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Public subsidies and cooperation in research and development: Evidence from the lab

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PUBLIC SUBSIDIES AND COOPERATION IN RESEARCH AND DEVELOPMENT.

EVIDENCE FROM THE LAB

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Abstract.   We implement an experimental design based on a duopoly game in which subjects choose whether to cooperate in Research and Development (R&D) activities. We first conduct six experimental markets that differ in both the levels of knowledge spillovers and the intensity of competition. Consistently with the theory, we find that the probability of cooperation increases in the level of spillovers and decreases in that of market competition. We then replicate the experimental markets by providing subsidies to subjects who cooperate. Subsidies relevantly increase the probability of cooperation in focus markets, causing, however, a sensible reduction of R&D investments. Overall, our evidence suggests that, depending on the characteristics of the market, the use of public subsidies might be redundant, for firms would anyway joined their R&D efforts; or counterproductive, inducing firms to significantly reduce R&D investments compared to the non-cooperative scenario.

JEL Classification: L24, O3**.**

Keywords: Cooperation in R&D; Public subsidies; knowledge spillovers; market competition.

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1. Introduction

The empirical evidence on the impact of public subsidies on firms' investment activities in Research and Development (R&D hereafter) is mixed. Some studies show that public subsidies are complementary to firms' private investments, thereby boosting their innovation rate (e.g. Czarnitzki and Hussinger, 2004; Bronzini and Piselli, 2016; Szücs, 2020); others document instead a crowding-out effect (e.g., Cerulli, 2010; Zúñiga-Vicente et al., 2014; Fölster, 1995; Griliches, 1998; Belderbos et al., 2004; Colombo et al., 2006; Czarnitzki and Hottenrott, 2012; Crescenzi et al., 2018; Cantabene and Grassi, 2018), or show that public subsidies do not affect firms' private investments at all (e.g., Aristei et al., 2017).

The standard method to study the determinants of firms' investment behaviour in R&D is based on the econometric analysis of observational data. This approach, however, exhibits three main problems. First, unobservable features of the market structure and firms' organization make harder the identification of the causal nexuses. Second, the use of different measurement techniques may generate conflicting results. Third, econometric analyses can provide only *ex-post* evidence on the effect of public intervention, without the possibility of building up a counterfactual where the policy at issue is not implemented (Sørensen et al., 2010).

In this paper, we rely on experimental methods to investigate the impact of public subsidies on firms' cooperation in R&D. We analyze contexts characterized by various degrees of product market competition and levels of knowledge spillovers, for these are generally considered by both the theoretical and empirical literature as the key conditions in influencing firms' willingness to cooperate. The effect of knowledge spillovers on cooperation is theoretically clear. As cooperating firms internalize positive externalities and reduce fixed costs duplication, the higher is the level of spillovers, the more firms are willing to cooperate in R&D (D'Aspremont and Jacquemin, 1988; Cassiman and Veugelers, 2002; Suetens, 2005). On the contrary, the effect of product market competition on R&D activities is far less clear. Indeed, several studies (e.g., Cassiman and Veugelers, 2002; Belderbos et al., 2004; Aghion et al., 2005; Wu, 2012, Ruble and Versaevel, 2014) have shown that product market competition and firms' willingness to cooperate in R&D are linked in a not monotonic fashion.

The experimental method provides the working prototype of a small world where the effects of interest are cleaned from confounding factors (Angrist and Pischke, 2010; Plott, 1996; Kagel 2009). In cases like the one at hand, recourse to the Lab can be particularly fruitful, for the effect of policy measures can be simulated under a great variety of circumstances and useful evidence can be collected to improve the policy design. The experimental manipulation may provide the empirical ground for an *ex-ante* evaluation of the efficacy of public policies in fostering firms' cooperation in R&D.

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Specifically, by relying on the exogenous variation of the market setting, experimental investigations can shed some light on the conditions that make public subsidies efficacious to boost cooperation in R&D, as well as on the circumstances under which public subsidies are redundant or even counterproductive.

So far, the experimental literature has mainly investigated the effect of market competition (e.g., Reynolds, 1988; Darai et al., 2010; Aghion et al., 2018; Silipo, 2005; Østbye and Roelofs, 2013), and knowledge spillovers (e.g., Isaac and Reynolds, 1988; Suetens, 2005; Halbheer et al., 2009; Roelofs et al.,, 2017) on subjects' investments and cooperation in R&D. Moreover, some experiments investigated the optimal allocation of public subsidies amongst innovating firms, to design incentive-compatible mechanisms that induce them to reveal truthfully their funding needs (e.g. Russo et al., 2007; Giebe et al., 2006). To the best of our knowledge, no experimental investigation has assessed the effect of public subsidies on firms' cooperation rate and investment behaviour in market settings with different levels of knowledge spillovers and product market competition.

Our experiment is based on a simplified version of the theoretical setting proposed by Capuano and Grassi (2019). In line with a huge theoretical literature, they model a duopoly game where cooperation in R&D may emerge as a sub-game perfect Nash equilibrium. In the first stage, firms declare their potential interest in R&D cooperation; in the second, they decide whether to jointly invest in R&D or not; in the third, they face Cournot competition in the product market. An important feature of the model is that it considers a "breakthrough innovation, i.e. an innovation involving a significant technological jump, creating a completely new market whose demand is independent of preexisting goods" (Capuano and Grassi, 2019: 2). The main result is that the optimal scheme of subsidies should be designed taking properly into account the intensity of the spillovers; the level of R&D costs; the probability of successful innovation; the intensity of market competition.

The framework we present in Section 2 below takes all these elements into consideration, delivering two clear predictions: *i*) given the level of market competition, higher spillovers favor cooperation among firms (as in D'Aspremont and Jacquemin, 1988), but induce lower R&D investments if firms decide not to cooperate; *ii*) given spillovers, cooperation reduces R&D investment levels when market competition intensifies.

From these predictions, two consequences directly follow. First, in market characterized by relevant spillovers, the provision of subsidies to foster cooperation might be useless, for cooperation would emerge anyway. Second, in highly competitive markets, public subsidies, by encouraging cooperation, may favour a reduction of the overall level of R&D investments which might be inconsistent with the goals pursued by public authorities.

Experimentally, we extend Suetens (2005)'s design on duopolistic markets to make it cope with a

setting in which the invention process is stochastic, different levels of market competition and spillovers are possible, and subsidies to cooperating firms might be provided.

Subjects play a duopoly game for 25 rounds with random and anonymous matching to avoid reputation effects and preserve the one-shot nature of the strategic interaction. As control groups, we implement six markets that differ in both the level of spillovers and the degree of market competition. Then, in the treatment groups, we replicate the six experimental markets incentivizing cooperation by means of lump sum subsidies. Hence, for any combination of knowledge spillovers and competition level, we can assess the impact of public subsidies on cooperation and investment rates by comparing subjects' behaviour in treatment (subsidies are provided) and control (no subsidies are provided) markets.

In control markets, we find that the probability that a subject is willing to cooperate in R&D increases on average by 10 percentage points in the level of knowledge spillovers; it instead decreases on average by 20 percentage points as market competition increases. As far as investment rates are concerned, we find that these decrease by 24 percentage points, on average, in the level of knowledge spillovers, and by 11 percentage points in the level of market competition.

In *focus* markets – i.e., in markets in which the provision of incentives is expected to induce a shift in the equilibrium strategies, from non-cooperation to cooperation – the probability that a subject is willing to cooperate in R&D increases on average by 36 percentage points compared to the control: hence, subsidies prove effective in boosting R&D cooperation. However, there is evidence that when subjects cooperate *because* of the provision of subsidies, the average investment rate declines (up to 16 percentage points in focus markets). This supports the strand of literature (e.g., Fölster, 1995; Griliches, 1998; Belderbos et al., 2004; Colombo et al., 2006; Czarnitzki and Hottenrott, 2012; Crescenzi et al., 2018; Cantabene and Grassi, 2018), according to which public intervention to boost cooperation in R&D might be counterproductive if the goal is to promote a higher level of investment in R&D.

As a policy implication, these results suggest that the use of public subsidies is not to be indiscriminate. Contingent on market conditions, subsidies can be redundant - for firms would cooperate anyway - or even counterproductive, for, by inducing a higher rate of cooperation, they can indirectly stimulate lower R&D investments. All of this might translate into a waste of public funds. The remaining of the paper is organized as follows. Section 2 sketches the theoretical setting. Section 3 illustrates the experimental design in detail, while Section 4 investigates the effects on cooperation and investments deriving by changes in the structural parameters. Section 5 examines the effect of public subsidies on both subjects' cooperation rate and investment behaviour. Section 6 concludes.

2. Theoretical setting

Our experiment is based on the theoretical framework proposed by Capuano and Grassi (2019). This setting has the following basic characteristics. Two firms (i, j) have the chance to rely on binding contracts to share the cost of R&D activities aimed at developing a new product. Coordination allows firms to fully internalize knowledge spillovers and partially reduce fixed costs duplication.

There are two phases in the model: an *investment* and a *production* phase. The R&D phase contemplates two mutually exclusive scenarios, depending on whether firms decide to coordinate their R&D activities (cooperative scenario) or not (non-cooperative scenario). In the first scenario, firms jointly decide the investment level, sharing the associated cost; if the investment is successful, both firms will be able to produce and sell the innovative good. When firms agree to coordinate their R&D investments, they receive a lump sum subsidy $S \geq 0$ from the government.

In the second scenario, each firm acts independently, bearing the whole cost of the investment and being aware that the rival may be able to imitate due to the presence of knowledge spillovers. When firms decide not to cooperate, they may realize either duopolistic profits (D) - i.e., the profits that the two firms in the duopoly realize when they both manage to innovate - or monopolistic (M) profits - i.e., the profits that only one firm realizes as it is the only one that innovates. The production phase is characterized by Cournot competition in any scenario. The strength of competition is measured by an index of product differentiation, $\alpha \in [0,1]$, computed as the ratio between the non-cooperative duopolistic (D) and monopolistic (M) profits, i.e. $\alpha = D / M$. Hence, the larger is α the lower the difference between monopolistic and duopolistic profit: i.e., the lower are the competitive pressures in the product market.

As shown in Figure 1, the interaction between firms is modelled as a non-repeated game with complete information.

Figure 1. Timing of the game

$t = 0$	$t = 1$	$t = 2$	$t = 3$
Public subsidies announced	Firms agree to cooperate or not	Firms set R&D investments	Competition in the product market

At time $t = 0$, the government announces the level of the lump sum public subsidy $(S \geq 0)$ that firms get if they cooperate in R&D; at time $t = 1$, firms simultaneously decide whether to create a Research Joint Venture (RJV) or not; at time $t = 2$, any firm chooses the investment level, jointly (if both opt for an RJV) or independently (otherwise); finally, at $t = 3$, once R&D outcomes and spillovers are observed, each firm independently decides its Cournot production level.

The innovation process is stochastic. The probability of innovation, $\rho(.) \in [0.1]$, is assumed to be increasing in the investment level, with investments being characterized by diminishing marginal returns: $\rho' > 0, \rho'' < 0$.

If at time $t = 1$ an agreement is not reached (non-cooperative scenario), each firm independently decides the level of its R&D activities. In this case, firm $k = (i, j)$'s probability of innovating, $\rho(k) \in [0,1]$, is assumed to be independent of: i) the R&D activities brought about by its rival, i.e. x_{-k}; ii) the probability $\rho(x_{-k}) \in [0,1]$ that the rival is successful at innovating given its investment decisions (non-tournament approach).

Each firm is aware that in case no agreement is reached, its competitor might - with probability $\beta \in [0,1]$ - imitate its innovation (presence of spillovers effects)[4]. In this case, given the probability of successful innovation, ρ, spillover effects, β, and the differentiation index, $\alpha = D/M$, firm k's expected profits can be written as follows:

$$E\Pi_k^{NC} = r_k^d \cdot D + r_k^m \cdot M - x_k^{NC} \tag{1}$$

where:

- $r_k^d = \rho_k \rho_{-k} + \rho_k (1 - \rho_{-k})\beta + (1 - \rho_k)(\rho_{-k})\beta$ is the probability that the relevant firm $k = (i, j)$ is engaged in duopolistic competition in the production phase: this occurs when both firms innovate or one innovates and the other is successful at imitating;

- $r_k^m = \rho_k (1 - \rho_{-k})(1 - \beta)$, is the probability that firm $k = (i, j)$ enjoys monopoly profits in the production phase: this occurs when the relevant firm innovates and the rival neither innovates nor is successful at imitating.

If at time $t = 1$ an agreement is reached (cooperative scenario), firms jointly invest in R&D and equally share the whole cost of the investment. The expected profit of firm $k = (i, j)$ will be:

$$E\Pi_k^C = r_k^c \cdot D - x_k^C + S \tag{2}$$

where S is the level of public subsidy and $r_k^c = \rho(2x_k)$ is the probability of innovating induced by the overall R&D expenditure, given that $x_k^C = x_{-k}^C$.

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[4] As in Capuano and Grassi (2019), knowledge spillovers are ex-post, measured as the probability to be imitated.

The market for a new product is created when at least one competitor innovates. If none innovates, no revenues are obtained by firms (profits are instead negative, because of R&D expenditures). If one firm innovates and the other does not, the innovator gains the monopolistic profit, M > 0, while the rival obtains zero, unless it imitates the firm obtaining the innovation. If either both firms innovate or one firm innovates and the other imitates, each firm obtains duopoly profits D, where D = αM with α ∈ [0,1].

In any sub-game, firms – independently or jointly – set a level of R&D expenditure such that expected profits are maximized. Hence, cooperation in R&D emerges as a sub-game perfect Nash equilibrium (SPNE) of the game if and only if the difference between $E\Pi_k^C$ and $E\Pi_k^{NC}$ is non-negative for any firm $k = (i, j)$ whose investment decisions are optimal in any sub-game. By construction, the difference $E\Pi_k^C - E\Pi_k^{NC}$ is increasing in both the level of the public subsidy and the probability of knowledge spillovers, while it decreases with market differentiation. Some further considerations are due in order to understand how the possibility of cooperation affects investment decisions.

2.1 Theoretical predictions

The model stresses the trade-off between two distinct effects that affect incentives to cooperate in presence of knowledge spillovers. On the one hand, cooperation, by fully internalizing spillovers, increases the probability that firms successfully innovate for any given pair of balanced investment levels: this stimulates cooperation. On the other hand, due to the assumption of joint patenting, the probability of becoming a monopolist in the production phase is zero. Thus, the tougher the duopolistic competition, the lower the per-firm expected profit in a duopoly, the lower hence is the incentive to cooperate. For the same reasons, aggregate investment levels can decrease with cooperation.

Moreover, when competition in the product market is tough (i.e., differentiation between final goods is low), expected returns for additional R&D investment decrease, and this has a negative impact on the overall investment level. Therefore, even if public subsidies *mechanically* encourage cooperation, they cannot, in general, be advocated on the grounds that they increase the overall investment level in R&D.

In equilibrium (SPNE) the private incentive to cooperate in R&D is positively affected by the level of spillovers and negatively affected by the intensity of market competition.

It is then possible to state the following theoretical predictions:

- Given the level of market competition, higher spillovers favor cooperation among firms but induce lower R&D investments if firms do not cooperate;

- Given spillovers, cooperation reduces R&D investment levels in presence of strong market

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competition.

The theoretical model sketched above makes clear that when the policymaker is not exclusively concerned with implementing cooperation *per se*, but rather, for example, with increasing the overall investment level to favor the emergence of innovations, providing subsidies without considering market conditions does not qualify as an efficient use of public resources. This may for example occur whenever firms have sufficiently high private incentives to spontaneously cooperate and jointly invest in R&D (as it is in presence of high spillovers and high product differentiation).

3. Materials and Methods

In this section, we illustrate our experimental design. It extends Suetens (2005)'s experimental setting along two key dimensions. First, it introduces the level of product differentiation as a structural parameter affecting subjects' R&D investments. Second, it introduces uncertainty in the innovation process, in the spirit of the stochastic invention model that Isaac and Reynolds (1988) first tested in the lab.

3.1 *The setting*

A gender-balanced sample of 120 undergraduate and master students in economics from the University of Economics (VSE) and Charles University of Prague, took part in a trial run at the Laboratory of Experimental Economics (LEE, VSE) in March 2016. Participation granted a show-up fee of 100 CZK (3.7 euros). Potential subjects were randomly selected from the database of the Laboratory of Experimental Economics (LEE) and formally invited by e-mail to sign-up to ORSEE (On-line Recruitment System for Economic Experiments).

Once recruited, subjects were randomly assigned to one of 12 experimental sessions, 6 for the control and 6 for the treatment. Each session comprised a group of 10 subjects. The trial was designed as a computer-based experiment managed by a z-tree script (Fischbacher 2007). Subjects were randomly assigned to computer slots that were completely isolated to guarantee full anonymity. They were not allowed to talk during the session and lab assistants checked for compliance (Instructions are reported in the Supplementary material).

The experimental design was based on the duopoly game described in Section 2 above. Each subject knew that (s)he would have played the game for 25 rounds, with random and anonymous matching in any round. These features of the matching process preserve the one-shot nature of the strategic interaction.

Participants were informed at the beginning of the experiment about the circumstances characterizing

the interaction between subjects: the level of knowledge spillovers (β) and the degree of product differentiation (α).

Experimentally, we consider three possible levels of product differentiation, $\alpha \in \{0.10, 0.45, 0.70\}$. The higher is the level of differentiation, the lower is the competitive constraint in a duopoly (in our theoretical setting, the parameter α plays the role of an inverse index of market competition). By differentiating their products from competitors, firms can create a monopolistic market, where they enjoy a price-making power.

We consider only two possible levels of knowledge spillovers, $\beta \in \{0.20, 0.80\}$.

By combining the possible values taken up by parameters α and β, six experimental markets can be conceived, each of whom characterizes one of the six control sessions and one of the six treatment sessions. In some of these markets, public subsidies are necessary for cooperation to occur, i.e. without subsidies, cooperation does not emerge as a SPNE of the game.

3.2 Interaction

Each session in the control was characterized by a specific (α, β)-pair and involved a group of 10 subjects. The game was repeated for 25 rounds (plus two rounds at the beginning, just for practicing) to ensure that subjects became familiar with its rules. Subjects were aware of the random and anonymous matching process.

In every round, each participant was endowed with 200 monetary units (MU) and could invest in R&D any amount of this endowment. Monetary units not invested in a given round could be converted in CZK crown at the end of the experiment[5].

At the end of each round, any subject was informed about his own round-specific profit; he was aware of the choices of his opponent only in the case of cooperation.

The game was implemented in the lab through three phases: *information* phase, *investment* phase, *production* phase.

Information Phase. At the beginning of each session subjects observed a printed graphic with the probability of innovation, $\rho \in (0, 0.45)$, depicted as an increasing concave function of the investment level (see Figure 1).

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[5] Given the exchange rate, the gain for a subject who abstained from investing throughout the experiment was about 12 euro: 200MU $\times 25 = 5000$ MU = 300 CZK ~ 12 EUR. The exchange rate was set at 0.06 CZK for any MU.

They could thus recognize the intrinsic uncertainty of the innovation process. Subjects could also observe two matrices displaying the expected payoffs associated with specific investment levels (see the Supplementary material). These matrices conveyed information both for the non-cooperative scenario - where participants invest autonomously in R&D - and for the cooperative one, where agreements upon a joint investment level in R&D is allowed (see Tables A1NC/A1C- A6NC/A6C in the Supplementary material). These matrices were printed in two separate sheets of paper and were built by computing expected profits for various (α, β)-pair and different combinations of investment levels.

We assumed throughout that monopoly profits M equal 1000 MU.

Investment Phase. Given the information set, subjects had to decide in any round whether to coordinate their R&D decisions or not. As specified above, two different scenarios could arise.

A Cooperative scenario comes about whenever both subjects in the duopoly are willing to coordinate their R&D investments, in which case they are given the chance to bargain on the joint investment level.

The use of a profit calculator - to simulate the expected payoffs for any possible joint level of investment so as to formulate a proposal to the counterpart - was allowed during the experiment. No restrictions were imposed on the number of proposals. As soon as subjects agreed on a joint investment level, then a *symmetric* binding contract entailing each subject to bear half of the cost of the investment was automatically made.

A Non-cooperative scenario comes about whenever either one of the two subjects randomly paired is not willing to coordinate R&D investments or subjects fail to reach an agreement in the contracting phase. In this scenario subjects were free to decide their investment level autonomously, being aware of the possibility of being copied by the competitor.

Production Phase. According to the experimental rules, monopoly profits (equal 1000 MU) can be obtained only in the non-cooperative scenario, in the event that only one subject is able to produce and sell the innovative good. Otherwise, subjects get duopoly profits, with production *fixed* at the Cournot-Nash equilibrium. Collusion in the product market is not allowed.

3.3 *Treatment*

Each session in the treatment was characterized by a triplet (α, β, S). The six control markets were replicated by providing S = 30 monetary units (the lump sum public subsidy) to those who managed

to sign a symmetric binding agreement on a joint R&D investment. Subsidies were announced at the beginning of the Session. They were only provided from round 7 to 21, and this was publicly known. This latter design feature allows measuring subjects' reaction to changes in the incentive structure also *within* the treatment.

Notice that, due to the random and anonymous matching, the finitely repeated duopoly game implemented in the lab has a unique SPNE outcome that corresponds to the equilibrium outcome of the one-shot game. On these grounds, in Table 1, for each triplet (α, β, S) we summarize the theoretically predicted outcomes in terms of cooperative (C) and non-cooperative (NC) investment behaviour, both in the control (S=0 MU) and in the treatment groups (S=30 MU), given the shape of the innovation function and the other parameter values.

Table 1 illustrates the choices - i.e. whether cooperate (C) or not (NC) in R&D activities – that subjects are expected to make for each combination of the parameters α and β. The Table considers both the control (left panel) and the treatment groups (right panel).

[Table 1, near here]

In the control groups, subjects are expected to cooperate, in equilibrium, in cases IV to VI. The provision of 30 MUs is clearly not expected to alter, in these cases, the incentives subjects have, hence their equilibrium strategies. For case I, instead, providing subjects with 30 MUs is not enough to incentivize cooperation. Table 1 also clarifies that in cases II (α=0.10, β=0.80) and III (α=0.45, β=0.80) the provision of subsidies is able to change the incentives of the game compared to the control group, thereby supporting cooperation in R&D as a SPNE.

3.4 Testable Hypotheses

Grounding on the theoretical model sketched in Section 3 above, we make the following experimental hypotheses:

HP1. *In the control, the willingness to coordinate R&D investments is increasing in α and β.*

The rationale behind HP1 goes as follows: for given levels of product differentiation (α), the higher is the level of knowledge spillovers (β), the lower is the appropriability of returns deriving from non-cooperative investments. Hence, subjects in a duopoly market with higher β have a stronger incentive to coordinate R&D investments to internalize spillovers, increase the probability of innovating for any balanced investment levels, and getting duopoly profits.

As for market competition, remember that when subjects sign a symmetric binding agreement, the

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probability of getting monopoly profits is zero. Thus, for given levels of spillovers, the lower is the level of product differentiation (i.e. the lower is α), the lower are the expected profits of cooperative investments compared to the non-cooperative ones. Conversely, when final products are strongly differentiated, firms' profits are weakly affected by the presence of a competitor: i.e., duopolistic profits tend to monopolistic ones as α increases. At the same time, cooperation reduces fixed costs duplication. Hence, when products are strongly differentiated (i.e., the level of market competition is low) subjects' expected profits of cooperation are higher.

HP2. *In the control, the investment levels in the non-cooperative scenario are decreasing in β*.
The rationale behind this hypothesis follows from the previous argument. For a given level of market differentiation, if subjects do not cooperate, the higher the probability of being imitated, the lower is the incentive to invest in R&D.

HP3. *In the control, the average investment level is increasing in α.*
For a given level of knowledge spillovers, the duopolistic profits approximate the monopolistic ones as the level of market differentiation increases. Hence, subjects have a stronger incentive to invest in R&D, both in the cooperative and in the non-cooperative scenario.

We now turn to the effect of public subsidies. Therefore, we focus on cases II (α=0.10, β=0.80) and III (α=0.45, β=0.20), where the provision of additional monetary units is expected to induce a change in subjects' investment behaviour.

HP4. *In cases II (α=0.10, β=0.80) and III (α=0.45, β=0.20), the provision of additional 30 monetary units increases the average willingness to cooperate in R&D investments compared to the control.*
This hypothesis directly follows from the assumption that subjects rationally react to the change in the incentive structure of the game converging to the SPNE outcome. Indeed, the provision of public subsidies increases the expected profits of cooperation, inducing subjects to coordinate their R&D investments.

HP5. *In cases II (α=0.10, β=0.80) and III (α=0.45, β=0.20), cooperation induced by public subsidies is associated with lower investments in R&D .*
The rationale behind HP5 is the following. In these market settings, the relatively high level of competition makes subjects' expected profits from cooperation lower, compared to the expected profits of non-cooperative investments. Whenever subjects choose to cooperate, theinvest less

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compared to the non-cooperative scenario. Hence, if public subsidies encourage cooperation, then they indirectly induce a lower level of investments in R&D.

4. Results: Effects of spillovers and competition on cooperation and investments in R&D

In this section, we test hypotheses HP1-HP3, providing evidence on how subjects react, in the baseline, to changes in incentives due to the exogenous variation in the level of both knowledge spillovers (β) and product differentiation (α). To this end, we estimate the following behavioural equations:

$$C_{it} = \gamma_0 + \gamma_1 SP_{high} + \gamma_2 PD_{med} + \gamma_3 PD_{high} + \eta_{it} \tag{3}$$

$$IR_{it} = \delta_0 + \delta_1 SP_{high} + \delta_2 PD_{med} + \delta_3 PD_{high} + \varepsilon_{it} \tag{4}$$

In equation 3, C_{it} is a dummy variable taking value 1 when the individual is willing to cooperate in R&D at time t, and 0 otherwise; SP_{high} is a dummy variable taking value 1 for the highest level of spillovers and 0 otherwise; PD_{med} and PD_{high} are dummy variables taking value 1 for an intermediate to a high level of product differentiation ; η_{it} is an error term. In equation 4, the dependent variable IR_{it} stands for the individual investment rate (i.e. the ratio between the investment level and the endowment) at t. The standard errors were bootstrapped for 10000 replications to take into account the correlation among observations across rounds (MacKinnon 2006, Horowitz 2019). Results are in Table 2.

As for the effect of exogenous changes in α and β on subjects' average willingness to cooperate, results (first column) are consistent with our theoretical expectations. Indeed, the probability that subjects are willing to cooperate in R&D significantly increases by 10 percentage points moving from a low to a high level of knowledge spillovers. Moreover, an increase of 35 percentage points in the level of product differentiation induces an increase in the individual willingness to cooperate of 16 percentage points; while an increase of 60 percentage points in the degree of product differentiation induces an increase of 40 percentage points in the individual willingness to cooperate in R&D. This entails that a change from a low to a medium level of product differentiation - as well as a change from a medium to a high level of product differentiation - induces an *average* increase in the individual willingness to cooperate in R&D of about 20 percentage points. The experimental investigation, therefore, confirms that the probability of cooperation tends to increase with both knowledge spillovers and product differentiation.

[Table 2, near here]

We now turn to the effect of a change in the value of the structural parameters on investment behaviour (HP2 – HP3) by estimating equation 4. Table 2 (second column) shows that an increase in the level of knowledge spillovers significantly reduces the average investment rate by 24 percentage points. This supports HP2. Moreover, in line with HP3, an increase in product differentiation induces an average increase in the individual investment rate of approximately 11 percentage points.

5. Results: Effect of subsidies on cooperation and investment rate

In this section, we analyse the effect of subsidizing cooperation in R&D. We also examine the difference in investment behaviour between cooperating and non-cooperating subjects. For our purposes, we first restrict our analysis to cases II (α=0.10, β=0.80) and III (α=0.20, β=0.45). Indeed, these are the only cases in which the provision of public subsidies is expected to induce a shift from non-cooperation to cooperation: in all the other cases, equilibrium strategies dictate either «never cooperate» or «always cooperate», independently from the provision of subsidies. Finally we examine cases I and IV-VI too.

5.1 *Effect of subsidies on cooperation: cases II and III*

Here we test whether *the provision of additional monetary units increases the average willingness to cooperate in R&D investments* (HP4). As detailed in Section 3, we partitioned the 25 rounds played by treated subjects into three time periods, depending on whether subsidies are only announced (rounds 1-6), provided (rounds 7-21) or removed (rounds 22-25). This design feature allows us to exploit both within and between-subject behavioural variations, and implementing a difference-in-differences analysis.

As a preliminary step, in Figure 2 we plot the dynamics of subjects' average willingness to coordinate R&D investments both in the treatment and control, by jointly considering Cases II and III.

[Figure 2, near here]

We observe that, in control groups, individuals' willingness to cooperate is approximately stable through rounds. Conversely, in treatment groups, it significantly increases when additional monetary units are provided (rounds 7-21) and then falls when subsidies are removed. Thus, *the provision of public subsidies does not induce any announcement or persistence effect* influencing the average willingness to cooperate in R&D, as subjects simply respond to changes in the material incentives of

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the game.

To provide support to this evidence, we implement a difference-in-differences analysis between treatment and control group by estimating the following behavioural equation:

$$C_{it} = \pi_0 + \pi_1 S + \pi_2 time + \pi_3 DID + v_{it} \tag{5}$$

where C_{it} is a dummy capturing the individual willingness to cooperate in R&D. As S is the dummy denoting the treatment group, π_1 measures the average difference in the individual willingness to cooperate in R&D between treatment and control groups when subsidies *are not* provided (i.e., in rounds 1-6 and 22-25). The dummy variable *time* takes value 1 in those rounds where public subsidies are provided to cooperating subjects, and 0 otherwise; therefore, π_2 measures the difference in the individual willingness to cooperate in R&D investments between rounds 7-21 and the other rounds. *DID* stands for the usual difference-in-differences interaction term between S and *time*.

We estimate equation (5) for cases II and III, where the provision of public subsidies is expected to boost subjects' cooperation. Results are in Table 3. Estimations support HP 4, as the provision of subsidies significantly increases the probability of cooperation in R&D.

[Table 3, near here]

Specifically, looking at the coefficient associated to *S*, no difference between treatment and control group is recorded when public subsidies are not provided. Moreover, the coefficient associated with the dummy *time*, documents that subjects in the control group do not exhibit a significant difference in their willingness to cooperate between rounds 7-21 and the other rounds. Hence, the significant increase in the willingness to cooperate measured by the positive coefficient associated with the difference-in-differences interaction term (*Time*S*) can be attributed to the actual provision of subsidies. More specifically, in Cases II and III, when public subsidies are provided (rounds 7-21), the probability that a subject is willing to cooperate in R&D increases, on average, by 36 percentage points compared to the control. In other words, public subsidies increase individuals' average willingness to cooperate in R&D by 80% of its actual mean (i.e., 0.45).

5.2 *Effect of subsidies on cooperation: cases I and IV-VI*

In this Section we consider all the market settings in which subsidies do not change the incentive structure of the duopoly game. Thus, in Figure 3 we plot the average willingness to cooperate in R&D over rounds. We separately consider Cases IV to VI (panel a), where subjects are expected to

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cooperate in both treatment and control[6] and Case I (panel b), where subjects should never cooperate. In panel *a*, we observe that willingness to cooperate tends to overlap between treatment and control, suggesting that the provision of public subsidies does not impact on subjects' behavior.

In Case I (Fig 3, panel b), the pattern is less clear. During the pre-treatment period (i.e., round 1-6), the average willingness to cooperate in R&D is lower in the treatment group. However, in rounds 7-21 it increases, remaining stably higher than in the control group up to the end of the treatment period (round 21). This seems to suggest that the provision of public subsidies, though not affecting the incentive structure of the game, may induce subjects, in this case, to display a higher willingness to cooperate.

[Figure 3, near here]

Estimating equation (5) for cases I and IV-VI delivers results coherent with the graphical analysis. In Cases IV to VI the coefficient associated to the interaction term (*Time*S*) is not significantly different from zero: i.e., since the provision of public subsidies in these market settings does not affect the incentives of the game, no difference is recorded in subjects' willingness to cooperate in R&D.

However, results are at odds with our expectations in Case I (Column 1), where subjects should not be conditioned by the provision of subsidies. Indeed, the coefficient associated to the difference-in-differences interaction term (*Time*S*) is significantly positive, documenting that subjects in the treatment group tend to increase their willingness to cooperate in rounds 7-21 compared to the control.

[Table 4, near here]

A plausible explanation of this result is related with the well-known framing effect (Kahnemann and Tversky, 2013). In an environment in which the incentive structure obviously dictates non-cooperation, the provision of subsidies might change the way the game is perceived. Taking into account the computational difficulties subjects face in comparing the two different scenarios to determine the profit-maximizing choice, the provision of subsidies might be meant by subjects as a *cue* that the right *scenario* – the one whose selection gives rise to a *right* to be rewarded – is the cooperative one. Indeed, this kind of effect is not observed in cases IV to VI, where public subsidies

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[6] The pattern of the average willingness to cooperate in each case singularly taken from 4 to 6 is analogous to the aggregated one presented in panel a of Figure 1. Graphics are available upon request.

do not change the perception of the game: it was, and still is, after the provision of subsidies, a game which must be played cooperatively.

5.3 *Investment behavior*

In this section, we perform a within-control and a within-treatment analysis to get more details on subjects' investment behaviour.

Preliminarily, in Figure 4 we plot the dynamics of cooperative and non-cooperative investment rates - control and treatment groups, cases II and III - together with the theoretically predicted rates of non-cooperative (i.e., the horizontal grey line) and cooperative (i.e., the horizontal dashed black line) investments.

[Figure 4, near here]

In the control, we observe that in both cases the dynamics of the average rate of cooperative and non-cooperative investments do not follow a clear pattern and tend to overlap, providing graphical evidence of no significant differences between them.[7]

As for the treatment groups, in both cases the average of cooperative investment rates exhibit a clearer pattern. In case II, when subsidies are provided, cooperating subjects invest on average 10% of their endowment, a significantly larger share than the theoretically predicted rate of 4%. In case II, instead, cooperating subjects invest on average 43% of their endowment when subsidies are provided, slightly lower than the theoretically predicted rate of 48%.

In Case II, the dynamics of cooperative and non-cooperative investment rates tend to overlap, due to the small difference between the respective theoretically predicted rates. Nonetheless, in line with our theoretical predictions, non-cooperative investment rates are on average higher than cooperative ones when public subsidies are provided, with a small positive difference of 0.031 that is statistically significant only if we consider the one-tailed p-value of 0.074 (Wilcoxon signed-rank test).

In Case III, we observe that in the first 6 rounds – when subsidies are only announced – the dynamics of the average cooperative investment rate is highly variable, while it is more stable across rounds when subsidies are provided. Overall, the average non-cooperative investment rate exhibits an increasing trend in rounds 7-21. Hence, when subsidies are provided, non-cooperative investment rates are on average higher than the cooperative ones, with a statistically significant positive

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[7] In both cases, the average difference between cooperative and non-cooperative investment rates are never statistically significant.

differences of 0.266 (two-tailed p-value = 0.000, Wilcoxon signed-rank test).

In Figure 5, we plot the dynamics of the average cooperative and non-cooperative investment rates in the remaining cases both for the control (left panel) and treatment groups (right panel).

[Figure 5, near here]

In cases IV to VI we do not observe substantial differences between control and treatment groups, with the exception of case VI, where the dynamics of the average cooperative and non-cooperative investment rates in the treatment are more clearly separated than in the control.

For case I, instead, we observe some differences. In the control group, the dynamics of cooperative and non-cooperative investment rates tend to overlap. In the treatment, the average cooperative investment rate exhibits a declining trend from round 11 onward. As a consequence, cooperative investment rates are on average lower than non-cooperative ones, especially when subsidies are provided (diff = 0.403 p-value = 0.000).

We deepen the graphical analysis by performing a Difference-in-differences estimation within the control and within the treatment groups, focusing on cases II and III only. We estimate the following model:

$$IR_{it} = \theta_0 + \theta_1 CI_{it} + \theta_2 time + \theta_3 DID1 + \varepsilon_{it} \tag{6}$$

where CI_{it} is a dummy variable taking value 1 if subjects invest cooperatively in R&D at time t; hence, θ_1 measures the average difference between cooperative and non-cooperative investment rates when the dummy variable *time* equals zero (i.e., in rounds 1-6 and 22-25). Parameter θ_2 (associated with the dummy *time* for the rounds 7-21 when subsidies are provided) measures the difference in average *non-cooperative* investment rate between rounds 7-21 and the other rounds. Finally, *DID*1 is the difference-in-differences interaction term between cooperative investments (CI) and *time*; θ_3, therefore, compares cooperative and non-cooperative investment rates before and after the provision of public subsidies in rounds 7-21. Results are reported in Table 5.

[Table 5, near here]

Considering within control estimates (first two columns), regressions results record no significant

differences between cooperative and non-cooperative investment rates. The picture changes if one considers within treatment estimates (last two columns). Table 5 documents that, in line with our theoretical expectations, cooperative investment rates are systematically lower than non-cooperative ones. Specifically, in both cases the negative coefficient associated to the dummy variable CI_i documents that cooperative investment rates are significantly lower than the non-cooperative ones in rounds where subsidies are not provided (i.e., rounds 1-6 and 22-25).

In Case II, the insignificant (and close to 0) coefficient associated to the dummy *time* shows that non-cooperative investment rates do not significantly change in rounds 7-21. Moreover, the insignificant coefficient associated to the difference-in-difference interaction term documents that, on average, cooperative investment rates do not significantly vary when public subsidies are provided compared to non-cooperative investment rates.

In Case III the significant positive coefficient associated to the dummy *time*, documents that non-cooperative investment rates significantly increase when public subsidies are provided. Due to that, the coefficient associated with the differences-in-differences interaction term (*CI*time*) measures a negative and statistically significant difference of 16 percentage points between cooperative and non-cooperative investment rates when subsidies are provided.

Overall, regression analysis shows that, in competitive markets, cooperation induced by public subsidies entails a lower than average investment rate compared to the non-cooperative scenario. This is consistent with the strand of literature pointing to a crowding out effect of public subsidies on R&D investments.

6. Discussion and concluding remarks

In this paper, we have analyzed the impact of public subsidies on firms' R&D activities in markets characterized by varying degrees of competition and spillovers. We have found that the probability of cooperation increases with the level of knowledge spillovers and decreases with level of product differentiation (the opposite is true as far investment rates are concerned).

To assess the impact of public subsidies on cooperation rates, we first focused on cases in which the provision of additional monetary units is expected to induce a shift from a non-cooperative to a cooperative strategy. Our Difference-in-Differences analysis has documented a significant and substantial positive effect of public subsidies on cooperation. We have also analyzed cases in which the provision of additional monetary units is not expected to have an impact, for subjects would have incentives to cooperate anyway.

The relevant policy implication is that targeting public subsidies on a careful diagnosis of the structural parameters of the market would avoid a waste of resources whenever public funds are

delivered to firms that would have cooperated anyway: i.e. either when competition in the product market is low or when the level of knowledge spillovers is high.

We have also analyzed the impact of public subsidies on investment rates. What we have found is that in competitive markets the provision of additional monetary units encourages cooperation but may reduce the average investment rate. Hence, consistently with the relevant literature on the subject (e.g. Cerulli 2010; Zúñiga-Vicente et al. 2014; Fölster, 1995; Griliches 1998; Belderbos et al. 2004; Colombo et al. 2006; Czarnitzki and Hottenrott 2012; Crescenzi et al. 2018; Cantabene and Grassi 201), we showed that, even if public subsidies mechanically encourage cooperation, they cannot, in general, be advocated on the grounds that they increase the overall investment level in R&D.

On the whole, the message is that the use of public subsidies is not to be indiscriminate. Contingent on market conditions, subsidies can indeed be redundant, for firms would have cooperated anyway, or inefficacious, for they are not capable to foster cooperation appreciably. All of this might translate into an inefficient use of public funds.

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Appendix

Figure 1. Probability of successful innovation as a function of investment.
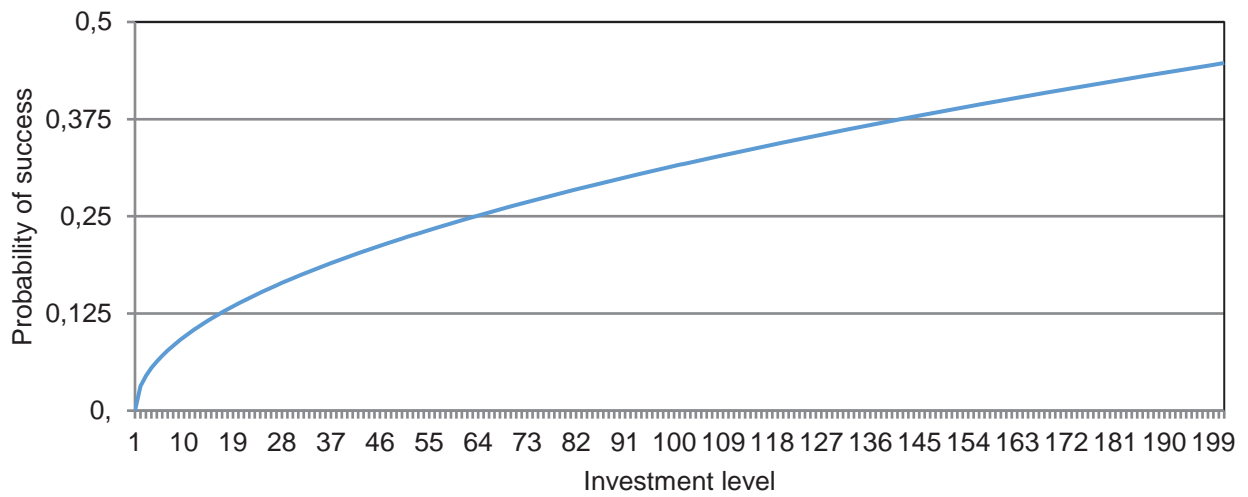
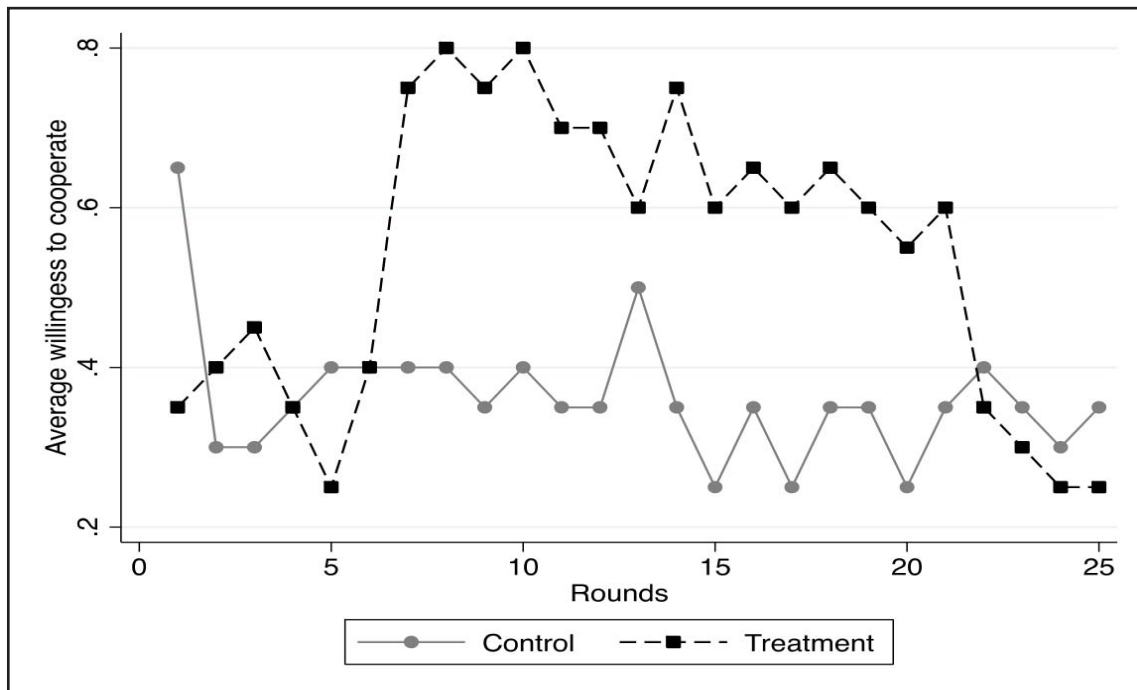**Figure 2. Dynamics of the average willingness to cooperate (cases II and III).**
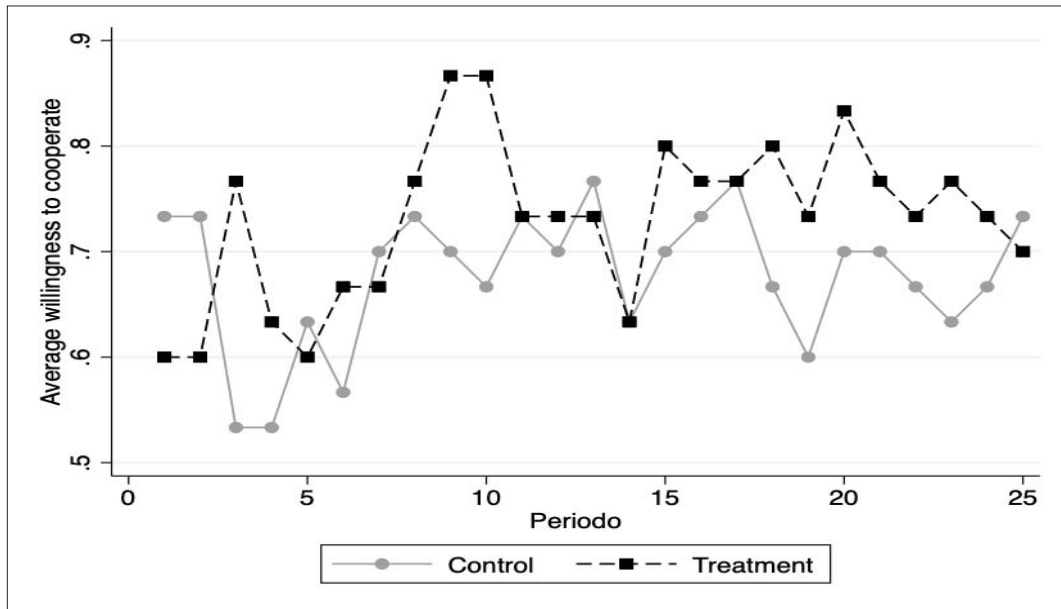
Figure 3. Dynamics of the average willingness to cooperate (Cases IV-VI and Case I).

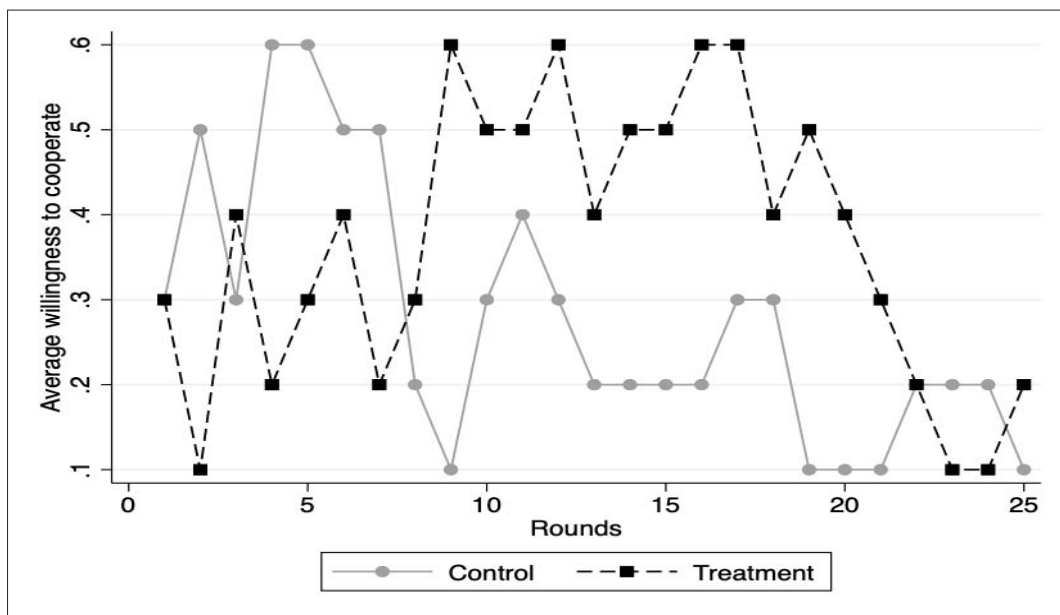**a) Cases IV-VI**

b) Case I

Figure 4.   Dynamics of average investment rate Cases II and III (Control and Treatment).
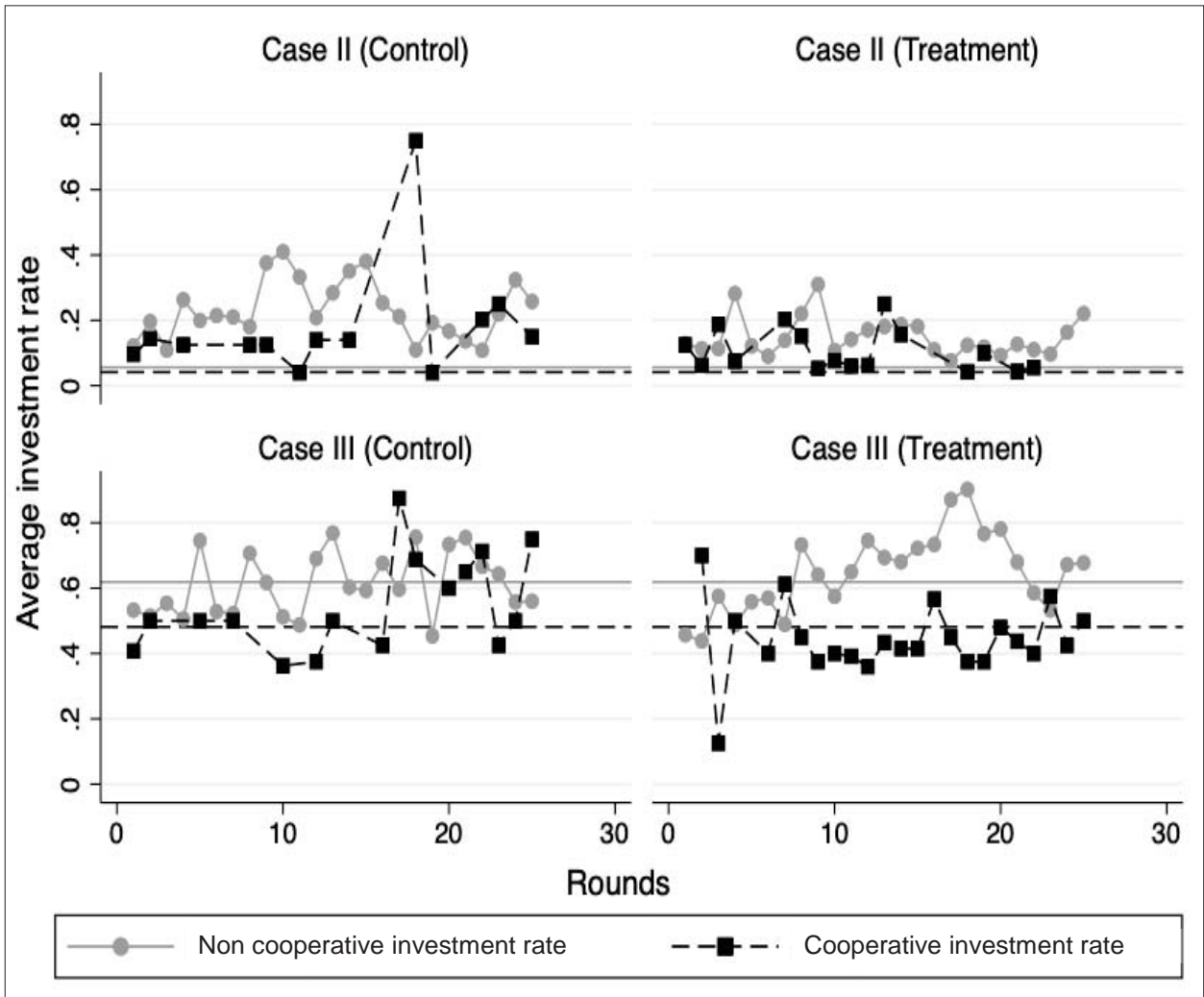
Figure 5. Dynamics of average investment rate Cases I, IV, V, VI (Control & Treatment).
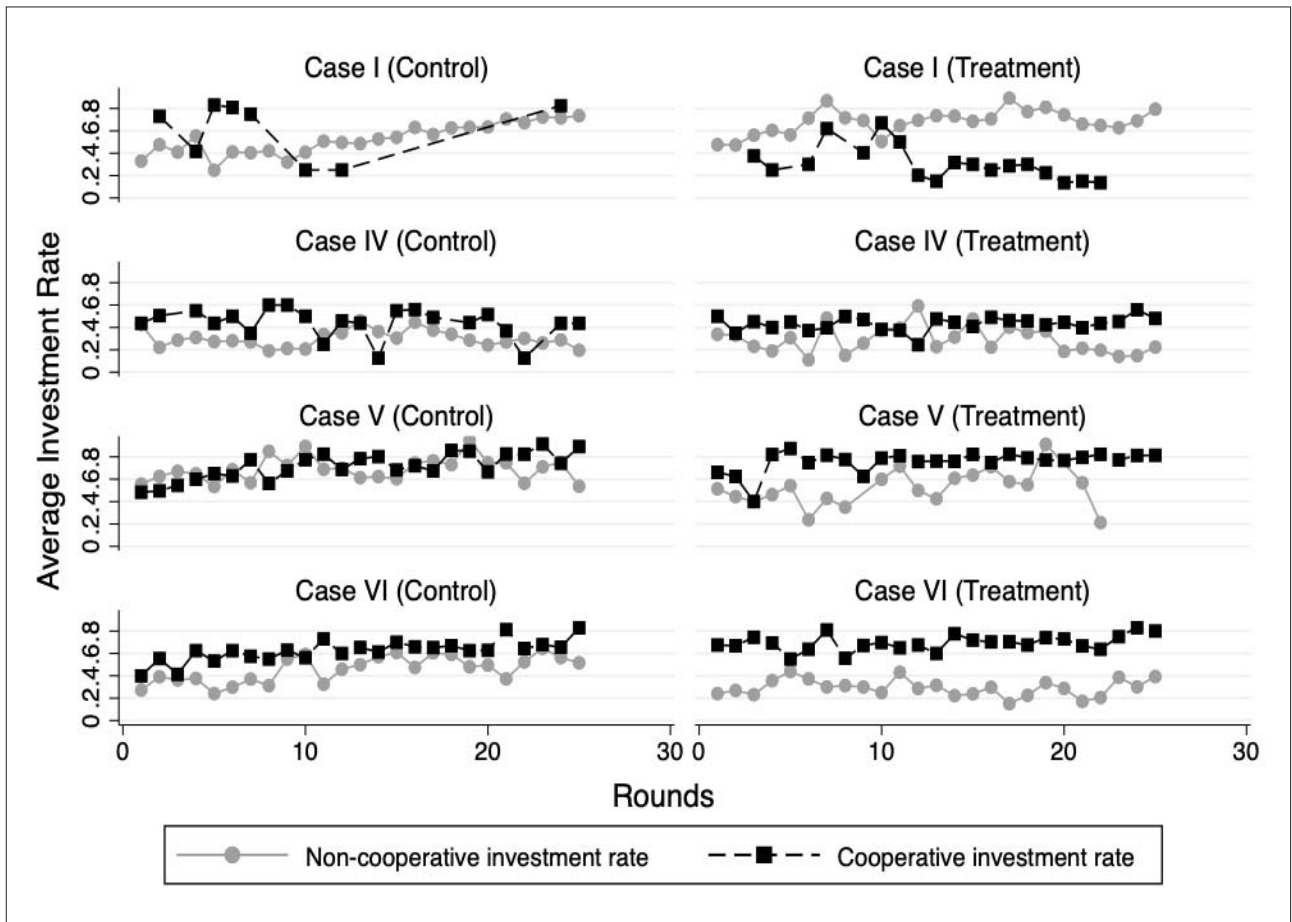
Table 1. Predicted outcomes in Control and Treatment groups.

	Control Groups S=0 MUs			Treatment Groups S=30 MUs	
	β=0.20	β=0.80		β=0.20	β=0.80
α=0.10	NC (I)	**NC (II)**		NC (I)	**C (II)**
α=0.45	**NC (III)**	C (IV)		**C (III)**	C (IV)
α=0.70	C (V)	C (VI)		C (V)	C (VI)

Note. *The parameter α is a measure of product differentiation. The parameter β is a measure of knowledge spillovers. Subsidies are 30 monetary units provided to cooperating subjects in the treatment groups during rounds 7-21.*

Table 2. Effect of knowledge spillovers and competition on cooperation and investments in R&D.

	Willingness to Cooperate in R&D	Investment Rate in R&D
SP_{high} **(High level of knowledge spillovers)**	**0.100***** (0.024)	**−0.247***** (0.014)
PD_{high} **(High level of product differentiation)**	**0.400***** (0.029)	**0.236***** (0.017)
PD_{med} **(Intermediate level of product differentiation)**	**0.164***** (0.029)	**0.083***** (0.018)
Constant	**0.268***** (0.024)	**0.502***** (0.016)
R-squared	0.116	0.257
N	1500	1500

Note. In the first column, the dependent variable is a dummy taking the value of one if subjects are willing to cooperate and zero otherwise. In the second column, the dependent variable is the subjects' investment rate: i.e., the ratio between the per-round individual investment level and the endowment of 200 MUs. The variable SP_{high} is a dummy taking value one for high levels of spillovers. The variables PD_{high} and PD_{med} are dummies taking value one for high and intermediate levels of product differentiation respectively. The variable Agreement is a dummy taking value one when subjects manage to sign a binding agreement, and zero otherwise. Bootstrapped standard errors in parenthesis.

Table 3. Treatment effect of subsidies (Cases II and III).

	Case II	Case III
Subsidies	−0.060 (0.066)	−0.030 (0.069)
time **(Rounds 7-21)**	−0.006 (0.061)	−0.053 (0.062)
*time***S**	**0.326*** (0.086)**	**0.410*** (0.087)**
Constant	**0.360*** (0.048)**	**0.400*** (0.049)**
R-squared	0.069	0.109
n	500	

Note. *The dependent variable is a dummy taking value one if subjects are willing to cooperate in R&D. The variable Subsidies is a dummy equal to one for the treatment groups. time is a dummy taking value one for those rounds (7-21) in the treatment groups where 30 MUs are provided to cooperating subjects. time*S is the differences-in-differences interaction term. Bootstrapped standard errors in parenthesis.*

Table 4. Treatment effect of subsidies (Cases I, IV, V, VI).

	Case I	Case IV	Case V	Case VI
Subsidies	**−0.120*** **(0.063)**	**0.130*** **(0.069)**	0.080 (0.060)	−0.100 (0.068)
time **(Rounds 7-21)**	**−0.116*** **(0.059)**	**0.100*** **(0.063)**	2.10e-1 (0.058)	0.060 (0.059)
time*S	**0.346*** ** **(0.083)**	−0.016 (0.083)	0.006 (0.077)	0.093 (0.085)
Constant	**0.350*** ** **(0.047)**	**0.530*** ** **(0.050)**	**0.720*** ** **(0.045)**	**0.680*** ** **(0.046)**
R-squared	0.045	0.027	0.009	0.017
n	500			

Note. The dependent variable is a dummy taking the value one if subjects are willing to cooperate in R&D. Subsidies is a dummy equal to one for the treatment groups. time is a dummy taking value one for those rounds (7-21) in the treatment groups where 30 MUs are provided to cooperating subjects. time*S is the differences-in-differences interaction term. Bootstrapped standard errors in parenthesis.

Table 5. Difference between cooperative and non-cooperative investment rates in cases II and III.

	Within Control		Within Treatment	
	Case II	**Case III**	**Case II**	**Case III**
CI	–0.048 (0.033)	–0.029 (0.046)	**–0.042*** (0.024)	–0.100* (0.051)
time (**Rounds 7-21**)	0.047 (0.041)	0.052 (0.042)	–0.003 (0.022)	0.150*** (0.044)
CI *time	–0.011 (0.078)	–0.064 (0.067)	0.010 (0.032)	–0.166*** (0.063)
Constant	0.206*** (0.029)	0.576*** (0.031)	0.143*** (0.018)	0.553*** (0.032)
R-squared	0.009	0.013	0.011	0.163
n	250			

Note. The dependent variable is the subjects' rate of investment (i.e., the ratio between the per-round individual investment level and the endowment of 200 MUs). The variable CI is a dummy equal to one for those subjects that invest cooperatively in R&D. time is a dummy variable taking the value one for those rounds (7-21) in the treatment groups where 30 MUs are provided to cooperating subjects. CI*time is the differences-in-differences interaction term. Bootstrapped standard errors in parenthesis