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Is there a U-shaped relation between competition and investment?*

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ABSTRACT: We consider a two-stage game with cost-reducing investments followed by a linear differentiated Cournot duopoly. With competition inversely parameterized by the extent of product differentiation, investment in the subgame-perfect equilibrium is typically minimal for intermediate levels of competition. Laboratory experiments partly confirm the U-shape in a reduced one-stage version of the game. In the two-stage version, there is no evidence for positive effects of moving from intermediate to intense competition.

JEL Classification: C92, L13, O31.

Keywords: Investment, intensity of competition, experiment, reciprocity.

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1 Introduction

A large game-theoretic literature deals with strategic investment decisions in oligopolies. One important class of papers investigates the relation between the intensity of competition and process innovation, typically using two-stage games. This relation is generally regarded as ambiguous; depending on the precise definition of competitive intensity and the particular oligopolistic environment, competition may have positive or negative effects on investment (Gilbert 2006; Schmutzler 2007; Vives 2008). In a general equilibrium setting, it has been argued that an inverse U-shaped relation is also conceivable (Aghion et al., 2005). This paper provides the surprising result that in a simple partial equilibrium framework a direct (non-inverted) U-relation between competition and investment can emerge naturally, and it investigates the claim in laboratory experiments.

In the first stage of our fairly standard model, duopolists choose cost-reducing investments; in the second stage, they engage in differentiated Cournot competition with linear inverse demand functions $p_i = a - q_i - bq_j$, where $a > 0$ and $b \in [0, 1]$. An increase in competition corresponds to a reduction in product differentiation (higher value of b). In the polar case $b = 0$ there are essentially two monopolies; $b = 1$ corresponds to a homogeneous Cournot market.

For symmetric firms, that is, identical initial marginal costs, it turns out that an increase in competition reduces investments as long as product differentiation remains sufficiently strong; as products become sufficiently similar, however, a further increase in competition raises investments. This U-shape becomes even more pronounced for firms that are initially more efficient than the competitors. However, if a firm lags substantially behind the competitor, increasing intensity of competition has an unambiguously negative effect on investments.

The paper is part of a larger research project that analyzes the effects of competition on innovation. The theoretical foundations and the economic intuition for the project have been clarified in Schmutzler (2007), a paper which shows what lies behind the ambiguous results on the relation between competition and innovation in a general two-stage setting. It provides a decomposition of the total effect of competition on R&D investments into four components which systematically go into different directions. Applying these general considerations to the specific model of the present paper, the U-shape we identify comes from the interplay of two effects: (i) the negative

effect that competition reduces profit margins and thereby the incentives to increase equilibrium demand by lowering marginal costs, and (ii) the positive effect that competition increases the effect of lower marginal costs on own equilibrium demand. Of course, while the existence of these countervailing effects suggests the possibility of a non-monotone relationship, it does not guarantee the U-shape. For this particular form of non-monotonicity, it is important that profit margins turn out to be a convex function of the competition parameter. Intuitively, as competition is intense, profits margins are already quite small, so the adverse effect of further competition on margins (i) is small, and the positive effect (ii) dominates.

In view of the large number of theoretical models that do *not* generate a U-shaped relation between competition and investment and the clear intuition for such ambiguity, we do not claim that we have exposed a general regularity. Rather, we want to highlight the theoretical possibility of a U-shaped relation in a non-pathological setting. For the broader research agenda, the existence of this possibility strongly reinforces the point that searching for a general relation between competition and investment may be in vain. Rather, it would appear more promising to identify the circumstances leading to each kind of relation.

The most transparent way to provide empirical support for a result that relies on a particular model of competition is to use a laboratory experiment. We considered both symmetric and asymmetric settings. In both cases, we compared the investments for weak competition ($b = 1/10$) to intermediate competition ($b = 2/3$) and intense competition ($b = 1$). We also distinguished treatments where both stages of the game were played out from treatments where only the first stage was played, and, for each combination of investments, subjects obtained the payoffs of the Nash equilibrium of the corresponding subgame. The latter simplified treatments provide some evidence for the main prediction: In the symmetric case and for leaders in the asymmetric case, investments are lowest for intermediate competition. However, in both cases, the positive effect of moving from intermediate to intense competition is insignificant. In the symmetric case, this reflects the fact that there is overinvestment relative to the Nash equilibrium which is less pronounced for $b = 1$ than for $b = 2/3$. In the asymmetric case, leaders invest less than in the Nash equilibrium, but this effect is stronger for $b = 1$. For laggards, the predicted negative effect of competition on investment holds, but it is also less pronounced: Laggards overinvest, and more so for $b = 1$.

Partly, these observations reflect best responses to wrong beliefs that play-

ers have about the investments of the other subjects. For laggards, however, substantial overinvestment remains even after taking into account mistaken beliefs. As investment imposes negative externalities on competitors, overinvestment may reflect social preferences: Laggards may deliberately overinvest to hurt leaders which are exogenously in an advantageous position.

More substantial deviations from the theoretical predictions arise in the two-stage treatments, where we only consider the symmetric cases with $b = 0.67$ and $b = 1$. There, contrary to the one-stage treatments, subjects underinvest both for intermediate and for intense competition. The deviation is more pronounced for intense competition, so that moving from intermediate to intense competition has no significant effect on investments. As to the second stage, for intense (but not for intermediate) competition, the output tends to be lower than in equilibrium. Also, subjects do not generally respond to higher investments of competitors with lower own outputs, contrary to predictions for subgame equilibria.

The observations can be jointly explained by reference to reciprocity and efficiency concerns. Reciprocity implies that subjects respond to uncooperative acts (high investments) by being uncooperative themselves (choosing high outputs). Anticipating the existence of reciprocal subjects, even selfish subjects will choose low investments. Efficiency concerns help to explain why the downward deviations in both stages are more pronounced for intense competition: With intense competition, subjects can benefit more from colluding, that is, refraining from actions (high investments and outputs) that impose negative externalities on competitors. Another explanation of the underinvestment might be anticipated collusive behavior in the output stage: If subjects expect to collude on low output levels in the future, they should rationally reduce first-stage investments.¹

While the theoretical analysis of oligopolistic investment models is well established, the experimental analysis is still in its infancy. Except for two early contributions of Isaac and Reynolds (1988, 1992) which deal with patent races and show that an increase in competition in the sense of a larger number of firms has a negative effect on investments, most of the literature has only developed recently. Moreover, to the extent that the literature deals with the effects of competition on investment, it considers only the role of the number of firms and of switches from Cournot to Bertrand competition. Darai et al.

¹For a related discussion of experimental evidence in two-stage investment games with spillovers, see Goeree and Hinlopen (forthcoming).

(2009) consider homogenous goods models with two and four firms. Consistent with the earlier literature, they show that a larger number of firms lowers investments for both Cournot and Bertrand competition, whereas increasing competition in the sense of moving from Cournot to Bertrand has a positive effect on investments. Halbheer, Fehr, Götte and Schmutzler (2007) also consider a Cournot investment game, but they do not deal with the effects of competition on investment. Instead, they ask whether investments tend to increase pre-existing asymmetries between firms. As theory predicts, this is indeed the case.²

Some papers consider related two stage games. For instance, Engelmann and Normann (2007) consider the strategic trade policy model of Brander and Spencer (1985). Like in our model, first-period actions (government subsidies) are aggressive in that they induce second-period actions (higher own firm outputs) that impose negative externalities on opponents, which triggers desirable behavior of opponents because outputs are strategic substitutes. The experimental results are also similar in that first period-actions are not as high as in equilibrium. Similar results are obtained by Huck et al. (2004a) who consider the delegation game of Ferschtman and Judd (1987), where firm owners can choose between output-based contracts and profit-based contracts before letting managers take decisions. Finally, Oechssler and Schuhmacher (2004) show that, in the setting of Brander-Lewis (1986) Cournot duopolists use less debt than predicted.

Thus, our results for the two-stage game share with this literature the observation that top-dog strategies appear to be considerably less important than theory would predict in two stage games where the second-stage has strategic substitutes. Compared to the literature, however, our analysis makes an important additional contribution: By allowing for a clean comparison of the two stage game with the reduced one-stage version where there is overinvestment, we can provide evidence that the absence of overinvestment in the two-stage game actually results from anticipated effects on second-period behavior.

We proceed as follows. Section 2 contains the model. Section 3 discusses the experimental design. Sections 4 and 5 contain the results for the treat-

²Suetens (2005) deals with investments in a Cournot-Duopoly. Suetens (2008) considers a R&D stage and a pricing stage to test whether R&D cooperation enhances price collusion. She deals with two treatments (no vs. complete spillovers) and finds out that, in general, prices are between the Nash equilibrium and the cooperative level. However, neither paper deals with the effects of increasing competition on investments.

ments with one and two stages, respectively. Section 6 concludes.

2 The Model

Consider a two-stage game. In stage 1, firms $i = 1, 2$ with initial marginal costs $c_i^0 > 0$ simultaneously choose investments $y_i \in [0, c_i^0)$, resulting in marginal costs $c_i = c_i^0 - y_i$.³ Investment costs are given by ky_i^2 , where $k > 0$.⁴ In stage 2, firms simultaneously choose quantities, that is, they compete à la Cournot. Suppose without loss of generality that $c_1^0 \leq c_2^0$. If the inequality holds strictly, then firm 1 is the *leader* and firm 2 is the *laggard*. Otherwise, firms are *symmetric*. The inverse demand functions are given by

$$p_i = a - q_i - bq_j, \quad i \neq j, \quad (1)$$

where $a > 0$ and $b \in [0, 1]$. For $b = 0$, equation (1) implies that both firms are monopolists. The other polar case $b = 1$ corresponds to a homogenous Cournot market. Thus, the higher b , the higher the intensity of competition.

From profit maximization, the equilibrium quantity of firm i in subgame (c_i, c_j) is given by⁵

$$q_i(c_i, c_j) = \frac{2(a - c_i) - b(a - c_j)}{4 - b^2}. \quad (2)$$

(2) implies the following profits in subgame (c_i, c_j) :

$$\Pi_i(c_i, c_j) = \left(\frac{2(a - c_i) - b(a - c_j)}{4 - b^2} \right)^2. \quad (3)$$

Using (3), the net profit of firm $i = 1, 2$ is given by

$$\pi_i(y_i, y_j) = \left(\frac{2(a - c_i^0 + y_i) - b(a - c_j^0 + y_j)}{4 - b^2} \right)^2 - ky_i^2, \quad i \neq j. \quad (4)$$

³We suppose both firms have zero fixed costs.

⁴Investments thus have a deterministic effect. However, the results readily generalize to a situation where risk-neutral firms invest into cost-reduction, but are successful with some positive probability. A reduction in this probability has the same effect on equilibrium investments as an increase in investment costs.

⁵For the leader and symmetric firms, (2) is always positive; for the laggard, it is positive as long as $b < \frac{2(a - c_2)}{a - c_1}$.

Maximization of (4) with respect to y_i leads to

$$\frac{\partial \pi_i}{\partial y_i} = \frac{8(a - c_i^0 + y_i) - 4b(a - c_j^0 + y_j)}{(4 - b^2)^2} - 2ky_i = 0. \quad (5)$$

An important implication of this formula is that $\frac{\partial^2 \pi_i}{\partial y_i \partial y_j} < 0$, so that reaction functions with respect to competitor investments are downward-sloping and the game satisfies strategic substitutes.^{6,7}

From (5), equilibrium investments can be derived as:

$$y_i^* = \frac{(4 + 4b^2k - 16k)(a - c_i^0) + (8bk - 2b^3k)(a - c_j^0)}{8k(4 - b^2) - k^2(4 - b^2)^3 - 4}. \quad (6)$$

For symmetric firms, the following simple result emerges.

Proposition 1 *When $c_1^0 = c_2^0$, an increase in competition leads to a reduction in equilibrium investments y_i^* , as long as $b < 2/3$. At $b = 2/3$, investments are minimal. For $b > 2/3$, investments are increasing in b .*

With asymmetric firms, such a general result is hard to obtain. However, numerical calculations show that the U-shaped pattern survives for leaders and for firms that are only slightly less efficient than competitors. For firms that lag far behind their competitors, however, the effect of competition becomes unambiguously negative. For the parameters we use in the experiment, these properties hold. Many other simulations provide analogous results (Section 3.1). The appendix contains a general result that provides strong intuitive support for the observations from the simulations: We show that, for leaders and firms that are lagging behind only slightly, the relation between competition and the marginal investment incentives ($\left| \frac{\partial \Pi_i}{\partial c_i} \right|$) is U-shaped, whereas it is negative for strong laggards. Though this does not strictly speaking imply the corresponding statements on equilibrium investments, it works in this direction.⁸

⁶This property is very common in investment games without knowledge spillovers, and it is unrelated to the fact that the second-stage Cournot games satisfies strategic substitutes.

⁷Further, note that the second-order condition is fulfilled if $k > \frac{4}{(4-b^2)^2}$.

⁸Schmutzler (2007) discusses these issues for general investment games. A positive (negative) relation between competition and investment incentives means that the para-

The U-shape reflects the interaction of two countervailing effects.⁹ First, in the differentiated Cournot model, as in most reasonable cases, increasing competition has a negative effect on the profit margin $p_i - c_i$ that a firm can command in equilibrium. Hence, the positive effect on equilibrium demand that comes from a cost-reducing investment is less valuable. This points to a negative effect of competition on marginal investment incentives. However, as competition increases, the positive effect of increasing efficiency on a firm's demand becomes more pronounced, suggesting a positive relation between competition and marginal investment incentives. The non-monotone relationship between competition and investment reflects the interaction of these two effects. Specifically, the driving force behind the U-shape is the fact that the profit margin is a convex function of the competition parameter. Hence, the negative effect of competition on margins is less pronounced when competition is already intense, and the positive effect dominates.

To understand the difference between leaders and laggards, note that, while both effects are still present for strong laggards, the positive effect becomes small for a firm that is much less efficient than the competitor: It has a much lower profit margin, so that it benefits much less from an increase in demand. When the firm becomes so inefficient that it barely survives in the market (the profit margin approaches zero), the gain from increasing demand approaches zero.

For the sake of completeness, we mention the following well-known result.

Proposition 2 *If $c_1^0 < c_2^0$, then $y_1 > y_2$.*

The result follows from (6), using the second-order condition. It actually holds for more general investment models. This follows from Theorem 1 in Athey and Schmutzler (2001), which gives general conditions for games with strategic substitutes guaranteeing that one firm invests more than another one. Intuitively, because $\frac{\partial^2 \pi_i}{\partial y_i \partial c_i^0} < 0$ firms with lower initial costs have greater investment incentives. Because of the strategic-substitutes property $\frac{\partial^2 \pi_i}{\partial y_i \partial y_j} <$

meter shifts reaction curves outwards (inwards), suggesting higher (lower) investments. However, when (i) investments are strategic substitutes and (ii) firms are initially asymmetric, there is not necessarily a one-to-one relation between effect on marginal investment incentives and on equilibrium effects.

⁹When investment incentives are increasing in the competition parameter, investments in the subgame perfect Nash equilibrium of the game are also increasing under fairly weak additional conditions (see Schmutzler, 2007).

0, these effects are mutually reinforcing: If a competitor invests more, this has an additional negative effect on own investments.¹⁰

Finally, we briefly compare the results of this section to those of a model with price competition, which is otherwise unchanged. With price competition, the U-shaped relation only holds for strong leaders; for symmetric firms and laggards, it becomes negative. It is also still true that leaders always invest more than laggards.¹¹

3 The Experiment

3.1 Choosing the Parameters

In the experiment, we choose $a = 50$, $k = 1$. For the symmetric case, we set $c_1^0 = c_2^0 = 21$; for the asymmetric case, $c_1^0 = 21$; $c_2^0 = 25$. Figure 1 plots the equilibrium investments for all $b \in [0, 1]$. As argued in Section 2, there is a U-shaped relation between the intensity of competition and investments for leaders and symmetric firms, whereas competition has a negative effect for the laggard. The pattern holds much more generally.¹²

We restricted investment choices to $y_i \in \{0, 1, \dots, 14\}$. We considered three values of b , which correspond to different intensities of competition: $b = 1/10$ (weak), $b = 2/3$ (intermediate), and $b = 1$ (intense). Thus, according to Figure 1 an increase of competition from weak to intermediate leads to a reduction of investments in all cases, whereas an increase from intermediate to intense competition only increases the investments of symmetric firms and leaders.¹³ The predicted equilibria for our parameter values are summarized

¹⁰However, an important countervailing effect would be introduced by generalizing the cost function to $K(y_i, c_i^0)$, such that marginal investments costs are decreasing in c_i^0 . Then, even though investments are more rewarding for leaders, they are less costly for laggards, and it is no longer clear who invests more. However, this modification does not affect the effects of competition on investments, as long as cost functions are independent of θ .

¹¹See Schmutzler (2007) for more details and for an intuitive discussion of the differences.

¹²For instance, the same qualitative picture emerges for all combinations of a , c_1^0 and c_2^0 where $a - c_1^0 = 29$ for the leader and $a - c_j^0 \in \{21, \dots, 28\}$ for the laggard. A U-shape for the laggard requires the laggard to be even closer to the leader than $a - c_j^0 = 28$.

¹³Of course, these qualitative properties could have been obtained by other choices of b . Our choice was guided by two considerations. First, we wanted to choose parameters so as to maximize the distance between predicted investments in the low and intermediate competition case as well as in the intense and intermediate cases. In itself, this would have led to parameters $b = 0$, $b = 2/3$, and $b = 1$. Second, however, we wanted to avoid the

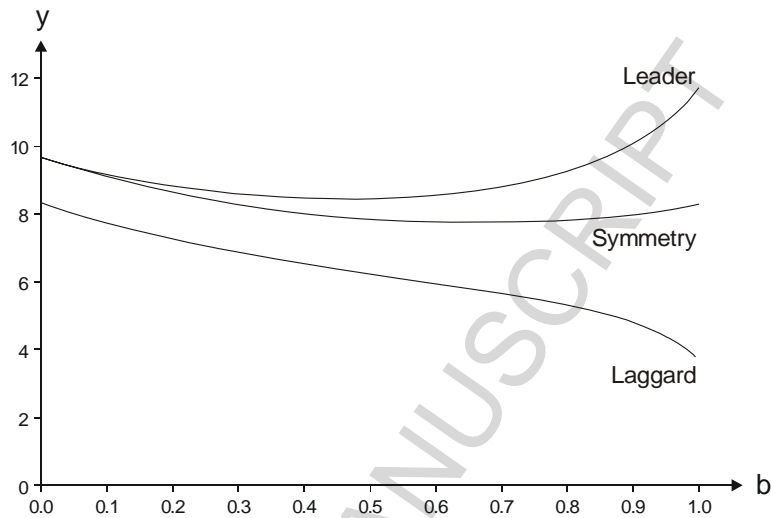


Figure 1: Equilibrium investments

in the Table 1.

Cost Structure		Predictions		
own costs	competitor costs	$b = 0.1$	$b = 0.67$	$b = 1$
21	21	9.09	7.75	8.29
21	25	9.18	8.69	11.71
25	21	7.75	5.75	3.71

Table 1: Equilibrium investment predictions

In a first set of treatments, we did not model the product market stage explicitly. Instead, for each investment profile, players earned the unique Nash equilibrium profits of the corresponding subgame, net of investment cost. This was a deliberate modeling choice ensuring that, whatever deviations from the equilibrium investments might arise, they do not result from anticipated second-period deviations from the product market equilibrium. Nevertheless, for the symmetric case and $b = 2/3$ and $b = 1$, we also considered a full version of the game where both stages were played out explicitly. In this case, outputs were chosen from $q_i \in \{0, 1, \dots, 19\}$.

pure monopoly case $b = 0$ to make the weak competition treatments at least somewhat interesting for subjects as well as outside observers. We therefore chose $b = 0.1$ instead.

3.2 Procedures

We conducted ten sessions at the University of Zurich; see Table 2.¹⁴ Each session had 20 periods, with a switch of the competition parameter after period 10. In different sessions, we reversed the order of the parameterizations to allow for sequencing effects. Eight sessions dealt with the reduced one-stage version of the game. In the asymmetric sessions, the roles of leader and laggard were randomly assigned and there was no switch over the 20 periods. Sessions S1-S4 implemented the symmetric case; A1-A4 dealt with the asymmetric case. Sessions S5 and S6 implemented symmetric two-stage treatments.

Symmetric/Asymmetric	Period 1-10	Period 11-20	Stages
S1/A1	$b = 0.1$	$b = 0.67$	1
S2/A2	$b = 0.67$	$b = 0.1$	1
S3/A3	$b = 0.67$	$b = 1$	1
S4/A4	$b = 1$	$b = 0.67$	1
S5	$b = 0.67$	$b = 1$	2
S6	$b = 1$	$b = 0.67$	2

Table 2: Six symmetric and four asymmetric sessions.

We formed fixed matching groups with 6 players each. The participants were randomly matched into groups of size two within the matching groups.¹⁵ At the end of each period, subjects learned the investment level of the other group member and their own net profit for that period. Moreover, in each period, subjects were asked to give a belief about the investment of the other group member.

In each session, participants received an initial endowment of CHF 20 (\approx EUR 12). Average earnings including the endowment were CHF 38 (\approx EUR 24) for S1 and S2, and CHF 30 (\approx EUR 19) for S3 and S4. In A1 and A2, average earnings were CHF 40 (\approx EUR 25) and CHF 32 (\approx EUR 20) for leaders

¹⁴The sessions took place in 2007 and 2008. Participants were undergraduate students. We did not exclude any disciplines. In eight of the ten sessions, there were 36 subjects. In S3 and S6, there were 30 participants. Sessions lasted about 2 hours each. No subject participated in more than one session. The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007).

¹⁵Consistent with a wide-spread practice, subjects were informed that they were not matched with the same player in each period, but they were not informed about the size of the matching group.

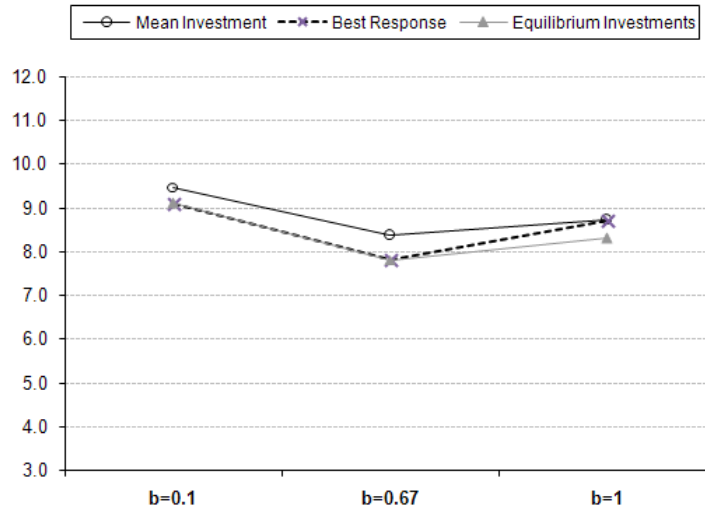


Figure 2: S1-S4: Investments in Periods 1-10

and laggards, respectively. In A3 and A4, leaders earned on average CHF 35 (\approx EUR 22); laggards CHF 24 (\approx EUR 15). For both S5 and S6, average earnings including the endowment were CHF 30 (\approx EUR 19).

4 Results for the one-stage treatments

4.1 The Symmetric Setting

Figure 2 depicts average investments in the first ten periods of S1-S4 for the different parameter values. While it confirms the U-shape, it reveals that there is overinvestment for all values of b .

The figure also addresses a potential explanation for overinvestment, namely that investments are best responses to mistaken beliefs. If subjects believe that their group members invest less than the equilibrium, then, with strategic substitutes, optimal responses to these beliefs would involve overinvestment relative to the equilibrium. Indeed, for $b = 1$, mean investments essentially coincide with the best response to the underestimated beliefs.¹⁶

¹⁶ Average beliefs are approximately 8.7 for $b = 1$, whereas the equilibrium is 9.09.

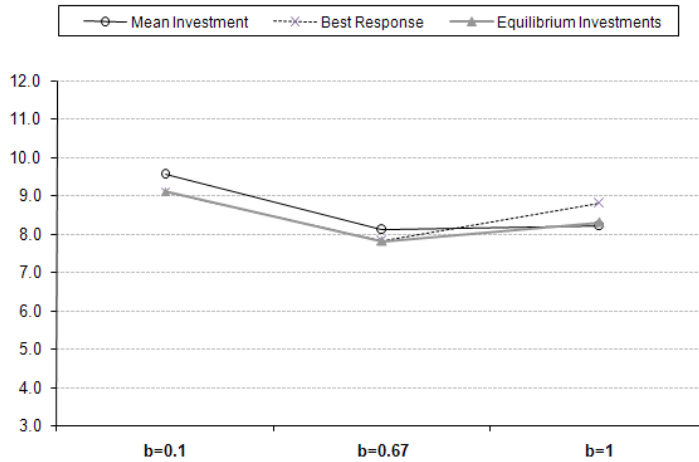


Figure 3: S1-S4: Investments in Periods 11-20

However, we have no explanation for why subjects are underestimating investments. Also, for $b = 0.1$ and $b = 0.67$, there is essentially no difference between equilibrium investments and best responses to beliefs, so that the overinvestment must have other sources. In the last ten periods, for weak and intermediate competition, Figure 3 indicates overinvestment; for intense competition, there is slight underinvestment. In this case, mean investments differ substantially from best responses to beliefs for all values of b .

To test how strong the effects of competition in treatments S1-S4 are, we consider the following OLS model:

$$y_t^i = \beta_0 + \beta_1 \delta_{weak}^i + \beta_2 \delta_{intense}^i + e_t^i, \quad (7)$$

where y_t^i is the investment of subject i in period t ; e_t^i is a residual term. The dummy variable δ_{weak}^i takes the value 1 if $b = 0.1$. Otherwise, it takes the value 0. Similarly, $\delta_{intense}^i$ takes the value 1 if and only if $b = 1$. Estimates are shown in Table 3. Here and in the following regressions, standard errors are corrected for matching group clusters.

Both for periods 1 to 10 and for periods 11 to 20, the coefficient *weak* is positive and significant at the 1%-level. The coefficient *intense* is positive,

	Period 1-10 investment	Period 11-20 investment
<i>const</i>	8.3591*** (0.1906)	8.0917*** (0.1407)
<i>weak</i>	1.1076*** (0.2199)	1.4667*** (0.3199)
<i>intense</i>	0.3437 (0.4485)	0.1050 (0.2016)
<i>N</i>	1380	1380
<i>R</i> ²	0.03715	0.09207

Note: OLS regression with standard errors corrected for matching group clusters in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Effects of the intensity of competition on the investment behavior.

but not significant.¹⁷

A similar OLS model, with the independent variables as in (7), but investment y_t^i replaced by overinvestment $\Delta_t^i \equiv y_t^i - y_i^*$, can be estimated to capture the size and significance of overinvestment. Overinvestment is significant at the 1%-level in both period ranges.¹⁸ Summing up, we obtain:

Result 1 *In S1-S4, there is substantial overinvestment. Investments are lowest for intermediate competition, but the positive effect of intense competition on investment is insignificant.*

4.2 The Asymmetric Setting

In the asymmetric case, we obtain evidence for the main comparative-statics predictions, but, as in the symmetric case, there are notable deviations from equilibrium and substantial differences between early and late periods.

Figure 4 considers the first ten periods. For leaders, there is underinvestment when competition is intense ($b = 1$); for laggards, there is overinvest-

¹⁷Inclusion of blocked period dummies for the first and second half of the respective periods does not change anything substantial; these dummies are not significant. Also, the coefficient remains insignificant if the investments of all 20 periods are considered.

¹⁸The constant coefficients are 0.609 (0.342) for periods 1-10 (11-20).

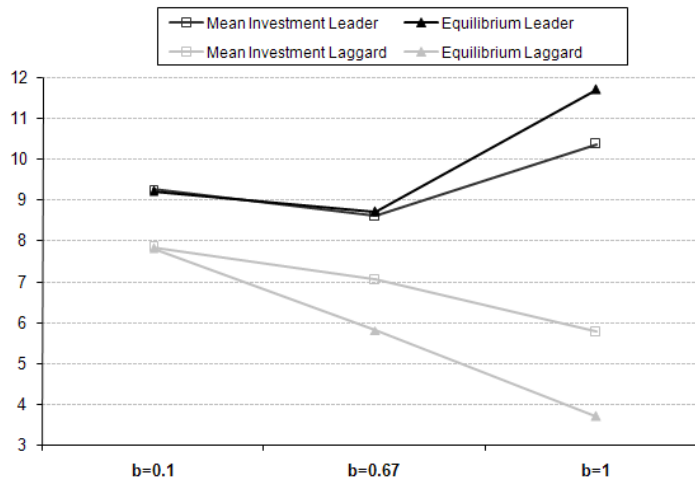


Figure 4: A1-A4: Investments in Periods 1-10

ment when competition is intermediate and intense ($b = 0.67$, $b = 1$). Even so, the difference between leaders and laggards remains highly significant.

These deviations from the equilibrium are related to mistaken beliefs about other players' actions. Leaders believe that laggards invest more than they actually do and thus more than in equilibrium (Figure 5). Given their mistaken beliefs, leaders essentially choose the optimal investment level.¹⁹ For laggards such reasoning can only partly explain the deviations from equilibrium. Laggards believe that leaders invest less than they do and hence less than in equilibrium, but their investments are even higher than the best response to the wrong beliefs. One explanation may be that laggards deliberately hurt leaders who have an exogenous advantage, reflecting social preferences.

In periods 11-20, leaders also invest more than laggards (Figure 6). Moreover, for leaders, there is slight overinvestment when competition is weak and intermediate, and substantial underinvestment for intense competition. For laggards, there is overinvestment for all values of b .

Figure 7 reveals that, for $b = 1$, leaders believe that laggards invest more

¹⁹Recall that own investments and beliefs about other players' investments are strategic substitutes, so that overestimation of competitor's investments leads to underinvestment.

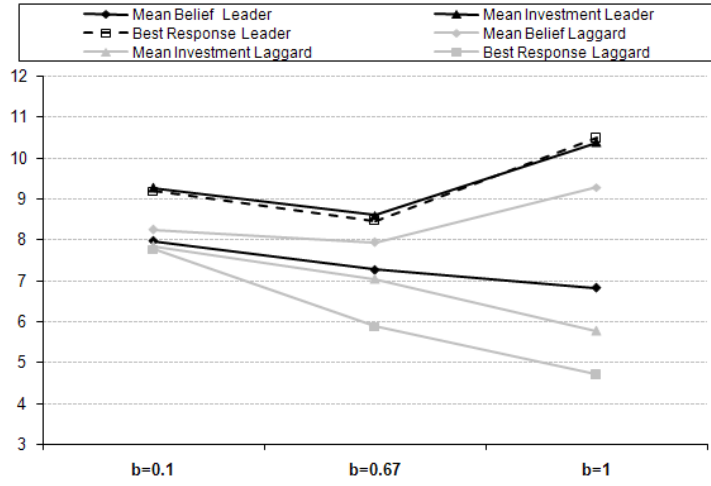


Figure 5: A1-A4: Investments and beliefs in Periods 1-10

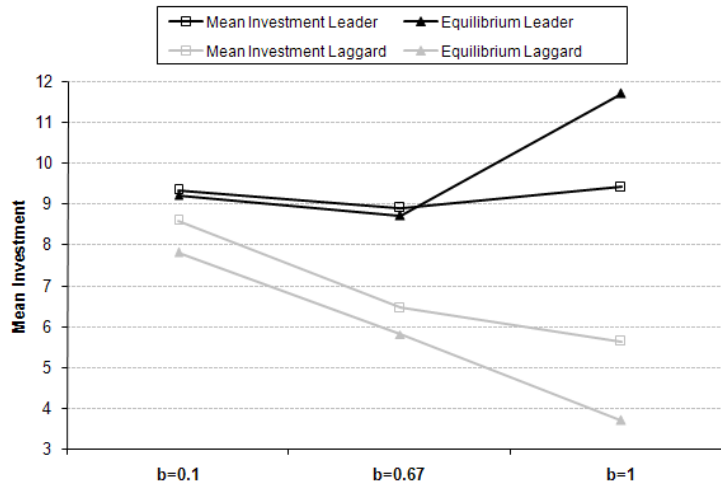


Figure 6: A1-A4: Investments in Periods 11-20

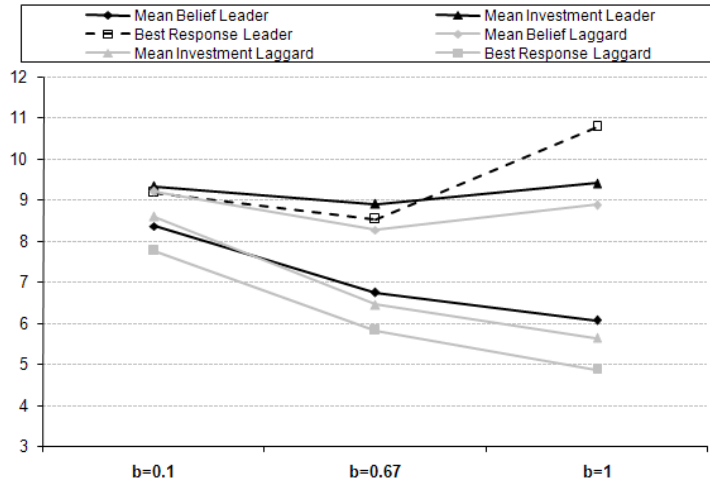


Figure 7: A1-A4: Investments and beliefs in periods 11-20

than they actually do and thus more than in equilibrium. However, this does not fully explain the underinvestment behavior. Investments of leaders are even lower than the best response to the own overestimated beliefs. Further, for laggards, the overinvestment corresponds to an underestimation of leaders' investments. Like in the first ten periods, laggards invest even more than the best response to the wrong beliefs.

To test how strong the U-shaped relation is, we consider the OLS model given by (7) for leaders and laggards separately. Estimates are shown in Table 4. First, consider leaders. Both for periods 1 to 10 and for 11-20, the coefficients related to *weak* and *intense* are positive. However, the only significant relation is for *intense* in periods 1-10.

Second, consider laggards. The negative effect of moving from weak to intermediate competition is substantial and significant in each period range, whereas the effects of moving from intermediate to intense competition are only significant (at the 10%-level) for early periods.²⁰

We summarize our results as follows.

²⁰ Again, blocked period dummies are not significant. Also, the OLS model (7) can be adapted to test for over- and underinvestment. It turns out that the overinvestment of laggards is significant at the 1%-level, whereas the underinvestment of the leader is not significant.

	<i>Leader</i>		<i>Laggard</i>	
	Period 1-10 investment	Period 11-20 investment	Period 1-10 investment	Period 11-20 investment
<i>const</i>	8.5944*** (0.1956)	8.8972*** (0.2598)	7.0333*** (0.2743)	6.4417*** (0.2181)
<i>weak</i>	0.6611 (0.4101)	0.4361 (0.3046)	0.7944* (0.3243)	2.1417** (0.5430)
<i>intense</i>	1.7667*** (0.3044)	0.5028 (0.4924)	-1.2722 (0.6416)	-0.8194 (0.5653)
<i>N</i>	720	720	720	720
<i>R</i> ²	0.09467	0.01125	0.08508	0.1759

Note: OLS regression with standard errors corrected for matching group clusters in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Effects of the intensity of competition on the investment behavior.

Result 2 *In treatments (A1)-(A4), we observe the following qualitative results, some of which are significant: (a) Leaders invest more than laggards. (b) Leaders' investments are lowest for intermediate competition, though the relation is not significant in all cases. (c) Laggards' investments strictly decrease with increasing intensity of competition.*

A final comment on the partial non-significance of the positive effects of increasing competition is in order. The predicted positive effect of more intense competition on investment is fairly small in percentage terms. The lack of significance of the intense competition dummy, both in the symmetric and in the asymmetric treatments, may reflect this fact.

5 Results for the two-stage treatments

5.1 Investments

The one-stage approach is useful because it identifies deviations from the equilibrium of the investment game that, by definition, cannot result from expected deviations in the output game. However, the next result shows that this simplification is not innocuous: Once one allows for the possibility of such deviations, first-period behavior changes massively.

Result 3 *Under both intense and intermediate competition, mean invest-*

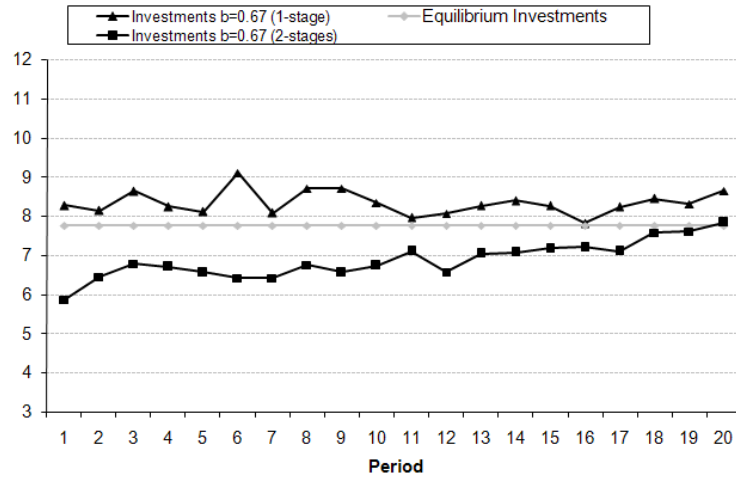


Figure 8: One stage vs. two stages: Mean investments for $b = 1$

ments are lower than in the one-stage treatments.

Figures 8 and 9 show that investments in the two-stage treatments are lower in the subgame perfect equilibrium, which on average lies below the investments in the one-stage treatments.²¹

In the one-stage experiment, this increase of b from 0.67 to 1 has a positive effect on investments. However, the two-stage experiment does not yield the same result.

Result 4 *In S5 and S6, higher intensity of competition does not increase investments.*

Comparison of Figures 8 and 9 that, for the two intensities of competition, investments are close. Contrary to the prediction, they are higher for $b = 0.67$ than for $b = 1$, in particular, in late periods.²²

²¹We test the results with an OLS-regression over a second-stage dummy and with a Wilcoxon test. For periods 1-10, the average effect of the second-stage dummy is -1.94 for $b = 1$ and -1.84 for $b = 0.67$. For periods 11-20, the corresponding coefficients are -1.61 and -1.51 . All results are significant at the 1%-level, with standard errors corrected for matching group clusters. The Wilcoxon test yields significance only for $b = 1$, however.

²²Over all periods and subjects, the mean investment is 6.87 (6.56) for $b = 0.67$ (1).

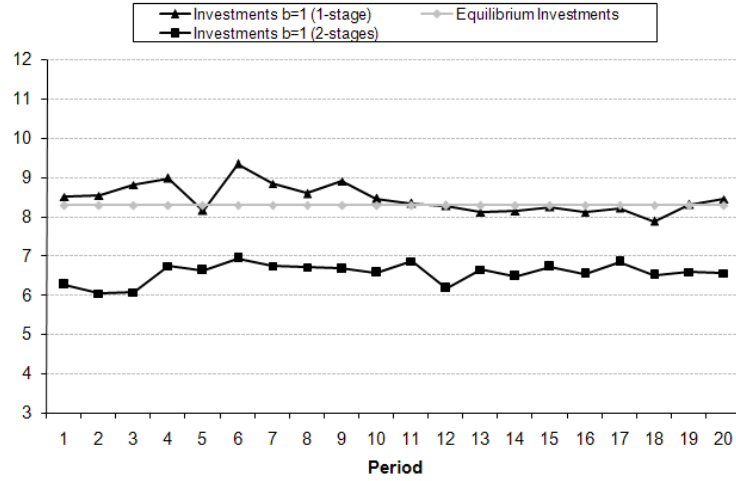


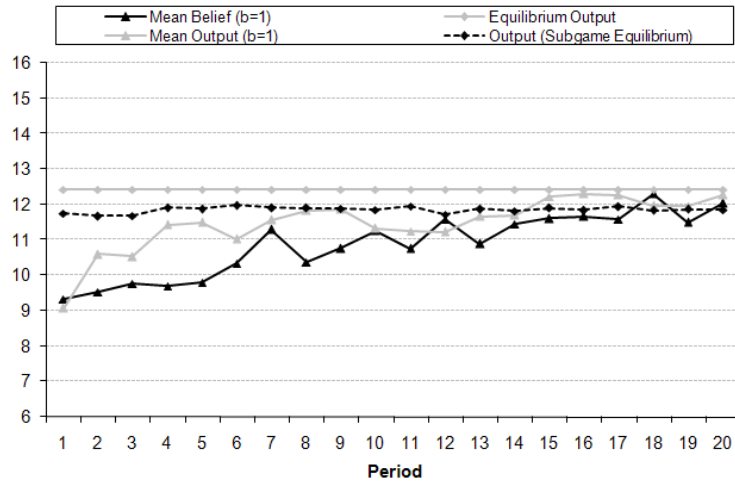
Figure 9: One stage vs. two stages: Mean investments for $b = 0.67$

5.2 Output stage

The output stage is interesting in its own right. As players typically choose different investments in stage 1, the second-stage game endogenously becomes an asymmetric duopoly. Experimental investigations of asymmetric Cournot duopolies are rare (Mason et al. 1992, Mason and Phillips 1997). Contrary to the corresponding symmetric duopoly games (Huck et al. 2004b), they tend to reveal outputs above the equilibrium. Using (2), we obtain the following predictions for fixed values of b .

1. Subgame equilibrium outputs are increasing in own investments.
2. Subgame equilibrium outputs are decreasing in competitor investments.
3. For symmetric subgames, equilibrium outputs are increasing in total investments.

Intuitively, the first two results arise because own cost reductions shift reaction functions in the output diagram outwards, whereas competitor cost reductions shift them inwards. The third result states that the own effect dominates over the cross effect. To substantiate the last claim, note that average subgame equilibrium outputs are $q(\bar{y}) \equiv \frac{(a-c^0+\bar{y})}{2+b}$ for $c^0 \equiv c_1^0 = c_2^0$.

Figure 10: S5-S6: Outputs and beliefs for $b = 1$

5.2.1 Intense competition

For $b = 1$, Figure 10 gives an overview of the observations. The horizontal line denotes the outputs in the subgame perfect equilibrium. The dotted line is a useful reference case. It reflects average outputs $q(\bar{y}_t)$ in any subgame equilibrium corresponding to the average investments \bar{y}_t of the period under consideration. Because actual investments are below subgame perfect equilibrium investments, $q(\bar{y}_t)$ is typically below the subgame equilibrium outputs. Actual outputs are usually even below this reference level, which is clearly not in line with the above-mentioned findings of Mason et al. (1992), Mason and Phillips (1997) according to which outputs tend to be above equilibrium.

Next, consider the relation between investments and outputs at the individual level. For output levels x_t^i , and investments $y_t^i, y_t^j, j \neq i$, and a dummy δ_t^i if t belongs to the first five periods under consideration, we considered an OLS-regression

$$x_t^i = \beta_0 + \beta_1 y_t^i + \beta_2 y_t^j + \beta_3 \delta_t^i + e_t^i, \quad (8)$$

with standard errors corrected for matching group clusters.

Table 5 shows that the relation between own investments and outputs is positive as predicted. Further, in periods 1-10, there is a negative relation between the competitor's investments and own outputs, which is significant

at the 10%-level. However, the predicted negative relation does not arise in late periods. The coefficient is essentially zero.

	<i>Intermediate competition</i>		<i>Intense competition</i>	
	Period 1-10 output	Period 11-20 output	Period 1-10 output	Period 11-20 output
<i>const</i>	9.1173*** (1.0389)	10.179*** (0.9205)	8.2878** (1.8269)	9.0106*** (1.0216)
<i>own inv</i>	0.5187*** (0.1265)	0.7100** (0.1963)	0.6320 * (0.2326)	0.4769** (0.1486)
<i>inv other</i>	0.06865 (0.1064)	-0.1227 (0.1283)	-0.1500* (0.06523)	-0.0004275 (0.1105)
<i>period 1-5</i>	-0.9936** (0.3611)		-0.7201 (0.4946)	
<i>period 11-15</i>		-1.2354** (0.2880)		-0.5312** (0.1610)
<i>N</i>	360	300	300	360
<i>R</i> ²	0.1336	0.2537	0.1527	0.1078

Note: OLS regression with standard errors corrected for matching group clusters in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Effects of the intensity of competition on output behavior.

5.2.2 Intermediate competition

Figure 11 reveals a different situation for intermediate competition. Average outputs are closer to the equilibrium outputs in most periods, and even higher in the final periods. Also, the subgame equilibrium outputs $q(\bar{y})$ corresponding to observed investments are very close to actual outputs.

Contrary to the case of intense competition, downward deviations from equilibrium outputs therefore tend to be less pronounced for intermediate competition where the negative externalities resulting from the other players are weaker than for intense competition. Outputs are lower for more intense competition than for intermediate competition, which is consistent with equilibrium predictions.

Table 5 also shows that output increases in own investments in both early and late rounds, as predicted, but the effect of other investment is not

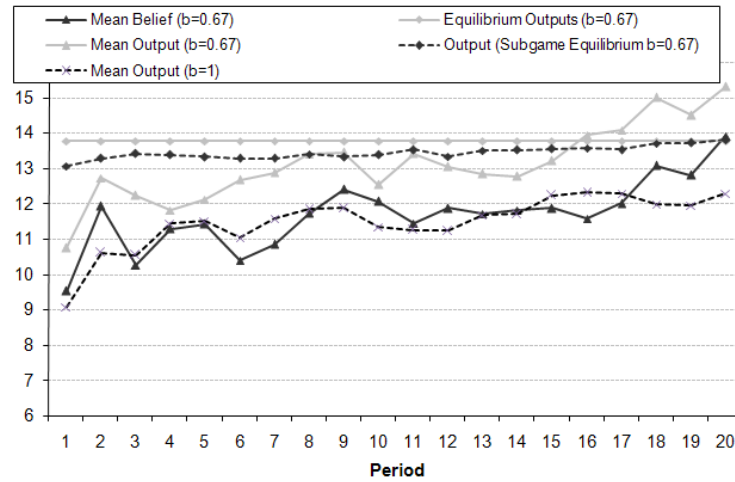


Figure 11: S5-S6: Outputs and beliefs in the two-stage treatments

significantly different from zero.

5.3 Towards an explanation

In the two-stage treatments, several interesting results emerge.

1. Contrary to the one-stage treatments, there is underinvestment relative to the subgame perfect equilibrium of the game.
2. While the reaction of outputs to own investments is consistent with subgame equilibrium behavior, there is generally no significant negative effect of competitor investments on own outputs.
3. Because underinvestment is more pronounced for intense competition, the predicted positive effect of moving from intermediate to intense competition is not observed.
4. Output is lower than in the SPE (and even in the subgame equilibria corresponding to the observed low investments) for intense competition, but not for intermediate competition.

To interpret these results, arguments based on social preferences are helpful. Underinvestment is cooperative behavior (with the firms as a reference group), because investments involve negative externalities. Hence, reciprocal behavior in the output stage would suggest a positive relation between own investments and competitor outputs rather than the negative effect suggested by theory. Thus, reciprocal output choices may imply that the strategic incentive to invest is smaller than predicted by theory. The “Top-Dog” logic that aggressive cost reductions induce desired behavior of the competitor (output reductions) no longer holds in the presence of reciprocity or is at least weakened, because reciprocal subjects may respond to aggressive investments with output increases rather than reductions.

These reciprocity-based arguments are consistent with observations 1 and 2, but they have nothing to say about observations 3 and 4. These observations point to systematic differences between intermediate and intense competition both in the output and in the investment stage. These differences are related: The downward output deviations in the intense competition case fit well with downward deviations in investments: If expected outputs are low, so should cost-reducing investments be; conversely, if investments are low, optimal outputs are low. To explain why there is a stronger tendency for both activities to lie below the equilibrium in the intense competition case than in the intermediate competition case, efficiency considerations might play a role: Equilibrium outputs and investments are both excessive from the perspective of joint profit maximization, so that refraining from these activities increases joint payoffs. As increasing competition increases the benefits of such collusive activities, one expects them to be more important for $b = 1$ than for $b = 0.67$. This is consistent with subjects underinvesting more substantially for intense than for intermediate competition. A puzzle with this explanation arises when it is contrasted with the one-stage games. The one-stage investment game is very similar to a standard Cournot output game; in particular, it involves negative externalities. It is thus unclear why subjects collude in the output game, but not in the qualitatively similar one-stage investment game.

6 Conclusion

We considered a simple two-stage model where there is a U-shaped relation between competition and investment, except for firms that are initially much

less efficient than competitors. In the one-stage treatments, where subjects only take investment decisions, there is overinvestment for both intermediate and intense competition. As predicted, however, an increase in competition yields higher investments; though the effect is not always significant. Interestingly, the two-stage experiment, where subjects take investment and output decisions, does not support the one-stage results. For both intermediate and intense competition, there is underinvestment; further, an increase in competition does not lead to higher investments. The deviations from first-stage equilibrium investments seem related to deviations in second-stage outputs. In particular, in the intense competition case, subjects choose outputs below the equilibrium level, which correspond to relatively low investments. Both considerations of reciprocity and joint payoff maximization appear to play a role in explaining the deviations from predictions.

The substantial differences between the one-stage and two-stage treatments suggests an interesting avenue for future research. Is it possible to understand more generally how the behavior of subjects in simplified one-stage treatments differs from the behavior in the full two-stage game? This would be interesting, because simplicity of design is useful to understand the behavior of subjects in the laboratory. It would therefore be important to understand what the price of the simplification is.

7 Appendix

We provide a general result about the relation between competition b and marginal investment incentives, $\left| \frac{\partial \Pi_i}{\partial c_i} \right|$, which is captured by

$$\frac{\partial^2 \Pi_i}{\partial c_i \partial b} = \frac{(16 + 12b^2)(a - c_j) - 32b(a - c_i)}{(4 - b^2)^3}. \quad (9)$$

The result shows that there is a U-shaped relation for the leader and firms that are only lagging behind slightly. Investigation of (9) yields Proposition 1, using $Y_i^0 \equiv a - c_i^0$.

Proposition 3 *Suppose $0 \leq b \leq 1$ and $0 < c_1 \leq c_2 < a$. Then, the following holds: (i) For the leader, there is a U-shaped relation between the intensity of competition and marginal incentives to invest, with the minimum at $0 < b \leq \frac{2}{3}$. (ii) For the laggard, there is a U-shaped relation with the*

minimum at $\frac{2}{3} \leq b \leq 1$ if $\frac{Y_1^0}{Y_2^0} \leq \frac{8}{7}$. (iii) If $\frac{Y_1^0}{Y_2^0} > \frac{8}{7}$, the marginal incentives for the laggard are strictly decreasing. (iv) For symmetric firms, there is a U-shaped relation with the minimum at $b = \frac{2}{3}$.

Proof. By (9), if $\frac{2}{3} < b \leq 1$ and $0 < c_1 \leq c_2 < a$, then $\frac{\partial^2 \Pi_1}{\partial c_1 \partial b} < 0$. Further, (9) has a unique zero $\hat{b} \in (0, \frac{2}{3}]$, given by

$$\hat{b} = \frac{4 - 2\sqrt{-3Q^2 + 4}}{3Q}, \quad (10)$$

where $Q = \frac{Y_2^0}{Y_1^0} \leq 1$. For $Q^2 < \frac{4}{3}$, \hat{b} is well-defined. If $\frac{Y_2^0}{Y_1^0} \rightarrow 1$, then $\hat{b} \rightarrow \frac{2}{3}$. If $0 \leq b < \frac{2}{3}$ and $0 < c_1 \leq c_2 < a$, then $\frac{\partial^2 \Pi_2}{\partial c_2 \partial b} > 0$. Further, $\frac{\partial^2 \Pi_2}{\partial c_2 \partial b}$ has a unique zero $\tilde{b} \in [\frac{2}{3}, 1]$. \tilde{b} is given by (10), where $Q = \frac{Y_1^0}{Y_2^0}$. By $Q^2 \leq \frac{4}{3}$, \tilde{b} is well-defined. By $Q^2 \leq \frac{64}{49}$, $\tilde{b} \in [0, 1]$. If $\frac{64}{49} < Q^2 \leq \frac{4}{3}$, then $\tilde{b} \in (1, \frac{2}{3}]$. If $Q^2 > \frac{4}{3}$, there is no \tilde{b} . This yields statements (i) to (iv). ■

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