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Competition and Incentives

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ABSTRACT: We report on two experiments that identify *non-monetary* incentive effects of competition. As the number of competitors increases, monetary incentives to engage in cost reduction tend to decrease. We test the hypothesis that there are non-monetary incentive effects of competition going in the opposite direction. In the experiments we change the number of competitors exogenously keeping the monetary incentives to spend effort constant. The first experiment shows that subjects spend significantly more effort in duopolistic and oligopolistic markets than in a monopoly. The second experiment focuses on social comparisons as one potential mechanism for this effect. It shows that competition turns the effort decisions of competing managers into strategic complements.

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1 Introduction

How does competition as measured by the number of firms in a market affect the incentives to reduce costs and to increase productivity? The theoretical IO literature finds that "increasing the number of firms tends to decrease cost reduction expenditure per firm" (Vives, 2008). However, the empirical literature on this topic is far from conclusive. Many empirical studies suggest that there is a positive or inverted U-shaped relationship between the degree of competition and measures of cost reduction and productivity. One possible explanation for these findings is that there are non-monetary incentives provided by competition that have been ignored by the theoretical literature so far.

In this paper we use laboratory experiments to identify *non-monetary* incentive effects of competition. We focus on the incentives of the managers of the firms to invest effort in cost reduction. Our hypothesis is that the number of competitors has a direct positive incentive effect that is independent of the monetary incentives provided by competition. This countervailing effect may contribute to the explanation for why a positive association between competition and effort incentives is often observed.

We conduct two experiments in which we change the number of competitors exogenously keeping the monetary incentives to spend effort constant. In the first experiment (with simultaneous investments) we compare a monopoly to a duopoly and to an oligopoly with four firms. Competition has a highly significant causal effect on behavior. We find that our experimental subjects engage in significantly more effort in the treatments with competition than in the monopoly treatment. Furthermore, effort falls slightly (but non-significantly) in the oligopoly treatment as compared to the duopoly treatment. Combined with the negative effect on monetary incentives this is consistent with the sometimes observed inverted U-shaped relationship between competition and incentives.

In this experiment the monetary incentives for a manager to invest in cost reduction are kept constant *in equilibrium*. However, because subjects do not behave as predicted by Nash equilibrium, the actual monetary incentives to provide effort are not identical across treatments. In fact, as the number of competitors changes several other dimensions of the decision environment change as well. In the monopoly treatment each subject has to choose his effort level playing against nature. This is a one-person decision problem with objectively given probabilities. In the duopoly and oligopoly treatments several players interact strategically. Thus, subjects have to form beliefs about the strategies taken by their opponents. The decision problem with competition is also more complex because it involves more possible contingencies. Furthermore, with competition there is social interaction with one or more other managers. Subjects may care about the payoffs that their opponents receive, and they may react to each other. The optimal strategy depends on the (possibly mistaken) beliefs about the strategies of their opponents and on their (possibly social) preferences. These differences are natural. In the real world an increase of the number of competitors necessarily affects all of these dimensions as well.

In our second experiment we zoom in on the role of social interaction. We control for all differences between a monopolistic and a duopolistic market except for the scope for social comparisons. In the duopoly there is a second person (the competitor) to whom the manager can compare himself, which is not the case in a monopoly situation. The behavioral and experimental literature proposes two mechanisms by which social comparisons may affect behavior. First, models of inequity aversion (Fehr and Schmidt, 1999; Bolton and Ockenfels, 2000) and envy (Bolton, 1991) claim that people suffer a utility loss if they fall behind. Second, the literature on contests and auctions claims that there is a "joy of winning" that explains overbidding (Cox et al., 1992; Sheremeta, 2010). Both types of models predict that subjects have an incentive to invest more cost reducing effort in a duopoly than in a monopoly, but they differ in their predictions on whether effort choices are strategic complements or substitutes.

In this second experiment we achieve control over all other factors by making investments sequential. In the duopoly treatment the second duopolist observes the effort choice of the first duopolist, so there is no strategic uncertainty at the second stage. In the monopoly treatment the monopolist also faces exogenous uncertainty about "market conditions". An increase of the effort chosen by the first duopolist in the duopoly treatment corresponds to an increase of the probability of unfavorable market conditions in the monopoly treatment. The experiment is designed such that the monopolist and the second duopolist face exactly the same decision problem with the same information structure, the same probabilities and the same monetary payoffs. In fact, they both have the same dominant strategy (i.e., their optimal strategies are independent of market conditions and of what the first duopolist does). The only difference is that in the duopoly treatment there is a second player with whom the duopolist interacts, while there is no social interaction in the monopoly treatment.

We find that the average effort level chosen by subjects in the duopoly treatment is again higher than in the monopoly treatment, but the difference is no longer statistically significant. Thus, social comparisons alone cannot explain the strong effect observed in the first experiment. However, in the duopoly treatment there is a strong (and highly significant) positive reaction of the second duopolist to the effort chosen by the first duopolist, i.e. efforts are strategic complements which is consistent with models of inequity aversion and envy, but not with a "joy of winning". In contrast, in the monopoly treatment an increase in the probability of non-favorable market conditions (which is payoff equivalent to an increase in the effort of the first duopolist) has a negative effect on the effort chosen by the monopolist. Thus, more effort of their competitors induces subjects to work harder, while more challenging market conditions in a monopoly induces them to be more complacent.

We conducted our experimental study in a lab environment which offers several advantages over field studies. First, in our experiments we can change the number of competitors exogenously. This allows us to identify causal effects. In contrast, in field studies it is difficult to identify causal effects because the number of competitors in a market is endogenous and causality can go in both directions. While the number of competitors affects the incentives to invest in cost reduction, the productivity of firms also affects entry and exit decisions. Second, by using the induced value method we can control for the monetary incentive effects of competition (the costs and the returns of the effort invested) which is much more difficult in an empirical study. Finally, we can eliminate potential selection biases that often plague empirical studies. For example, many monopolistic companies are either state-owned or tightly regulated, thus exhibiting different wage and pension systems than competitive firms. Therefore, they may attract managers and workers with different characteristics than companies acting under competitive pressure. In our experiments subjects are randomly assigned to treatments, so there is no self-selection of individuals into more or less competitive markets.

The remainder of the paper is organized as follows. Section 2 discusses the relation to the literature. In Section 3 we set up a simple theoretical model of the monetary incentive effects of competition (as measured by the number of firms in the market) for managers to invest in cost reduction. Section 4 reports on our first experiment with simultaneous investments and strategic uncertainty. We describe the experimental design in subsection 4.1, derive the theoretical hypotheses in subsection 4.2 and report the experimental results in subsection 4.3. Section 5 discusses the second experiment with sequential investments that focuses on the effects of social comparisons. The experimental design, described in Subsection 5.1, is such that decision makers in the monopoly and the duopoly treatment face exactly the same decision problem (except for the presence of a second duopolist). The theoretical predictions are derived in Subsection 5.2. We report the results of this experiment in Subsection 5.3. Section 6 concludes.

2 Relation to the Literature

Our paper is closely related to two strands of literature—the theoretical and empirical literature on competition and innovation and the experimental literature on contests and competition.

The theoretical literature on competition, investment incentives, and innovation goes back at least to Schumpeter (1942) who argued that monopolies will invest more in innovation and Arrow (1962) who argued that the incentives for innovation are stronger with competition. One problem of this literature is that a change in the degree of competition can mean very different things: a change of the number of competitors, a change of the degree of product substitutability, a change from Bertrand to Cournot competition, or a change in regulation or in barriers to entry. Here we focus on just one aspect of competition, the number of firms in the market. In a comprehensive study Vives (2008) compares many different models of competition (Bertrand and Cournot, with free and restricted entry, and with different demand systems such as linear, CES, Logit, etc.). He concludes that increasing the number of firms tends to decrease cost reduction expenditures per firm.

While this literature looks at the incentives of firms to invest in cost reduction, we are mainly interested in the incentives of managers who are maximizing their own utility. Jensen and Meckling (1976) argue that the degree of competition cannot affect managerial incentives because a monopolist has the same incentives to minimize costs and to reduce agency costs as a competitive firm, so both types of firm should offer the same incentive scheme. However, this argument ignores that competition changes the environment in which the firm operates and thereby the optimal incentive scheme. There are a few agency models investigating how the effects of competition on firm profits translate into managerial incentives (Martin, 1993; Schmidt, 1997; Raith, 2003).We show in Section 3 that the incentives of the owner to reduce costs are translated monotonically via the optimal incentive scheme into the monetary incentives of the manager to invest effort into cost reduction. Thus, if an increase in the number of firms decreases the incentives of the firm to invest in cost reduction, then the monetary incentives of the manager of the firm will also decrease.[1]

Most empirical studies find either that measures of innovation and productivity increase monotonically with the degree of competition as measured by a concentration index (Geroski, 1994; Nickell, 1996; Blundell et al., 1999) or that there is an inverted U-shaped relationship between competition and incentives (Scherer and Ross, 1990).[2] More recently Bloom and Van Reenen (2007), using a survey of management practices of medium-sized firms in the U.S., France, Germany, and the U.K., show that competition measured by the number of competitors strongly increases managerial effort and managerial performance. However, an important problem of all of these studies is that entry and exit are endogenous which makes it difficult to establish a causal impact of competition on behavior.

There is also a small experimental literature on the relationship between competition and innovation. Isaac and Reynolds (1992) compare a monopoly to an oligopoly with four firms and find a positive effect of competition on cost-reducing R&D investments. Darai et al. (2010) consider two different measures of the degree of competition. A change from Cournot to Bertrand competition increases cost-reducing investments in their experiments,

[1]There is another branch of the literature focussing on the additional information that is provided by additional competitors (Holmström, 1982; Hart, 1983; Scharfstein, 1988). This additional information is always beneficial for the principal, but whether it results in a higher effort level of the manager depends on the informational structure of the model.

[2]See Gilbert (2006) and Vives (2008) for overviews of this literature.

while an increase from two to four players in a Cournot setting leads to lower average investments. In Sacco and Schmutzler (2011) the degree of competition is varied by the degree of product differentiation. They find weak experimental evidence for a U-shaped relationship between competition and innovation. In all of these papers changes in the degree of competition change the monetary incentives to invest. Thus, these papers cannot disentangle the monetary effects and the non-monetary effects of competition. This is a novel contribution of our paper.

Finally our paper is related to the experimental literature on contests and tournaments. Most experimental studies find that there is a negative relationship between the number of players and individual effort, as predicted by theory.[3] The experimental literature has also shown that the rent dissipation rate (total effort divided by the prize) is significantly higher than predicted by Nash equilibrium, i.e. contestants spend too much effort.[4] In our experiments we also find that subjects overinvest. Furthermore, similar to these studies, we find a high variation in individual investments. However, in contrast to this literature, in our setting the "prize" is not fixed but determined endogeneously on the market, and we focus on changes in the degree of competition keeping monetary incentives constant.

3 Monetary Incentives to Reduce Costs

There is a widespread consensus that an increase in the number of competitors on a given market reduces the incentives of each individual firm to engage in cost reduction. In a comprehensive survey, Vives (2008, p. 423) summarizes this as follows:

> *"Increasing the number of firms tends to decrease cost reduction expenditures per firm. In Bertrand the result holds for all leading examples (including linear, constant elasticity, constant expenditure, and logit demand systems). In Cournot the result holds in the usual case of outputs being strategic substitutes."*

[3] See e.g. Sheremeta (2011) and Gneezy and Smorodinsky (2006). Dechenaux et al. (2015) offer a detailed overview of this literature.

[4] In a recent study Sheremeta (2015) shows that overbidding is correlated with various personal characteristics, in particular with impulsive behavior. Other related papers on overbidding in contests include Price and Sheremeta (2011) and Brookins and Ryvkin (2014).

The intuition for this result is straightforward. The direct effect of an increase in the number of firms is that the market share of each firm is reduced which makes a cost reduction less profitable. There is also an indirect effect, however, that may work in the opposite direction. Given the costs of all other firms, the cost reduction of one firm leads to an increase of this firm's market share. Depending on the elasticity of demand this increase in market share may become larger (or smaller) as the number of competitors increases. But this indirect effect is (almost) always dominated by the direct effect.

Vives (2008) refers to models in which the firm's owner chooses how much to invest in cost reduction. In this paper we are interested in the incentives of the manager of the firm (who maximizes his own utility rather than firm's profits) to spend effort in order to implement the cost reduction. The manager has to be induced to spend effort by an incentive scheme offered by the firm's owner. Thus, the question is how the optimal incentive scheme and thereby the optimal effort level of the manager changes as the number of competitors increases.

Consider a simple model that motivates the experiments described in the following sections. There are $n \geq 1$ firms each with an initial cost parameter c^H. Suppose first that the owner of each firm chooses an effort level that determines the probability with which a cost reduction to c^L, $c^L < c^H$, will be successful. Let $E\Pi^H(n)$ ($E\Pi^L(n)$) denote the firm's gross expected profit if there are $n \geq 1$ competitors in the market and if the firm's cost parameter is c^H (c^L, respectively). For simplicity we assume that the effort cost function is quadratic and given by

$$G(p) = \frac{K}{2}p^2 \,.^{5} \tag{1}$$

The owner chooses p to maximize

$$\max_p pE\Pi^L(n) + (1-p)E\Pi^H(n) - \frac{K}{2}p^2 \,. \tag{2}$$

The optimal solution to this problem is the efficient effort level

$$p^* = \frac{E\Pi^L(n) - E\Pi^H(n)}{K} \,. \tag{3}$$

[5] It is straightforward to generalize the following analysis to the case of a general convex cost function. See Schmidt (1997).

Thus, the owner chooses a higher effort level the smaller larger $E\Pi^L(n) - E\Pi^H(n)$, i.e. the larger the expected value of a cost reduction. As the number of firms n in the market increases, the cost reducing effort of each owner is reduced if and only if for all $n \geq 1$

$$E\Pi^L(n) - E\Pi^L(n) \; > \; E\Pi^L(n+1) - E\Pi^L(n+1)\,. \tag{4}$$

Vives (2008) shows that in (almost) all models of competition an increase in the number of firms reduces the expected value of a cost reduction and thereby the incentives of each firm to invest.

Suppose now that the owner does not choose the effort himself but hires a manager to do this. The manager is assumed to be risk neutral and wealth-constrained. The optimal incentive scheme for the manager is the solution to the following maximization problem:

$$\max_{p,w^L,w^H} p[E\Pi^L(n) - w^L] + (1-p)[E\Pi^H(n) - w^H] \tag{5}$$

subject to

$$p \in \arg\max_{p' \in [0,1]} p'w^L + (1-p')w^H - \frac{K}{2}p^2\,, \tag{IC}$$

$$pw^L + (1-p)w^H - \frac{K}{2}p^2 \geq 0\,, \tag{PC}$$

$$w^L, w^H \geq 0\,. \tag{WC}$$

The solution to this problem is straightforward. Replacing the incentive constraint (IC) by the first order condition of the manager's maximization problem we get $p = \frac{(w^L - w^H)}{K}$. Substituting p in the agent's participation constraint shows that (PC) is always satisfied if the wealth constraint (WC) holds. The principal wants to minimize the rent that has to be paid to the agent, so he will set $w^H = 0$. Thus the principal's maximization problem reduces to

$$\max_{w} \frac{w^L}{K}[E\Pi^L(n) - w^L] + (1 - \frac{w^L}{K})E\Pi^H(n) \tag{6}$$

which is solved by

$$w^L = \frac{E\Pi^L(n) - E\Pi^H(n)}{2} \tag{7}$$

and

$$p^M = \frac{E\Pi^L(n) - E\Pi^H(n)}{2K}\,. \tag{8}$$

This result shows that the effort of the manager, p^M, is smaller than the efficient effort level, p^*, that the owner would choose himself. More importantly, both effort levels increase monotonically with the expected value of a cost reduction. Thus, if the value of a cost reduction decreases as the number of competitors goes up, then both, the effort chosen by the owner and the effort chosen by the manager decrease.

4 Non-monetary Incentives with Simultaneous Investments

In the following we focus on non-monetary incentive effects that may arise as the number of competitors in a market increases keeping monetary incentives constant. We consider a laboratory experiment of a market that is served by either one, two or four firms. From the previous section we know that the monetary incentives for cost reduction go down as the number of firms increases. Thus, to cleanly identify the non-monetary effects of competition we adjust the incentive scheme of the manager such that his monetary incentives to invest in cost reduction are kept constant (in equilibrium). Thus, if we observe different effort levels in the different treatments they must be due to non-monetary effects.

4.1 Experimental Design and Procedures

Consider a manager who has to decide how much costly effort to invest into a risky project that may reduce the firm's cost. The more he invests the higher is the probability that the cost reduction is successful which increases the profits of his firm. The manager has a monetary incentive to spend costly effort because his compensation is tied to the profits of his company.

We compare three treatments: In the MONOPOLY treatment there is only one manager and one firm. The firm's profit depends only on whether its manager is successful in reducing costs. In the DUOPOLY treatment there are two firms and two managers. Each firm's profit depends not only on the effort of its own manager, but also on the success (or failure) of the competing firm. Finally, in the OLIGOPOLY treatment four firms are competing with each other and the profit of each firm depends on the success of its own manager and on how many other firms have been successful.

In order to keep the monetary incentives constant across treatments we chose the bonus payments that the manager receives as a function of the profit of his firm such that in the unique Nash equilibrium a risk neutral manager chooses the same effort level in all treatments. Note that in the experiment managers compete only by choosing their effort levels. Product market competition is modeled in reduced form and affects the managers' decision problems only via their payoff functions.

In all treatments subjects receive a show-up fee and an initial endowment to cover potential losses. Each manager i has to chose a discrete effort level e_i. The larger his effort, the larger is the probability that his project is successful. The cost of effort is linear and given by $c(e_i) = 2 \cdot e_i$. The benefit of effort is an increased probability of success. Table 1 shows the relationship between investment and probability of success.[6]

Effort	e	0	10	20	30	40	50	60	70	80	90	100
Probability of success (in %)	$p(e)$	0	27	39	47	55	61	67	73	78	83	86

Table 1: Relationship between effort and probability of success

The sequence of events is as follows. In each period managers have to choose their effort levels simultaneously. A random mechanism determines success or failure of each firm according to the chosen probabilities. In the MONOPOLY treatment the manager learns whether he was successful and what his payoff in this period is. In the two competition treatments the manager learns about his own success and whether the competing managers have been successful and what the monetary payoffs of each of the competing managers are.

In all treatments, the game is repeated over 20 periods. In the DUOPOLY and OLIGOPOLY treatments subjects are randomly re-matched in each period. We use a between-subject design in which each participant participates in only one treatment. Before the experiment began, the instructions were read aloud and the subjects had to answer sev-

[6]The numbers in the table have been derived from the quadratic function $e(p) = 133.\overline{3}p^2$. Note also that the maximal probability of success is 86%, so success cannot be guaranteed.

eral control questions.[7] After the last period, subjects answered questions regarding their risk, loss and ambiguity aversion, and filled in a standard questionnaire with demographic information.[8]

We conducted the experiments at the experimental laboratory MELESSA of the University of Munich in 2012/13. We had two sessions per treatment with 20-24 subjects in each session.[9] A total of 130 subjects participated in the experiments. In each duopoly treatment we had three matching groups with six subjects each and one matching group with four subjects. In each oligopoly treatment we had one matching group with 12 and one with 8 subjects. About 61% of all participants were female and the average age was 24.6 years. Sessions lasted for about 75 minutes. Subjects were paid their earnings of all periods plus the outcome of the subsequent tests. On average subjects earned EUR 19.64 (about USD 26 at the time of the experiment), including a show-up fee of EUR 4. During the experiment payoffs where expressed in points (500 points = 1 Euro).

4.2 Theoretical Predictions and Hypotheses

In this section we derive the optimal effort choices in the experiments assuming that managers are fully rational, only interested in their own monetary payoff, and risk neutral.

MONOPOLY Treatment

In the MONOPOLY treatment the monetary payoff function of the manager is given by

$$\Pi^M = 310 + B^M - 2e \tag{9}$$

[7]The instructions of the experiment are included in the Online Appendix.

[8]The test used forf the elicitation of risk aversion is based on Dohmen et al. (2010) and Holt and Laury (2002), the test for loss aversion is based on Gaechter et al. (2010) and Fehr and Goette (2007) and the test for ambiguity aversion is a modified version of Ederer and Manso (2013). For each participant one of these lotteries was randomly chosen for payment at the end of the experiment. The tests can be found in the Online Appendix.

[9]The experiment was computerized using the software z-Tree (Fischbacher, 2007) and subjects were recruited using ORSEE (Greiner, 2004).

where the bonus payment B^M depends on whether or not the manager is successful:

$$B^M = \begin{cases} 290 & \text{if success} \\ 0 & \text{if no success} \end{cases} \tag{10}$$

Thus, the managers expected payoff is

$$E\Pi^M(e) = 310 + 290p(e) - 2e. \tag{11}$$

Lemma 1. *The optimal effort level in the* MONOPOLY *treatment is given by* $e^M = 40$.

All proofs are relegated to the Appendix.

DUOPOLY Treatment

In the DUOPOLY treatment the payoff of manager i depends not only on his own success, but also on whether the competing firm is successful or not. He gets the highest payoff if he is the only one who is successful. If both managers are successful his payoff is higher than if no manager is successful. His payoff is lowest if the other firm is successful while he is not. In the experiment manager i's payoff function is given by

$$\Pi_i^D = 210 + B_i^D - 2e_i\,, \tag{12}$$

where B_i^D depends on the success and failure of managers i and j, $i, j \in \{1, 2\}$, $i \neq j$:

$$B_i^D = \begin{cases} 480 & \text{if } i \text{ succeeds and } j \text{ fails} \\ 200 & \text{if } i \text{ and } j \text{ both succeed} \\ 80 & \text{if } i \text{ and } j \text{ both fail} \\ 0 & \text{if } j \text{ succeeds and } i \text{ fails} \end{cases} \tag{13}$$

Thus, manager i's expected monetary payoff is given by

$$E\Pi^D(e_i, e_j) = 210 + 480p(e_i)(1 - p(e_j)) + 200p(e_i)p(e_j) + 80(1 - p(e_i))(1 - p(e_j)) - 2e_i. \tag{14}$$

The two managers have to choose their effort levels independently. Note that effort levels are strategic substitutes, i.e., the more manager j invests the smaller is the investment incentive for manager i.

Lemma 2. *The unique Nash equilibrium in the* DUOPOLY *treatment is for each manager* i*,* $i \in \{1,2\}$*, to choose* $e_i^D = 40$*.*

OLIGOPOLY Treatment

Finally, in the OLIGOPOLY treatment there are four managers competing with each other. The monetary payoff of each manager i, $i = 1,2,3,4$ is given by

$$\Pi_i^O = 210 + B_i^O - 2e_i \, , \tag{15}$$

where the bonus payments B_i^O depend on the success and failure of manager i and on how many other managers have been successful:

$$B_i^O = \begin{cases} 760 & \text{if } i \text{ succeeds and all others fail} \\ 350 & \text{if } i \text{ and one other manager succeed} \\ 190 & \text{if } i \text{ and two other managers succeed} \\ 90 & \text{if all managers succeed} \\ 40 & \text{if all managers fail} \\ 0 & \text{if } i \text{ fails and at least one other manager succeeds} \end{cases} \tag{16}$$

Thus, manager i's expected monetary payoff is given by

$$\begin{aligned} E\Pi_i^O(e_i, e_j, e_k, e_l) \;&=\; 210 + 760 \cdot [p_i(1-p_j)(1-p_k)(1-p_l)] \\ &+ 350 \cdot [p_i p_j(1-p_k)(1-p_l) + p_i p_k(1-p_j)(1-p_l) + p_i p_l(1-p_j)(1-p_k)] \\ &+190 \cdot [p_i p_j p_k(1-p_l) + p_i p_l p_k(1-p_j) + p_i p_j p_l(1-p_k)] \\ &+90 \cdot [p_i \; p_j \; p_k \; p_l + 40 \cdot (1-p_i)(1-p_j)(1-p_k)(1-p_l) - 2e_i. \end{aligned} \tag{17}$$

Again, the investments of the four managers are strategic substitutes.

Lemma 3. *The unique Nash equilibrium in the* OLIGOPOLY *treatment is for each manager* i*,* $i \in \{1,2,3,4\}$ *to choose* $e_i = 40$*.*

Lemmas 1 to 3 show that the optimal investment in the MONOPOLY treatment and the Nash equilibrium investments in the DUOPOLY and in the OLIGOPOLY treatment are identical. Thus, the standard neoclassical theory that considers only monetary incentive effects gives rise to the following hypothesis:

Hypothesis 1. *In the* MONOPOLY, DUOPOLY *and* OLIGOPOLY *treatments subjects have the same incentives to invest and choose the same effort level of* $e_i = 40$.

4.3 Results

Comparing the average effort levels over all periods across treatments shows significant differences between treatments and large deviations from the Nash equilibrium prediction. The average effort level in the MONOPOLY treatment is 50.4 points. In the DUOPOLY treatment, the average effort is 63.5 points and 59.5 points in the OLIGOPOLY treatment. Figure 1 shows the average effort levels per treatment with 95% confidence interval error bars. Average efforts from period 5–20 are very similar to the average over all periods.

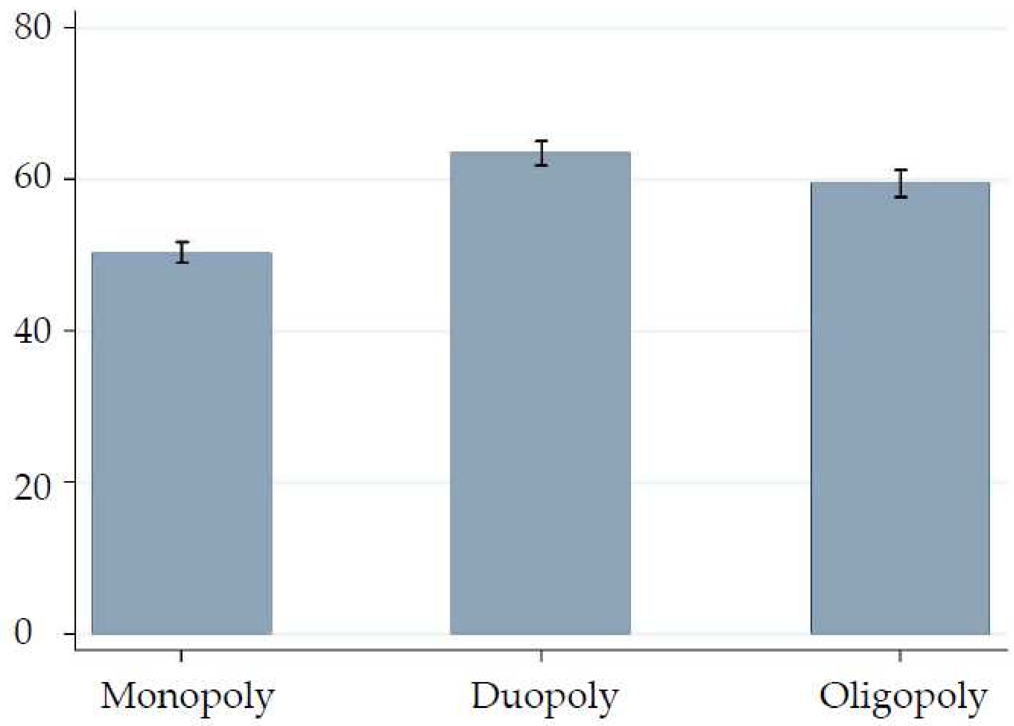

Figure 1: Average effort invested by treatment

Result 1. *In all treatments subjects invest significantly more effort than predicted by Nash equilibrium.*

The result that subjects exert too much effort compared to the profit-maximising equilibrium prediction is highly significant in all three treatments (sign tests, p-values < 0.001).

Result 2. *The average effort invested in the* DUOPOLY *treatment and the average effort invested in the* OLIGOPOLY *treatment are significantly higher than the average effort invested in the* MONOPOLY *treatment.*

A Wilcoxon rank-sum test on the equality of investments (on subject averages) yields a p-value < 0.001 comparing the MONOPOLY and the DUOPOLY treatment and a p-value of 0.0327 comparing the MONOPOLY and the OLIGOPOLY treatment. We also find that the average investment is lower in the OLIGOPOLY treatment than in the DUOPOLY treatment which is consistent with the often observed inverse U-shaped relationship between competition and incentives. However, this difference is not statistically significant (Wilcoxon rank-sum test, $p = 0.1517$).

The treatment difference between the MONOPOLY treatment and the competition treatments is also significant in an OLS regression in which we compare efforts across treatments. Table 2 reports the regression results. The results of regression (1) show that subjects in the DUOPOLY treatment invest on average 13.13 points more than in the MONOPOLY treatment ($p < 0.001$) and that subjects in the OLIGOPOLY treatment invest 9.12 points more than in the MONOPOLY treatment ($p = 0.017$).[10] In regression (2) we cluster by matching group rather than by subject, which has no effect on significance levels. Regression (3) restricts attention to period 1, so there cannot be any effect of repeated interaction. The results are very similar.

The treatment difference between the MONOPOLY treatment and the competition treatments stays significant when we control for *gender, age, risk aversion, loss aversion* and *ambiguity aversion* no matter whether we cluster at the subject or matching group level (regressions (4) and (5), respectively).[11] The only marginally significant control variable is *age*, which has a positive effect on effort. The variable period is not significant, so there is no

[10]The difference between the DUOPOLY and the OLIGOPOLY treatment is also not significant in an F-test of the dummy coefficients in regression (1) of Table 2 ($p = 0.3205$).

[11]See Footnote 8 for the description of the tests we used for the elicitation of risk, loss and ambiguity aversion (included in the Online Appendix). Points range from 0 to 10 in the risk self-assessment and 0 to 7 in the tests. Higher values imply a higher degree of aversion against risk, loss or ambiguity.

	Effort invested				
	(1)	(2)	(3)	(4)	(5)
Duopoly	13.13***	13.13***	10.05**	13.27***	13.27***
	(3.308)	(2.924)	(4.615)	(3.438)	(3.273)
Oligopoly	9.120**	9.120***	14.66***	9.319**	9.319***
	(3.786)	(2.559)	(3.424)	(3.624)	(2.266)
Female				-4.662	-4.662
				(3.155)	(3.122)
Age				0.544*	0.544*
				(0.276)	(0.303)
Risk aversion				1.248	1.248
				(1.266)	(1.073)
Risk aversion quest.				-0.671	-0.671
				(0.956)	(1.065)
Loss aversion				1.124	1.124
				(0.984)	(0.985)
Ambiguity aversion				-1.937	-1.937
				(1.699)	(1.763)
Period				0.0700	0.0700
				(0.0926)	(0.0834)
Constant	50.38***	50.38***	46.09***	40.44***	40.44***
	(2.161)	(2.171)	(2.786)	(11.37)	(11.03)
Restricted to period 1			yes		
Clustered by	sub	mg		sub	mg
Observations	2600	2600	130	2600	2600
Adjusted R^2	0.051	0.051	0.055	0.081	0.081

Notes: The table reports coefficients of OLS regressions. Robust standard errors are clustered and reported in parentheses. Clustering of standard errors by subject (sub), matching group (mg) or session (sess) as listed. By including dummy variables for periods, only the dummy variable for period 1 is slightly significant. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$

Table 2: Experiment 1, Determinants of effort invested

linear time trend in the data. We also ran regressions with dummies for each period, none of which is significant. Figure **??** in the Appendix shows average investments per treatment over periods and also does not indicate a time trend in any of the treatments.

Based on Result 2 we can reject Hypothesis 1. Investments differ significantly between the MONOPOLY treatment and the competition treatments. To examine the differences in the average investments in more detail, Figure 2 displays the distribution of investments in the R&D project. We observe that investments are dispersed over the whole range in all treatments. Some subjects invest nothing of their endowment in the project, others invest their whole endowment of 100 points. High investments of 80 or more points are chosen in only 13.6% of all cases in the MONOPOLY treatment, but in 32.5% of all cases in the DUOPOLY and in 30.1% of all cases in the OLIGOPOLY treatment. The highest possible investment was chosen in less than 2% of all cases in the MONOPOLY treatment compared to 14.3% and 16.8% in the DUOPOLY and the OLIGOPOLY treatment.

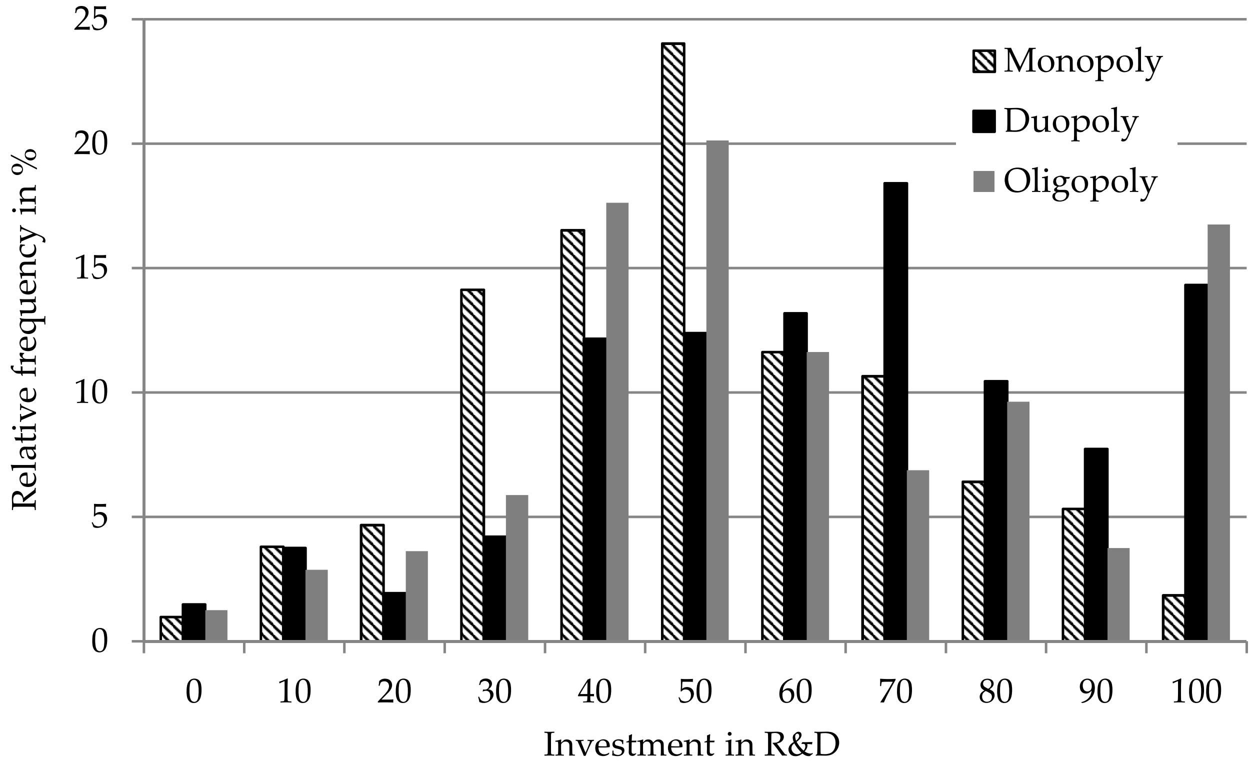

Figure 2: Frequencies of chosen investments in the R&D project by treatment

4.4 Discussion

Results 1 and 2 show that the number of firms in the market has a strong causal impact on behavior. The degree of competition is changed exogenously and subjects are allocated randomly to treatments. Thus, we can exclude reversed causality and self-selection effects. Managers in the competition treatments work much harder than managers in the monopoly treatment even though they face the same monetary incentives. This strongly confirms our hypothesis that competition has an incentive effect that goes beyond the monetary incentives it provides.

What explains the difference in behavior in the monopoly and in the competition treatments? In the experiment with simultaneous investments the monetary incentives to invest are equal across treatments *in equilibrium*. However, because subjects do not follow the Nash equilibrium prediction, the actual monetary incentives to provide effort are not identical across treatments. In fact, as the number of competitors changes several other dimensions of the decision environment change as well that may affect behavior.

First, decision making in the competition treatments involves strategic reasoning which is not the case for the MONOPOLY treatment. The manager in the MONOPOLY treatment faces exogenous uncertainty with known objective probabilities. In contrast, managers in the competition treatments have to form beliefs about the strategies chosen by their opponents. Thus, a possible explanation for the difference in behavior could be that subjects in the competition treatments form mistaken beliefs. However, mistaken beliefs cannot be the full story. Recall that investments in the competition treatments are strategic substitutes and that the average effort invested is about 60 points. For an investment level of 60 to be a best response a subject would have to believe that the expected investment of his opponent is below 20 in the DUOPOLY treatment and below 30 in the OLIGOPOLY treatment. If subjects did believe this, they should have realized over time that this belief is mistaken, that the actual investment levels of their opponents are much higher. Thus, they should have lowered their own effort levels over time. However, we do not observe any time trend in the data. Nevertheless, mistaken beliefs could have had some effect.

Second, competition makes the decision problem more complex by adding additional contingencies. There are only two possible payoffs in the MONOPOLY treatment but four (six, respectively) different payoffs in the DUOPOLY (OLIGOPOLY) treatment. Furthermore, payoffs in the competition treatments have a higher variance and expose the decision maker to more risk. This may affect behavior if subjects are risk averse or suffer from loss aversion. However, the regression analysis in Table 3 shows that neither risk aversion nor loss aversion are significantly correlated with the chosen effort levels. Thus, it seems unlikely that risk and/or loss aversion are driving the results, but again, the current experiment does not allow us to rule out this possibility.

Finally, competition involves social interaction with one or several competitors which is not the case in a monopolistic market. In the competition treatments subjects have to interact with other subjects and can make social comparisons, while managers in the MONOPOLY treatment face a one-person decision problem in social isolation. If subjects are envious, inequality averse, or have any other form of social preferences this may affect their behavior. Furthermore, the literature on contests claims that subjects spend too much effort as compared to the Nash prediction because there is a "joy of winning". In our experiments subjects could "win" in all treatments, but it is possible that they enjoy winning more if they win against another subject than if they win against nature.

In the real world all of these effects play a role. Competition involves strategic interaction and requires the formation of (possibly mistaken) beliefs about the strategies chosen by the opponents, competitive situations are more complex and more risky than situations without competition, and competition involves social comparisons. In the next section we zoom in on one of these differences, social comparisons.

5 Non-monetary Incentives with Sequential Investments: The Role of Social Comparisons

In this section we focus on the effects of social comparisons on the incentives to invest and to succeed. We modify the experiment of the previous section in order to control for all differences between monopolistic and duopolistic markets except for one: on a duopolistic market there is always a second person (the competing manager). This is not the case in a monopoly. Social comparisons with the competing player may give rise to non-monetary incentive effects for two reasons. First, a manager may suffer a utility loss if he falls behind his competitor. For example, this is the case if the manager is inequality averse (Fehr and Schmidt, 1999; Bolton and Ockenfels, 2000) or if he is envious (Bolton, 1991). Second, a manager may enjoy being ahead of his competitor. This has been modelled as a "joy of winning" in the literature on contests (Cox et al., 1992; Sheremeta, 2010). At first glance, these two effects seem to be very similar, but we show below that they give rise to different predictions that can be used to discriminate between them experimentally.

The main new feature of the second experiment is that in the duopoly treatment investments take place sequentially. After manager $D1$ chose his effort level, manager $D2$ observes the effort chosen by his competitor before choosing his own effort level. Thus, $D2$ *knows* the probability with which his competitor will be successful, so he does not have to form beliefs about it.[12] Furthermore, we modify the monopoly treatment in such a way that the decision problems in the new duopoly treatment (DUO-SEQ) and in the new monopoly treatment (MONO-SEQ) are identical. The bonus payment of manager M in the MONO-SEQ treatment now depends on two factors: First, on whether he is successful which depends probabilistically on the effort he chooses, and second on whether market conditions are favorable or unfavorable. His bonus payment if he is successful and the market is favorable is the same as the bonus payment of manager $D2$ in the DUO-SEQ treatment if this manager is successful and manager $D1$ fails. His bonus payment if he is successful and market conditions are adverse is the same as the bonus payment of manager $D2$ in the DUO-SEQ treatment if both managers are successful, and so on.

In the MONO-SEQ treatment manager M *knows* that the probability of unfavorable market conditions in period t is equal to p^t. We conducted the DUO-SEQ treatment first and used the probabilities chosen by the manager $D1$ in period t as the probability of adverse market conditions p^t in the corresponding MONO-SEQ treatment. Thus, the managers in the MONO-SEQ treatment faced exactly the same payoffs and the same probabilities as the corresponding second movers in the DUO-SEQ treatment. The only difference is that in the DUO-SEQ treatment the bad state of the world is that the competing manager is success-

[12] Herrmann and Orzen (n.d.) use a similar method to disentangle envious preferences and strategic uncertainty in an experimental Tullock contest.

ful, while in the MONO-SEQ treatment the bad state is described as unfavorable market conditions.

Finally, we change the bonus payments such that monetary incentives induce an optimal effort level that is independent of the effort chosen by the competitor (independent of the probability of adverse market conditions, respectively). As will be shown below, envy and inequity aversion turn social comparisons into strategic complements while a joy of winning turns them into strategic substitutes. This gives us a neutral baseline to discriminate between these models. We also simplify the decision problem of managers by letting them choose the probabilities of success directly.

5.1 Experimental Design and Parameters

Each subject has an initial endowment of 100 points in each period. Subjects choose the probability of success according to the function displayed in Table 3:[13]

Probability of success in %	p	0	10	20	30	40	50	60	70	80	90
Effort cost	e	0	1	5	11	20	31	45	61	80	100

Table 3: Relationship between probability of success and effort cost

In the DUO-SEQ treatment the sequence of events in each period t is as follows: First, manager $D1$ chooses his probability of success p_1^t and thereby how much effort to invest. Then manager $D2$ learns which probability was chosen. Finally manager $D2$ decides on his success probability p_2^t (and thus his effort investment). The probabilities p_1^t and p_2^t are stochastically independent. Both managers learn the outcomes of both projects and both of their bonus payments.

In the MONO-SEQ treatment there is only one manager M. Before choosing his effort level in period t the manager is informed that the probability of adverse market conditions in this period is equal to p^t. We have chosen $p^t = p_1^t$, i.e. equal to the probability of success chosen by a corresponding manager $D1$ in the DUO-SEQ treatment in period t. Furthermore, the bonus payments in the MONO-SEQ treatment are equal to the corresponding bonus

[13]The table is derived from the quadratic effort cost function $e(p) = 125p^2$.

payments in the DUO-SEQ treatment. Thus, the manager in the MONO-SEQ treatment faces the same probabilities, the same payoffs, and the same information as the corresponding manager $D2$ in the DUO-SEQ treatment. At the end of each period the manager learns whether he was successful and whether market conditions were favorable or not. The experiment runs for 20 periods with random rematching in the DUO-SEQ treatment. We take the complete history of probabilities $\{p_1^t\}$ of one first moving manager in the DUO-SEQ treatment and use them as the probabilities $\{p^t\}$ faced by one manager M in the DUO-SEQ treatment.

We conducted nine sessions for this experiment in 2013, three with the MONO-SEQ treatment and six with the DUO-SEQ treatment. Between 22 and 24 subjects participated in each session, a total of 210 subjects over all sessions. In the DUO-SEQ sessions we had either three matching groups with eight subjects or 2 groups with 8 subjects and 1 group with 6 subjects. Half of the participants in each DUO-SEQ sessions were chosen to be first movers (manager $D1$), the other ones second movers (manager $D2$).[14] About 61% of all participants were female and the average age was 24 years. Sessions lasted about 90 minutes. Subjects were paid their earnings of one period chosen randomly out of the 20 periods plus the outcome of one randomly chosen test in which we elicited subjects' risk, loss and ambiguity aversion.[15] On average, subjects earned EUR 16.44, including a show-up fee of EUR 4. During the experiment, payments were expressed in points (25 points = 1 Euro).

5.2 Theoretical Predictions and Hypotheses

Monetary Incentives in the DUO-SEQ and MONO-SEQTreatments

The payoff function π_i^D of subject $i = 1, 2$ with $i \neq j$ in the DUO-SEQ treatment is given by

$$\Pi_i^D(p_i) = 100 + B_i^D - e_i(p_i) \tag{18}$$

where the bonus payment B_i^D depends on manager i's own success and on whether or not

[14]The experiment was computerized using the software z-Tree (Fischbacher, 2007) and subjects were recruited using ORSEE (Greiner, 2004).

[15]See Footnotes 8 and 11 for a description of these tests.

the other manager was succesful:

$$B_i^D = \begin{cases} 200 & \text{if } i \text{ succeeds and } j \text{ fails} \\ 100 & \text{if } i \text{ and } j \text{ succeed} \\ 100 & \text{if } i \text{ and } j \text{ fail} \\ 0 & \text{if } j \text{ succeeds and } i \text{ fails} \end{cases} \tag{19}$$

Thus, manager i's expected payoff function is

$$\begin{aligned} E\Pi_i^D(p_i, p_j) &= 100 + p_i(1-p_j)200 + p_i p_j\, 100 + (1-p_i)(1-p_j)100 - 125p_i^2 \\ &= 200 + 100p_i - 100p_j - 125p_i^2 \end{aligned} \tag{20}$$

The monopolistic manager M in the MONO-SEQ treatment has the exact same payoff function. The only difference is that there is no second manager and that p_j is now interpreted as the probability of favorable market conditions.

Note that the payoff function (20) is globally concave. Differentiating (20) with respect to p_i yields the FOC for the optimal effort level

$$\frac{\partial \Pi_i^D}{\partial p_i} = 100 - 250p_i = 0 \tag{21}$$

which implies $p_i^* = \frac{100}{250} = 0.4$. Thus we get:

Lemma 4. *In the* DUO-SEQ *and the* MONO-SEQ *treatment it is a dominant strategy for each manager i, $i \in \{1, 2, M\}$, to choose $p_i = 0.4$.*

Hence, the standard neoclassical model predicts:

Hypothesis 2. *Manager $D2$ in the* DUO-SEQ *treatment and manager M in the* MONO-SEQ *treatment choose the same effort level, $p_2 = p^M = 0.4$. Furthermore, the effort of manager $D2$ is independent of the probability of success chosen by manager $D1$ and the effort of manager M is independent of the probability of unfavorable market conditions.*

Non-monetary Incentives and Social Comparisons

How are the incentives of a duopolistic managers affected by social comparisons? Suppose first that a manager in the duopoly treatment experiences a "joy of winning", i.e. his utility is increased by Δ_w if he is successful while his opponent fails. In this case his expected utility is

$$U_i^D \;=\; 200 + 100p_i - 100p_j + p_i(1-p_j)\Delta_w - 125p_i^2 \tag{22}$$

Differentiating with respect to p_i yields the FOC

$$\frac{\partial U_i^D}{\partial p_i} = 100 + (1-p_j)\Delta_w - 250p_i = 0 \tag{23}$$

which implies

$$p_i^* = \frac{100 + (1-p_j)\Delta_w}{250} \tag{24}$$

Note that with a joy of winning the manager no longer has a dominant strategy. His optimal effort level is now a decreasing function of the effort level chosen by his competitor, i.e. effort levels are strategic substitutes.

Suppose now that a manager in the duopoly treatment experiences a utility loss from falling behind, i.e. his utility is decreased by Δ_L if he fails while his opponent is successful.[16] Now his expected utility is

$$U_i^D \;=\; 200 + 100p_i - 100p_j - (1-p_i)p_j\Delta_L - 125p_i^2 \tag{25}$$

Differentiating with respect to p_i yields the FOC

$$\frac{\partial U_i^D}{\partial p_i} = 100 + p_j\Delta_L - 250p_i = 0 \tag{26}$$

which implies

$$p_i^* = \frac{100 + p_j\Delta_L}{250} \tag{27}$$

Hence, if there is a utility loss from falling behind, the manager's optimal strategy again depends on the effort chosen by his opponent, but now his optimal effort level is increasing with the effort level chosen by his competitor, i.e. effort levels are strategic complements.

Thus, models of social comparison give rise to the following predictions:

[16]The model of inequity aversion by Fehr and Schmidt (1999) assumes that this utility loss is proportional to the payoff difference in this state of the world, i.e. $\Delta_L = \alpha \cdot 200$. Furthermore, the model assumes that a player may also dislike (to a lesser extend) inequality to his advantage, i.e. he experiences a utility loss $\beta \cdot 200$, $0 \leq \beta < \alpha$, if he is successful while his competitor fails. This model yields the same qualitative result that effort levels are strategic complements.

Hypothesis 3. *Social comparisons have a positive non-monetary incentive effect on effort provision. In the* DUO-SEQ *treatment, if managers are motivated by a joy of winning, then their efforts are strategic substitutes, if they are motivated by a fear of falling behind, their efforts are strategic complements.*

5.3 Results

The average chosen probability of success is 53.6% for duopolist D2 in the DUO-SEQ treatment and 52.6% for the monopolist in the MONO-SEQ treatment. As in the experiment with simultaneous investments, we observe that subjects invest more than the equilibrium prediction in both treatments (sign tests, p-values< 0.001). The dominant strategy of $p = 0.4$ is chosen in only 12.5% of all investment decisions in the MONO-SEQ treatment and in 9.5% of all investment decisions in the DUO-SEQ treatment.

Result 3. *In both treatments, subjects on average invest significantly more than predicted by Hypothesis 2.*

The effort chosen by the manager is higher in the DUO-SEQ treatment than in the MONO-SEQ treatment, but the difference is small and statistically not significant. A Wilcoxon rank-sum test on equality of the chosen probability of success in the MONO-SEQ treatment and the DUO-SEQ treatment cannot be rejected (average over periods and subjects in a treatment, $p = 0.47$). This is confirmed by the simple OLS regression (1) reported in Table 4 where we regress the chosen success probabilities on the treatment variable *monopoly* only.

Result 4. *On average, subjects invest more in the* DUO-SEQ *than in the* MONO-SEQ *treatment, but the difference is not statistically significant.*

The fact that the investment level in the DUO-SEQ treatment is significantly higher than 0.4 is consistent with a positive non-monetary incentive effect of social comparison. However, the fact that there is no significant difference in average investment behavior between the DUO-SEQ and the MONO-SEQ treatment suggests that social comparisons alone cannot explain the statistically highly significant difference in investment behavior observed in the

	Probability chosen					
	(1)	(2)	(3)	(4)	(5)	(6)
Mono	-1.029	15.05***	15.05***	28.34**	15.35***	15.35***
	(2.647)	(4.754)	(4.367)	(9.811)	(4.727)	(4.153)
p_1, p, resp.		0.0940*	0.0940**	0.314***	0.0975*	0.0975**
		(0.0545)	(0.0439)	(0.0884)	(0.0530)	(0.0375)
Mono × p_1, p, resp.		-0.305***	-0.305***	-0.601***	-0.309***	-0.309***
		(0.0809)	(0.0742)	(0.174)	(0.0800)	(0.0714)
Female					5.792**	5.792*
					(2.607)	(3.109)
Age					0.284	0.284
					(0.240)	(0.257)
Risk aversion					-1.735	-1.735
					(1.146)	(1.103)
Risk aversion quest.					0.0947	0.0947
					(0.859)	(0.900)
Loss aversion					-1.198	-1.198
					(0.791)	(0.834)
Ambiguity aversion					-1.604	-1.604
					(1.611)	(1.651)
Period					0.120	0.120
					(0.0795)	(0.0775)
Constant	53.64***	48.68***	48.68***	35.72***	52.90***	52.90***
	(1.933)	(3.418)	(2.848)	(6.861)	(9.870)	(9.336)
Restricted to period 1				yes		
Clustered by	sub	sub	mg	sess	sub	mg
Observations	2800	2800	2800	140	2800	2800
Adjusted R^2	0.000	0.022	0.022	0.058	0.059	0.059

Notes: The table reports coefficients of OLS regressions. Robust standard errors are clustered by subject and reported in parentheses. Clustering of standard errors by subject (sub), matching group (mg) or session (sess) as listed. By including dummy variables for periods, only the dummy variables for period 1,2 and 13 are slightly significant. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$

Table 4: Experiment 2, Determinants of effort invested

first experiment with simultaneous investments. Thus, strategic uncertainty and complexity seem to be mainly responsible for the effect of an increase of the number of firms on observed behavior in the first experiment.

However, a Chi-test on independence of the distributions of the probabilities of success p^M and p_2 between the treatments rejects the hypothesis of equal investment distributions across treatments ($p < 0.001$). Furthermore, the treatment difference becomes significant in OLS regression (2)-(6) where we control for the probability of success of manager $D1$, respectively the probability of adverse market conditions. These regressions show that in the DUO-SEQ treatment (which is taken as the baseline) the effort p_1 of manager D1 has a significantly *positive effect* on manager D2's effort provision. Furthermore, the treatment variable *monopoly* has a highly significant and positive effect on the chosen probability, while *monopoly* interacted with p has a highly significant negative impact. This result holds no matter whether we cluster by subject (regression (2)) or by matching group (regression (3)), or whether we restrict attention to the first period only (regression (4)) in order to exclude any potential effects of repeated interaction. Regressions (5) and (6) show that the difference in the investment behaviour between treatments is still significant and almost unchanged if we control for gender, age, measures of risk aversion, loss aversion, and ambiguity aversion. Only the control variable *female* has a marginally significant and positive effect on the chosen probability. There also seems to be no time trend in the data.[17]

Result 5. *In the* DUO-SEQ *treatment the effort chosen by duopolist D2 depends positively on the effort chosen by duopolist D*1*. This effect is highly significant. It is consistent with models of social comparison that assume a utility loss if manager D2 fails while his competitor succeeds. It is not consistent with a joy of winning.*

This result shows that competition turns the efforts chosen by competing managers into strategic complements. Subjects try harder the more effort is spent by their competitors. In contrast, an increase in the probability of unfavorable market conditions (which is materially equivalent to more effort of the competitor) has a discouraging effect and induces a monopolistic manager to reduce his efforts.

[17]This is confirmed by a regression in which we included dummy variables for each period. Figure A.2 in the Appendix shows average investments per treatment over periods and also does not indicate a time trend in any of the two treatments.

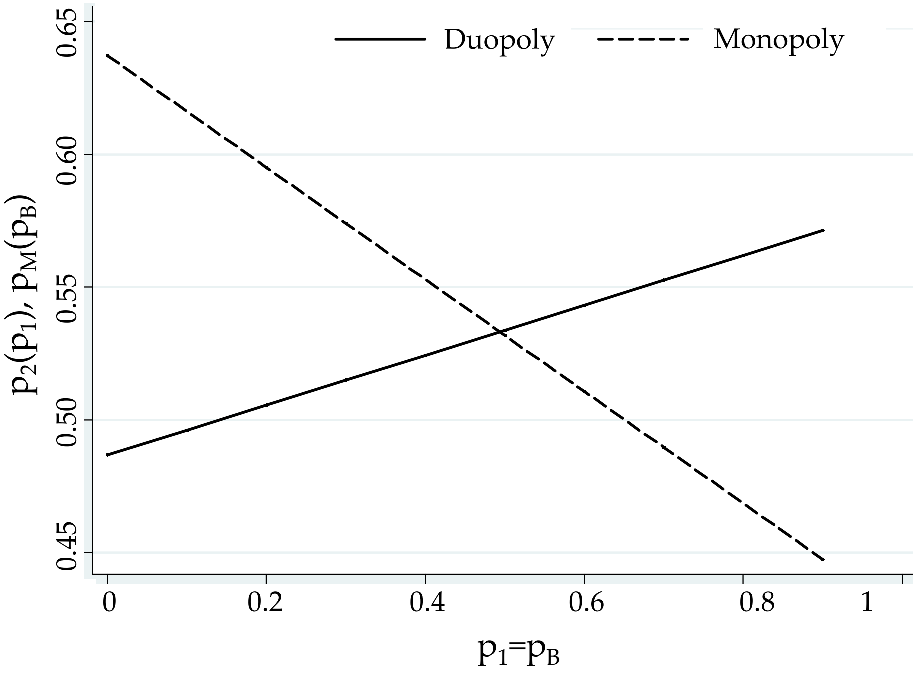

Figure 3: Reaction functions $p_2(p_1)$ and $p_M(p)$

Regression (2) of Table 4 estimates the following reaction functions $p_2(p_1)$ of manager $D2$ and $p_M(p)$ of manager M, which are depicted in Figure 3:

$$p_2(p_1) = 0.4868 + 9.4\, p_1 \tag{28}$$

$$p_M(p) = 0.6373 - 21.1\, p \tag{29}$$

Recall that in both treatments the marginal *monetary* return of effort is unaffected by the probability of success of the competitor and the probability of adverse market conditions, respectively (see Lemma 4). However, subjects react very differently in the two treatments. In the DUO-SEQ treatment, the higher probability of success of the competitor motivates duopolist $D2$ to increase his investment. This effect is reversed in the MONO-SEQ treatment, in which manager M is discouraged by a high probability of adverse market conditions and invests less.[18]

It is worth noting that the average effort chosen by duopolist D1 is 52.75 which is very close to (and not statistically different from) the average effort of duopolist D2. If effort levels are strategic complements, they reinforce each other. Thus, the fact that duopolists 2 are investing more gives an additional incentives to duopolists 1 to invest more as well, and vice versa.

5.4 Discussion

The two experiments with simultaneous and sequential investments are not directly comparable, because we had to change several features of the experimental design at the same time. Nevertheless, because the difference in average effort levels in MONO-SEQ and DUO-SEQ are not statistically different, the experiment with sequential investment suggests that social comparisons alone cannot explain why an increase in the number of competitors has a large effect on average effort in the first experiment with simultaneous investment. Other factors such as strategic uncertainty, complexity or risk aversion are likely to play a role, too. However, social comparisons do have a significant and economically important impact on behavior. A duopolist reacts to a higher effort level of his competitor by spending significantly more effort himself. The fact that investments are strategic complements suggests that subjects do not want to fall behind rather than like to be ahead. This is consistent with models of inequality aversion or envy, but not with a joy of winning.

6 Conclusions

The experiments reported in this paper show that there are non-monetary incentive effects of competition. The number of firms in the market has a causal and highly significant effect on behavior even though the monetary incentives to invest are unchanged (because of the

[18]It is possible that the negative effect in the MONO-SEQ treatment is is due to cognitive limitations. The term "unfavorable market conditions" suggests correctly that expected profits are lower. Some subjects may have concluded that the returns of their investments are also reduced, even though the marginal incentive to invest is independent of the probability of unfavorable market conditions. This issue does not arise in the DUO-SEQ treatment in which market conditions are never mentioned.

design of the experiments). The first experiment (with simultaneous investments) focuses on the overall effects of competition. It shows that competition induces experimental subjects to invest more than in a monopolistic situation even if the monetary incentives are identical. However, competition naturally changes the environment of a decision maker in several respects. First, with competition there is strategic interaction, so agents have to form beliefs about the strategies of their opponents. Second, in a competitive environment decision problems are more complex and more risky. Finally, with more competitors there is more scope for social comparisons which do not play a role in the case of a monopoly. All of these effects may partially explain why the number of firms affects managerial incentives even if there are no monetary incentives in equilibrium.

In the second experiment (with sequential investments) we focus on social comparisons – controlling for all other possible factors of influence. We find that in this case moving from a monopoly to a duopoly does not induce significantly more effort per se. Thus, social comparisons alone cannot explain the strong positive effect of additional competitors in the first experiment. However, the competitive situation turns investments that are (from a monetary perspective) strategically neutral into strategic complements, i.e. subjects invest more effort the more effort is invested by their competitors. In contrast, in a monopoly situation subjects invest less if the probability of adverse market conditions increases, even though this is payoff equivalent to a higher investment of a competitor in the duopoly market. Thus, managers in a duopoly try harder if they are challenged by a competitor, while the challenge of an unfavorable market induces a manager of a monopolistic firm to be more complacent.

These non-monetary incentive effects have been largely ignored in the literature so far. However, they could play an important role for our understanding of why many empirical papers find a positive or an inverted U-shaped relationship between competition and measures of productivity and innovation. Theory suggests that increasing the number of firms in a market reduces the monetary incentives of each firm and (via the optimal incentive scheme) of the firm's manager to invest in cost reduction. Thus, it is possible that in some industries the negative monetary incentive effects of competition is dominated by the positive non-monetary effects.

These results are only a first step. Much more research is required in order to better understand how competition affects behavior, how these effects can be modelled, and how important these effects are in real world settings.

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