treatments, the overall cooperation rates are significantly higher in the respective treatments with communication (BLEND vs. CTEND: $p < .0001$ [$p < .0001$], two-tailed MWU, n=31 [n=31], BLEX vs. CTEX: $p = .0002$ [$p = .0001$], two-tailed MWU, n=93 [n=93]). Inspection of communication protocols reveals that all duopolies that cooperated agreed on this beforehand. In those cases, at least one party explicitly proposed the corresponding investment levels and the other party agreed on making their choices accordingly. The finding that non-binding unstructured communication increased cooperation is in line with what is reported in other studies (Oprea et al., 2014). However, there was virtually no cooperation towards joint profit maximization in the treatments with exogenously set asymmetric knowledge sharing, irrespective of whether communication was available. As such, the overall effect is rooted in the treatments with symmetric knowledge sharing constellations.

Result IV: *Unstructured and non-binding communication increased cooperation in R&D investment whenever symmetric knowledge sharing was present, irrespective of whether there had been an active decision on knowledge sharing.*

Next, let's turn to Table 6 and the distribution of average individual R&D investment decisions in rounds 7 to 15, focusing on observations that lie beyond what already has been discussed above. First, consider the decisions made in constellations without knowledge sharing. In the BLEND treatment, around 70 percent of individual investment decisions were neither joint profit maximizing nor at the Nash level and as such off the theoretical benchmarks. In particular, 37.5 percent of investments were above the Nash-equilibrium level which corresponds to the highest investment level available, thereby decreasing social welfare and individual profits. In the corresponding BLEX treatment a related but substantially weaker behavioral pattern can be observed. Although more cooperative behavior was present (as previously discussed) and 18.2 percent of the decisions were at the non-cooperative Nash level, 43.4 percent of the decisions do not fall in any of the two categories. However, decisions for investments above the Nash level can be observed 71.2 percent more often in the corresponding BLEND treatment constellation. One potential reason for such behavior is the payoff scheme. In this knowledge sharing constellation, the investment level above the Nash level is the only one that guarantees the absence of disadvantageously unequal payoffs for the respective subject, whereas choosing Nash whilst the opponent chose the higher investment level would yield a loss three times that of the opponent. Hence, aversion against disadvantageous inequality might have been a reason for participants to avoid the potentially more profitable Nash-strategy.[34] An alternative explanation that also involves the structure of the payoff scheme is that participants were more likely to make errors (i.e., deviate from the Nash level) than in the other payoff schemes because unlike those, the Nash-equilibrium in this payoff scheme is not dominant.[35]

Turning to the individual decisions made under mutual knowledge sharing, it can be observed that in the BLEX treatment 66.3 percent of the decisions were either on the joint profit maximizing or the Nash level, while the other decisions were scattered across the range of investment levels. Notably, while quite similar in terms of cooperative behavior (as previously discussed), the share of Nash level decisions was almost twice of that in the BLEX treatment without knowledge sharing. This difference is statistically significant on the duopoly level below the 5 percent threshold (BLEX00 vs. BLEX11: $p=.0299$ [$p=.0264$], two-tailed MWU, n=30 [n=30]). However, when accounting for the overinvestment decisions made in the treat-

[32] For the treatments with unstructured non-binding communication comparison of behavior without mutual knowledge sharing in rounds 7 to 15 is impossible because duopolies always decide to mutually share knowledge in the CTEND treatment.

[33] Analysis of the messages that were exchanged reveals that about 50 percent of duopolies did coordinate on investment levels yielding a more equal payoff than the joint profit maximizing level. Chat protocols have been evaluated, qualified and quantified by a research assistant that has not been involved in the project otherwise.

[34] Competition among firms regularly involves strategies that include giving up profits to decrease the competitor's profit to a level below one's own profit to – in the long run – drive the competition out of the market (e.g., predatory price-cutting). Consequently, firms may try to avoid being put in a relatively weaker position by safeguarding that the competition yields no greater profits than oneself. In the situation present here, this is possible by deliberately choosing an off-equilibrium strategy that bears the potential of a relatively smaller loss in one's own profit. As such, behavior in the sense of aversion towards disadvantageous inequality can be observed in real-world inter-firm competition. For studies identifying inequality aversion as a potential motive for behavior in duopoly experiments see e.g., Horstmann et al. (2018), Huck et al. (2001) or İriş and Santos-Pinto (2014).

[35] Another alternative explanation could be an experimenter demand effect. The instructions include (among others) one example which corresponds to the observed levels of R&D investment. However, it seems implausible that such an effect would be 71.2 percent stronger in the BLEND treatment compared to the BLEX treatment. Furthermore, other example constellations with similar characteristics were included in the control questions which did not lead to a comparable frequency of choices. Finally, the data reveal that participants switched between different R&D investment levels which is also inconsistent with an experimenter demand effect.

Table 6
Distribution of Average Individual R&D Investment Decisions.

Know. Sharing	Treatment	1	2	3	4	5	Avg.	N	x^{NC}	x^{C}	x^{W}
		Rounds 1–15									
$s_i = s_j = 0$	BLEND	0.047	0.056	0.259	0.285	0.353	3.84	232	4	2	4
	BLEX	0.042	0.353	0.204	0.198	0.202	3.16	450	4	2	4
	CTEND	-	-	-	0.500	0.500	4.50	2	4	2	4
	CTEX	0.092	0.804	0.019	0.031	0.054	2.15	480	4	2	4
$s_i = s_j = 1$	BLEND	0.008	0.125	-	0.017	0.850	4.58	120	2	5	5
	BLEX	0.091	0.373	0.176	0.060	0.300	3.10	450	2	5	5
	CTEND	-	0.016	-	-	0.984	4.95	432	2	5	5
	CTEX	0.004	0.080	0.013	0.071	0.831	4.64	450	2	5	5
$s_i = 0, s_j = 1$	BLEND	0.016	0.047	0.063	0.125	0.750	4.55	64	5	4	5
	BLEX	0.138	0.104	0.158	0.108	0.492	3.71	240	5	4	5
	CTEND	0.125	-	-	-	0.875	4.50	8	5	4	5
	CTEX	0.504	0.086	0.050	0.083	0.275	2.54	240	5	4	5
$s_i = 1, s_j = 0$	BLEND	0.625	0.313	0.031	-	0.031	1.50	64	1	4	5
	BLEX	0.633	0.208	0.117	0.033	0.008	1.56	240	1	4	5
	CTEND	0.125	-	-	0.125	0.750	4.38	8	1	4	5
	CTEX	0.321	0.538	0.050	0.029	0.063	1.98	240	1	4	5
		Rounds 7–15									
$s_i = s_j = 0$	BLEND	0.044	0.044	0.243	0.294	0.375	3.91	160	4	2	4
	BLEX	0.019	0.385	0.196	0.182	0.219	3.20	270	4	2	4
	CTEND	-	-	-	0.500	0.500	4.50	2	4	2	4
	CTEX	0.090	0.813	0.010	0.028	0.059	2.15	288	4	2	4
$s_i = s_j = 1$	BLEND	-	0.056	-	-	0.944	4.83	72	2	5	5
	BLEX	0.100	0.352	0.167	0.070	0.311	3.14	270	2	5	5
	CTEND	-	-	-	-	1.00	5.00	268	2	5	5
	CTEX	-	0.067	0.011	0.070	0.852	4.71	270	2	5	5
$s_i = 0, s_j = 1$	BLEND	0.036	0.071	0.071	0.046	0.786	4.50	28	5	4	5
	BLEX	0.139	0.139	0.153	0.125	0.444	3.60	144	5	4	5
	CTEND	-	-	-	-	-	-	-	5	4	5
	CTEX	0.542	0.056	0.021	0.097	0.285	2.53	144	5	4	5
$s_i = 1, s_j = 0$	BLEND	0.643	0.286	0.071	-	-	1.43	28	1	4	5
	BLEX	0.625	0.236	0.104	0.021	0.014	1.56	144	1	4	5
	CTEND	-	-	-	-	-	-	-	1	4	5
	CTEX	0.306	0.521	0.069	0.042	0.063	2.03	144	1	4	5

Note: x^{NC}, x^{C} and x^{W} represent the R&D investment levels corresponding to the approximated non-cooperative equilibrium, the joint profit maximizing and the social welfare maximizing solutions available in the game.

ment with mutual knowledge sharing, this difference dissolves. As such, it is not particularly likely that the payoff scheme in the treatment with mutual knowledge sharing was inducing more competitive behavior than the scheme without mutual knowledge sharing, but rather that the payoff scheme without knowledge sharing induced inequality aversion or error.

Finally, consider the decisions made under an asymmetric knowledge sharing constellation. Note that the two categories (i.e., $s_i = 0,\ s_j = 1$ and $s_i = 1,\ s_j = 0$) in Table 6 do not constitute separate treatments. Instead, they represent duopoly observations with the decisions of the participant not sharing knowledge being documented under $s_i = 0,\ s_j = 1$ and the decisions of the participant sharing knowledge under $s_i = 1,\ s_j = 0$.

With an active decision on knowledge sharing and without communication (BLEND01/10), 78.6 percent of the decisions by participants who chose not to share knowledge were at the Nash level. The remaining decisions were almost evenly distributed across the other investment levels. Meanwhile, the decisions by participants who chose to share knowledge were 64.3 percent at the Nash level and 28.6 percent one level above. As such, in comparison to constellations without any knowledge sharing in the same treatment, behavior was far more competitive. This observation is statistically significant on the duopoly level at the 1 percent level (BLEND01/10 vs. BLEND00: *p=.0002* [*p=.0010*], two-tailed MWU, n=35 [n=42]). A potential explanation for the investment beyond the Nash level by those who unilaterally shared knowledge can be found by looking at the payoff scheme. Observe that such a decision in combination with the lowest possible investment by the participant who did not share knowledge would yield the highest possible payoff for the participant who did share knowledge. Given that in this scheme all payoffs are unequal, the participants with lower payoffs might have been speculating for inequality aversion on the side of the respective other participants.

Whenever the asymmetric knowledge sharing was exogenously determined (BLEX01/10), a total of 44.4 percent of the decisions made by the participants who did not share knowledge are at the Nash level. This is close to what is observed

Table 7
Assumed distribution of α and β parameters.

α	β	Rel. frequency
0	0	30%
0.5	0.25	30%
1	0.6	30%
4	0.6	10%

in the treatment with exogenously determined mutual knowledge sharing. It is, however, 56.5 percent less than in the corresponding treatment with an active decision on knowledge sharing (BLEND01/10). The remainder of decisions were quite evenly spread across the other investment levels, allowing for higher payoffs by those who did share knowledge. As such, inequality aversion may again have been a motive for the observed decisions. Meanwhile, 62.5 percent of the decisions by those who did share knowledge were at the Nash level and 23.6 percent of the decisions were one level above it. This is similar to what has been discussed above for the BLEND01/10 treatment data.

In the treatment in which asymmetric knowledge sharing was exogenously determined (CTEX01/10) virtually no joint profit maximizing decisions can be observed, which is in stark contrast to the treatments with symmetric knowledge sharing constellations. This is not particularly surprising as the joint profit maximizing investment levels would have yielded a substantially higher payoff for the participant who did not share knowledge. Instead, 54.2 percent of the decisions made by participants who did not share knowledge were at the lowest investment level, allowing the matched participants who shared knowledge to achieve their highest possible payoff in this constellation. This payoff would have been realized by choosing the investment level above the Nash level, which 52.1 percent of the participants who shared knowledge did. As the decision of those participants who were not sharing knowledge was costly compared to a Nash level investment, this behavior also indicates inequality aversion as a behavioral motive. Analysis of the messages that were exchanged reveals that the duopolies who ended up at this particular constellation explicitly agreed on those choices. They also communicated their intention to arrive at the highest payoff for those sharing knowledge and thus arriving at a less unequal payoff.[36]

In summary, a number of interesting observations can be made when scrutinizing the individual investment decisions. All explanations for behavior that was neither Nash play nor joint profit maximizing entail choice errors or inequality aversion. To evaluate these explanations, let us estimate a structural model following the approach by Hoppe and Schmitz (2013) that allows for bounded rationality and inequality aversion.

For the structural estimation, the logit Quantal Response Equilibrium (QRE) framework by McKelvey and Palfrey (1995) is applied. It allows for bounded rationality by assuming that players make errors in terms of not playing Nash best responses with certainty, but errors that reduce the expected payoff by a large amount are less likely than errors that reduce the expected payoff by a smaller amount. Thus, the probability of making an erroneous decision is higher the lower the utility loss that arises from that error. The probability of player i choosing action $k \in \{1, \ldots, n\} = \tilde{k}$ is given by

$$prob(k = \tilde{k}) = \frac{\exp[\frac{U_{i\tilde{k}}}{\mu}]}{\sum_{k=1}^{n} \exp[\frac{U_{ik}}{\mu}]} \tag{8}$$

with U_{ik} denoting player i's expected utility from making that particular decision, and following the parameterization suggested by Goeree et al. (2003), $\mu = \frac{1}{\lambda}$ with λ being the error or noise parameter. As such, $\mu = 0$ means playing Nash and $\mu = \infty$ converges to purely random action, i.e., all error. Inequality aversion is introduced by extending the logit QRE framework integrating the seminal model by Fehr and Schmidt (1999).[37] They introduce the following utility function:

$$U_i(y_i, y_j) = y_i - \alpha_i \max\{y_j - y_i, 0\} - \beta_i \max\{y_i - y_j, 0\}, i \neq j, \tag{9}$$

where y_i is player i's payoff. α captures the degree of disadvantageous inequality aversion as the second term of the utility function measures player i's loss in utility from disadvantageous inequality and β captures the degree of advantageous inequality as the third term measures the loss in utility from advantageous inequality aversion. Given that parameters are assumed to satisfy $\beta_i \leq \alpha_i$ and $0 \leq \beta_i < 1$, the loss in utility per unequally distributed payoff unit from disadvantageous inequality is greater than that from advantageous inequality. Finally, Fehr and Schmidt (1999) allow players to exhibit heterogeneous inequality parameters. Applying the specified utility function (8) to the particular subgames allows for multiple outcomes. Table 7 reports the α- and β parameter distribution derived by Fehr and Schmidt (1999) which is used for the following estimation.

To evaluate the explanatory contribution of inequality aversion with respect to participants' behavior, Rogers et al. (2009) and Hoppe and Schmitz (2013) will be followed by providing two benchmarks for the quality of fit. As a lower bound, consider a model in which all choice probabilities are equal, i.e., all decisions are made with equal

[36] Those participants who did not share knowledge and chose the Nash level investment by and large did not communicate with their matched participants, even though communication attempts were made by the matched participants.

[37] Although the model is mostly used in the context of ultimatum games, it can easily be adopted towards a wide array of games (Fehr and Schmidt, 2006).

Table 8
Quantal Response Equilibrium with Standard Preferences (ST) and Fehr-Schmidt Preferences (FS).

Know. Sharing	Treatment	ST		FS		Random	Empirical	N
		μ	lnL	μ	lnL	lnL	lnL	
		Rounds 1–15						
$s_i = s_j = 0$	BLEND	2.43 (0.63)	-336.96	6.96 (1.25)	-325.84	-373.39	-320.39	232
	BLEX	5.73 (2.56)	-707.14	20.55 (9.23)	-709.98	-724.25	-661.28	450
$s_i \neq s_j$	BLEND	2.35 (0.65)	-132.29	6.77 (1.52)	-156.04	-206.01	-110.80	128
	BLEX	5.76 (1.38)	-662.95	8.63 (1.68)	-626.15	-772.53	-578.42	480
	CTEX	81.40 (2200.85)	-771.61	19.95 (8.17)	-722.09	-772.53	-574.78	480
		Rounds 7–15						
$s_i = s_j = 0$	BLEND	2.30 (0.59)	-230.35	6.31 (1.29)	-219.79	-257.51	-215.29	160
	BLEX	5.02 (2.17)	-421.94	18.26 (7.91)	-423.62	-434.55	-378.81	270
$s_i \neq s_j$	BLEND	2.34 (0.91)	-58.09	5.55 (1.22)	-64.55	-90.13	-45.78	56
	BLEX	6.20 (1.87)	-404.65	8.56 (1.95)	-375.29	-463.52	-355.10	288
	CTEX	152.36 (798.43)	-463.34	22.00 (9.60)	-437.44	-463.52	-338.48	288

Note: Robust standard errors adjusted for duopolies in parentheses.

probabilities, leading to the random log likelihood results. A model that applies the relative frequencies of the decisions that have been made then constitutes the best possible fit, resulting in the empirical log likelihood data. Again, the logit QRE is applied to the aggregate data from the last nine rounds and all rounds separately. First, to uphold comparability with the already presented data, second, because QRE assumes players have accurate beliefs about the behavior of other players and third, QRE in the given experiment should be treated as a static concept (see e.g., Chowdhury et al., 2014).

Table 8 provides the results of the QRE estimation with the assumption of standard preferences and Fehr-Schmidt distributed inequality aversion. It reveals that for the BLEND treatment, when no knowledge was shared and allowing for errors, inequality aversion is better in explaining the data than standard preferences, albeit the noise parameter increases, i.e., more mistakes were made when assuming inequality aversion. Hence, the analysis suggests that participants chose to overinvest in order to avoid a potentially disadvantageous inequality that may have arisen from playing the Nash-equilibrium if the other party would have overinvested, whenever there was no knowledge sharing by mutual choice.

For the BLEX00 treatment, the explanatory power of bounded rationality assuming inequality aversion is lower than with standard preferences. Thus, the behavioral motive of inequality aversion appears to be absent when the same payoff scheme structure with no knowledge sharing was applied, but the knowledge sharing parameter was set exogenously. With standard preferences, the noise parameter for the BLEX00 treatment is relatively large, thereby providing an explanation for the relatively high share of overinvestment (in particular in comparison to the decisions in the BLEX11 treatment).

For the BLEND treatment with asymmetric knowledge sharing, the structural estimation yields better results under the assumption of standard preferences, including a relatively low noise parameter. In contrast, the results for the BLEX01/10 treatment as well as for the CTEX01/10 treatment are in support of inequality aversion as a behavioral motive for the decisions made.

In conclusion, arriving at a mutually non-cooperative knowledge sharing constellations by choice (i.e., by endogenously chosen knowledge sharing parameters) might have stimulated costly aversion against disadvantageous inequality as a behavioral motive for overinvestment beyond the Nash level in the subsequent investment decision. Aversion against advantageous inequality appears to have been triggered when asymmetries in the payoff scheme resulted from externally induced asymmetric knowledge sharing constellations. Conversely, this clearly was not the case whenever the asymmetric knowledge sharing constellation resulted from choice.

Result V: *Bounded rationality combined with Fehr-Schmidt preferences performs well in explaining overinvestment into R&D in the BLEND treatment, whenever duopolies mutually decided to not share knowledge. This is also the case for the investment decisions made under exogenously determined asymmetric knowledge sharing constellations.*

Knowledge Sharing

Having established the results that the decision to mutually share knowledge increased cooperation in R&D investment in stage 2, and that there was no cooperation whenever at least one party decided to not share knowledge, let's turn to the knowledge sharing decisions themselves in stage 1. Table 9 reports the shares of the resulting duopoly knowledge sharing constellations of BLEND and CTEND. In rounds 7 to 15 the share of duopolies that acted in a constellation with two-sided knowledge sharing in the baseline treatment was lower compared to the cheap-talk treatment, and non-parametric testing rejects the null hypothesis of independence from treatment at the 1 percent level ($p < .0001$ [$p < .0001$], two-tailed MWU, n=31 [n=31]). Inspection of communication protocols reveals that all duopolies which ended up in a two-sided full knowledge sharing constellation agreed on this beforehand.

Table 9
Knowledge Sharing Decisions in BLEND and CTEND.

Know. Sharing	Treatment	Share of Decisions	
		Rounds 1–15	Rounds 7–15
$s_i = s_j = 0$	BLEND	48.33%	55.56%
	CTEND	0.44%	0.74%
$s_i = s_j = 1$	BLEND	25.00%	25.00%
	CTEND	96.00%	99.26%
$s_i \neq s_j$	BLEND	26.66%	20.42%
	CTEND	3.56%	0.00%

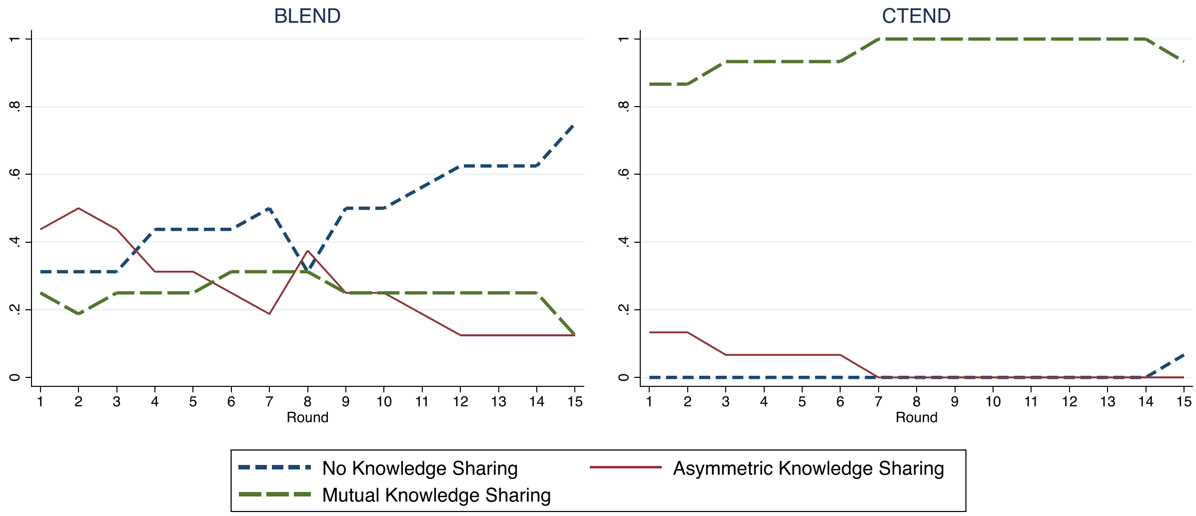

Fig. 2. Evolution of Duopoly Knowledge Sharing Constellations.

Result VI: *Virtually all duopolies mutually shared knowledge in the treatment in which non-binding, unstructured communication was available. Without communication, a quarter of duopolies decided to mutually share knowledge.*

Consider next Fig. 2, which illustrates the evolution of knowledge sharing constellations in BLEND and CTEND. To obtain a more complete picture of this evolution, in the following, let's focus on the data across all rounds. Observe from the left-hand panel that in BLEND, there was little change over time in the share of duopolies mutually sharing knowledge. In contrast, there was a volatile but rather continuous increase in duopolies without knowledge sharing and a corresponding decrease in asymmetric knowledge sharing constellations, that is, constellations in which only one party shared knowledge. This suggests that participants were trying to establish cooperation in knowledge sharing unsuccessfully and then turned to not sharing knowledge. Indeed, 56.45 percent of the asymmetric knowledge sharing constellations before round 15 were followed by a constellation without knowledge sharing. 35.48 percent were again followed by an asymmetric knowledge sharing constellation and 8.06 percent were followed by mutual knowledge sharing.

However, the individual data also reveal that in 87.50 percent of all duopolies knowledge was unilaterally shared more than once, and in all duopolies knowledge was shared at least once at least from one side. Therefore, it is a reasonable conjecture that participants (repeatedly) tried to establish cooperation towards a more profitable constellation with mutual knowledge sharing. Nevertheless, only 50 percent of all duopolies managed to establish such cooperation and 62.50 percent out of these duopolies maintained cooperation for more than two consecutive rounds.

To analyze the factors that influenced whether participants shared knowledge and selected the overall joint profit maximizing investment level, refer to Table 10. The results indicate that the strongest predictor of knowledge sharing is whether the respective other participant in the duopoly cooperated in R&D investment when mutual knowledge sharing was present in the previous round. This is evident in the last four rows of the table. When both participants shared knowledge without cooperating in R&D investment, 50 percent of the decisions were to share knowledge in the next round. Cooperation in knowledge sharing and R&D investment was followed by knowledge sharing in 95.6 percent of the decisions. Interestingly, when the respective other participant unilaterally chose a cooperative investment level under mutual knowledge sharing, this proportion decreased by only 6.7 percent. In contrast, those other participants decided to share knowledge in the following round only in 55.6 percent of the cases.

Whenever no knowledge was shared and there was no cooperation in R&D investment, only 15.6 percent of the decisions led to knowledge sharing in the next round. A third of the decisions made by participants who chose a cooperative investment level were to share knowledge in the next round themselves, whereas less than 10 percent of the decisions were structured in this way when the matched participant cooperated in R&D investment unilaterally.

Table 10
Share of Individual Knowledge Sharing and Joint Profit Maximizing Play in BLEND.

Previous Round				Rounds 1–15			Rounds 7–15		
s_i	s_j	c_i	c_j	$s_i = 1$	JPMS	N	$s_i = 1$	JPMS	N
0	0	0	0	0.156	0.108	186	0.118	0.000	136
0	0	0	1	0.091	0.000	11	0.000	0.000	7
0	0	1	0	0.364	0.000	11	0.286	0.000	7
0	1	0	0	0.204	0.185	54	0.185	0.035	29
0	1	1	0	0.375	0.000	8	0.000	0.000	1
1	0	0	0	0.278	0.185	54	0.241	0.035	29
1	0	0	1	0.375	0.250	8	0.000	0.000	1
1	1	0	0	0.500	0.125	8	0.667	0.167	6
1	1	0	1	0.889	0.222	9	1.000	0.500	2
1	1	1	0	0.556	0.333	9	0.500	0.500	2
1	1	1	1	0.956	0.922	90	0.956	0.927	68

Note: The first two columns s_i and s_j indicate whether knowledge was shared in the previous round by player i and j, respectively. The second two columns c_i and c_j indicate whether the players cooperated under the indicated knowledge sharing constellation in the previous round. The constellations missing were not present in the data. The following six columns present the share of participants who chose to share knowledge ($s_i = 1$) and the share of participants who chose the overall joint profit maximizing solution (JPMS) after the respective constellation indicated in the first four columns was present in the previous round. N represents the respective number of decisions made within each constellation in the previous period.

Notably, a unilateral decision to share knowledge, which, as previously discussed, might have been intended to signal willingness to cooperate, increased the proportion of decisions by matched participants to share knowledge in the following round by only a little over 4 percent compared to the situation without any knowledge sharing.

Next, turn to the overall joint profit maximizing solution that includes mutual knowledge sharing and cooperation in R&D investment. From the sixth column of Table 10 it can be seen that over 90 percent of the decisions that followed mutual overall joint profit maximizing behavior were again overall joint profit maximizing. Thus, if participants had managed to arrive at this highly profitable constellation, they rarely defected in the future. Interestingly, almost 12 percent of the decisions made by participants from duopolies that had not shared knowledge and had not chosen a cooperative investment level in the previous round were joint profit maximizing under mutual knowledge sharing in the following round. Even more notable is the fact that over 90 percent of the decisions by participants that shared knowledge, after the respective other participant had shared knowledge in the round before, were made in a constellation with mutual knowledge sharing and at the cooperative R&D investment level.

Comparison of behavior over all rounds with that in the last nine rounds reveals only little change in the responses towards the different constellations in the previous round in terms of knowledge sharing decisions. For the choice of the overall joint profit maximizing solution there is a tendency towards a concentration in the direction of previous overall joint profit maximizing behavior. In other words, other previous constellations were less frequently followed by overall joint profit maximizing behavior in rounds 7 to 15 than in the rounds before. There are two potential reasons for this: either there were less knowledge sharing decisions that allowed such a choice in the first place or participants simply were less likely to choose the cooperative R&D investment level whenever possible, given the previous constellation was not already overall joint profit maximizing. As there was little change with respect to the reactions in terms of knowledge sharing behavior, as mentioned above, the latter reason is more likely.

Summing up the numbers reported above, the following three observations can be formulated. First, participants tried to establish cooperation in knowledge sharing multiple times by unilaterally sharing knowledge. Second, with respect to the role of reciprocity, the data are slightly in favor of reciprocal behavior but mostly inconclusive. On the one hand, unilateral knowledge sharing had almost no effect on whether or not the other participant shared knowledge in the next round. Reciprocity considerations would in this case predict a strong increase in knowledge sharing of the respective other participant. On the other hand, whenever unilateral knowledge sharing had led to knowledge sharing of the other participant in the next round, most of the respective duopolies ended up mutually sharing knowledge and choosing the joint profit maximizing R&D investment level. Additionally, unilateral cooperative behavior in R&D investment increased the share of knowledge sharing by the other participant in the following round substantially whenever mutual knowledge sharing was present. As a consequence, these behavioral patterns spiraled towards the overall joint profit maximizing solution. Third, when arriving at the highly profitable joint profit maximizing solution, behavior remained very stable.

Finally, for the CTEND treatment, consult the right panel of Fig. 2. Here we see that there was only little change in the share of participants mutually sharing knowledge. Inspection of chat protocols reveals that all duopolies who did not coordinate on mutual knowledge sharing did so as a way of cooperation before they identified the overall joint profit maximizing strategy as more profitable and subsequently adjusted their behavior. Additionally, it can be observed that only one duopoly was subject to end effects.

***Result VII:** In the BLEND treatment, a substantial number of unsuccessful attempts to coordinate towards mutual knowledge sharing can be identified. Mutual knowledge sharing with cooperation in the R&D investment stage was almost always followed by the identical behavior in the following round. In the CTEND treatment, there was virtually no change over time in knowledge sharing behavior.*

5. Discussion and conclusion

The goal of this study was to investigate the impact of an active decision of whether to share knowledge on the subsequent R&D investment decisions in a controlled laboratory experiment. In particular, behavioral spillovers between the two decisions were considered. There is significant evidence of a strong positive correlation between the behavior (i.e., cooperation or non-cooperation) in the knowledge sharing decision and the behavior in the subsequent R&D investment decision. Meanwhile, the cooperation rates in the R&D investment decision were not influenced by the knowledge sharing constellation when it was exogenously determined and symmetric. As such, these findings are at odds with parts of what is reported by Roelofs et al. (2017) and Suetens (2005). The difference to Roelofs et al. (2017) probably can be best explained by the fundamentally altered strategic environment that is hardly comparable with the setting used here. Suetens (2005) finds an impact of the knowledge sharing constellation on cooperation in R&D investments in treatments comparable to treatments with exogenously determined knowledge sharing parameters and communication in this study. In those treatments of her study, participants cooperated more when knowledge was mutually transferred compared to a situation in which no knowledge was transferred. Besides, her findings are generally in line with what is observed here and the differences may be due to experimental design features in her study such as the use of contextualized instructions, more investment levels, more rounds that are played and fewer observations. Overall, the present findings favor behavioral spillovers as source of the, in the empirical literature documented, higher cooperation rates when mutual knowledge transfer is present, while contradicting the hypothesis that the increased attractiveness of cooperation with mutual knowledge transfers is sufficient to induce such cooperation.

The observations of this study also contradict Cason and Gangadharan (2013) who don't find behavioral spillovers between different stages in a simple two-stage cooperation game. They argue that it might depend on the degree of competitiveness within the stages whether cooperation spills over to another stage. In particular, they refer to their use of double auctions which result in more competitive outcomes. On the other hand, the observations are generally consistent with, e.g., Nicklisch (2012) and Suetens (2008). However, those two studies report higher overall cooperation rates, but substantially lower behavioral spillover to stage 2 after successful cooperation in stage 1 in the treatments comparable to the BLEND treatment of this study. The degree of competitiveness of the tasks used in those studies parallels that of the tasks used in this study. Hence, it is a reasonable conjecture to attribute the different outcomes to the reduced complexity of the experimental tasks implemented in this study. This reduction of complexity may have enabled participants to form stronger beliefs about the consequences of their behavior. Greater salience of the gains of cooperation may have increased the spillovers of cooperation. Meanwhile, an increase in the salience of the chances of competitive behavior may have decreased overall cooperation rates.

Further, it is revealed that without knowledge sharing and in the absence of communication, a substantial number of participants chose neither the joint profit maximizing cooperative R&D investment level, nor the non-cooperative Nash-equilibrium level. Instead, they invested beyond the Nash level, which decreased individual profits and social welfare. For the treatment with endogenously chosen knowledge sharing parameters this observation can be better explained by assuming bounded rationality and inequality aversion compared to standard preferences. This cannot be documented for the treatment with exogenously provided absence of knowledge sharing. Again, this parallels in its general tendency findings from other studies that speculate about inequality aversion as a behavioral motive in duopoly situations and particularly in a Cournot competition (Huck et al., 2001; 2004; İriş and Santos-Pinto, 2014). However, in contrast to the observations made in the present study, their findings suggest that inequality aversion would be a motive irrespective of how participants arrived at the investment stage. The observations in the present study imply that behavioral motives in the final stage are state dependent and are activated by the outcome of a previous stage if that outcome is determined by choice. This interpretation is supported by another finding: while decisions that are made in the treatments with exogenously provided asymmetric knowledge sharing can be better explained by assuming inequality aversion, this is not the case when the asymmetric knowledge sharing resulted from an active decision.

Finally, non-binding unstructured communication via a chat increased cooperation with and without endogenously chosen knowledge sharing parameters whenever these were symmetric. A remarkable finding is that with endogenously chosen knowledge sharing parameters, cooperation was close to 100 percent, which is substantially higher than with exogenously set symmetric knowledge sharing parameters.[38] Furthermore, with endogenous knowledge sharing parameters and non-

[38] These results are to a certain degree consistent with other findings related to the impact of communication on cooperation in general (e.g., Cason and Mui, 2014; Charness and Dufwenberg, 2006) and on spillovers of behavior in two-stage games in particular (Cooper and Kühn, 2014), although cooperation in these studies was substantially below 100 percent. As such, the higher degree of cooperation in this study may not only be attributed to the existence of a second stage but again could be explained by the salience of the gains of cooperation paired with a second stage and communication. Further, while end effects are present in one stage games, Cooper and Kíhn also find no end effects in treatments with communication. This indicates that these could be mitigated by a second stage.

binding communication, end effects were virtually nonexistent, while substantial end effects were present in the setting with communication and exogenously provided symmetric knowledge sharing parameters. This is an intriguing finding, since defection was way less profitable in those settings than defection would have been in the setting with an endogenous knowledge sharing decision. Whenever the exogenously provided knowledge sharing constellation was asymmetric, participants did not coordinate towards the joint profit maximizing R&D investment level but to a more egalitarian payoff. However, such “cooperation” was less frequent than cooperation towards the joint profit maximizing investment levels in the treatments with exogenously provided symmetric knowledge sharing parameters.

Summing up, the results reported here suggest that strategic decisions depend to a substantial degree on how the players arrived at the situation in which the decisions have to be made. In particular, the circumstances not only influence the likelihood of cooperation and its stability per se, but also the motives that drive behavior when there is no cooperation. These are relevant findings as strategic decision making is often considered in isolation. The results presented here, especially when they do not resemble findings from other studies with behavioral spillovers, indicate that a series of behavioral patterns in multi-stage games must be attributed to the stages leading there. Hence, the nature of these stages should be taken into account more prominently.

There are, however, several questions that remain to be answered. First and foremost, the exact behavioral mechanisms that underlie the data reported here have to be investigated in a structured way beyond what is possible in the present experimental setting. Such an investigation would have to include three aspects. First, why is no cooperation established, even when there are multiple attempts from both parties to do so? Second, what exactly triggers inequality aversion as a strong behavioral motive whenever no cooperation is established? Third, what exact characteristics of the setting with an active decision on knowledge sharing and non-binding communication stabilizes cooperation to a degree that is not reported in comparable studies?

From a policy perspective, the findings reported should be treated with caution as further research is needed. Nevertheless, for the treatments with an active decision on knowledge sharing, the documented outcomes are more desirable than those where the knowledge sharing constellation is exogenously determined ex-ante.[39] Therefore, governments might consider not only to allow but rather promote communication on R&D to increase knowledge sharing and subsequent cooperation in R&D and to prevent welfare decreasing overinvestment that arises due to anticipated predatory behavior. However, there is a caveat to be weighted against these welfare gains: behavioral spillovers leading to cooperation in knowledge sharing and R&D investment could extend to collusion in the product market, which in turn would reduce social welfare (see e.g., Suetens, 2008). Of course, there are limits to the inferences that can be drawn from the results of this study as – although this is true for most experimental research conducted in the controlled environment of a laboratory – it has to be investigated whether the mechanisms underlying the results survive a transition to the real-world. One aspect that deserves particular scrutiny in this respect is the role of inequality aversion and bounded rationality whenever no cooperation is established in the knowledge sharing stage, which ultimately leads to overinvestment. Furthermore, other questions are worth considering, such as what happens if knowledge sharing parameters can be varied freely between 0 and 1, particularly in combination with a continuous set of investment choices. It is also important to explore what occurs if parameters are chosen such that asymmetric solutions are optimal. These limitations and open questions call for separate experimental investigations.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jebo.2023.04.033

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[39] In terms of general welfare, recall that mutual knowledge sharing and cooperation in R&D investment is preferred over non-cooperative behavior in both stages, which in turn is preferred over cooperation in R&D investment without knowledge sharing, which is preferred over competition with mutual knowledge sharing. As such, behavioral spillovers between the two stages (i.e., either cooperation or non-cooperation in both stages) induce decisions that allow for higher levels of welfare.

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