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## Is there a U-shaped Relation between competition and Investment?

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

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July 2008

**ABSTRACT:** We argue that, in a simple setting, the relation between the intensity of competition and cost-reducing investment is U-shaped. We consider a two-stage game with cost-reducing investments followed by a linear differentiated Cournot duopoly. We first show that, except for firms that are much less efficient than the competitor, investment in the subgame-perfect equilibrium is minimal for intermediate levels of competition, which is inversely parameterized by the extent of product differentiation. An extensive set of laboratory experiments also provides support for the U-shape, both for symmetric firms and for leaders. Also consistent with predictions, the relation is negative for firms that are lagging behind.

*JEL Classification:* C92, L13, O31.

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

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# 1 Introduction

A large game-theoretic literature deals with strategic investment decisions in an oligopolistic environment. One important class of papers focuses on the relation between the intensity of competition and process investment, typically using two-stage oligopoly 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, forthcoming). 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, and it provides experimental support for the claim.

We consider a simple standard model: In the first stage of the game, 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  $b \in [0, 1]$ . An increase in competition corresponds to a reduction in product differentiation (higher value of  $b$ ). Thus, in the polar case where  $b = 0$  there are essentially two monopolies;  $b = 1$  corresponds to a homogeneous Cournot market. For symmetric firms, that is, identical initial marginal costs, 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 ahead of the competitors. However, if a firm lags substantially behind the competitor, increasing intensity of competition has an unambiguously negative effect on investments.

Thus, our model makes two main points. First, there is a U-shaped relation between intensity of competition and investment for a wide range of parameters; second, competition is more likely to have a negative effect on investments for strong laggards. As both points are made in a standard, but nevertheless rather specific model, it is important to understand the intuition. To this end, it is crucial to analyze the effects of the intensity of competition on marginal investment incentives, that is, the absolute value of the derivative of equilibrium profits (gross of investment costs) with respect

to own marginal costs.<sup>1</sup> This marginal investment incentive itself depends in a non-monotone way on the competition parameter, reflecting the interaction of two countervailing effects. First, in the differentiated Cournot model, as in most reasonable cases, competition has a negative effect on the absolute mark-up 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 demand effect of increasing efficiency becomes more pronounced, suggesting a positive relation between competition and marginal investment incentives. The U-shape thus comes from the interaction of these two effects.

The difference between leaders and laggards can be explained similarly. Essentially, while both effects are still present for strong laggards, the positive effect becomes small for a firm that has a low demand because it is less efficient than the competitor.

The paper also provides experimental evidence that supports the main results. In view of the simple structure of the model, we implement the experiment as a one-stage game where players choose investments, and then obtain the equilibrium profits corresponding to the resulting product market subgame.<sup>2</sup> We carried out a large number of experiments to identify the U-shaped relation between intensity of competition and investment and its robustness. 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 strong competition ( $b = 1$ ). In the symmetric case, investments are lowest for intermediate competition, as predicted. However, there is overinvestment for all values of  $b$ . In the asymmetric case, the U-shaped relation arises for leaders, but the positive effect of moving from intermediate to strong competition is not as intense as predicted. For laggards, the predicted negative effect of competition on investment holds, but it is also less pronounced. Interestingly, to a large extent, these deviations reflect best responses to wrong beliefs that players have about the investments of the other subjects. That is, symmetric players

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<sup>1</sup>When investment incentives are increasing, investments in the subgame perfect Nash equilibrium of the game are also increasing under fairly weak additional conditions (see Schmutzler, 2007).

<sup>2</sup>For the differentiated Cournot-Duopoly with symmetric players, Sacco (2008) compares one-stage with two-stage experiments, where subjects take investment and quantity decisions.

and laggards believe that the competitor invests less than he actually does; rather, leaders believe that the competitor invests more than he actually does.

Though the focus is on the effects of competition on investment, our analysis also provides some insights into a related debate. A large literature has dealt with the issue of self-reinforcing market dominance. When firms differ in their initial efficiency levels, is there a tendency for these differences to become larger over time? The theoretical literature has identified forces that go in both directions (see Athey and Schmutzler, 2001). Though our model is only static, one of the key mechanisms for weak increasing dominance is present: Firms that are initially more efficient than others invest more. The asymmetric treatments of our experiments allow us to test whether increasing dominance actually arises. Indeed, this question is answered in the affirmative, essentially independent of the degree of competition. However, because leaders underinvest and laggards overinvest relative to the Nash equilibrium, the difference between the investments of leaders and laggards is obviously smaller than predicted by the model.

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. Sacco and Schmutzler (2008) consider homogenous Cournot and Bertrand settings with two and four firms.<sup>3</sup> Consistent with the earlier literature, they show that a larger number of firms lowers investments, whereas increasing competition in the sense of moving from Cournot to Bertrand has a positive effect on investments.

The first experimental paper that analyzes whether weak increasing dominance emerges is Halbheer et al. (2007). These authors also identify weak increasing dominance in a simple static Cournot model. They treat the homogenous case allowing for parameterizations reflecting spillovers between firms.

In this paper, we proceed as follows. Section 2 contains the theoretical framework. Section 3 discusses the experimental design and results. Section 4 concludes.

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<sup>3</sup>Suetens (2005) deals with a Cournot-Duopoly. However, she is not concerned with the effects of increasing competition.

## 2 The Model

### 2.1 Differentiated Cournot-Duopoly

Consider firms  $i = 1, 2$  producing heterogenous goods. Suppose without loss of generality that  $c_1 \leq c_2$ . If the inequality strictly holds, then firm 1 plays the leader's role; 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  $b \in [0, 1]$ , and  $a > 0$ .

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  $i$  is given by

$$q_i = \frac{2Y_i - bY_j}{4 - b^2}, \quad (2)$$

where  $Y_i \equiv a - c_i > 0$  represents the efficiency level.<sup>4</sup>

(2) implies the following equilibrium profits:

$$\Pi_i = \left( \frac{2Y_i - bY_j}{4 - b^2} \right)^2. \quad (3)$$

The cost reduction incentives are given by

$$\frac{\partial \Pi_i}{\partial c_i} = -\frac{8Y_i - 4bY_j}{(4 - b^2)^2} = -\frac{4q_i}{4 - b^2} < 0. \quad (4)$$

Given  $q_i > 0$  and  $b \in [0, 1]$ , we have  $\frac{\partial \Pi_i}{\partial c_i} < 0$ , which means that a cost reduction increases firms' profits.

The effect of the intensity of competition on marginal incentives to invest is captured by

$$\frac{\partial^2 \Pi_i}{\partial c_i \partial b} = \frac{(16 + 12b^2)Y_j - 32bY_i}{(4 - b^2)^3}. \quad (5)$$

Investigation of (5) yields Proposition 1.

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<sup>4</sup>For the leader and symmetric firms, (2) is always positive; for the laggard, if  $b < \frac{2Y_2}{Y_1}$ .

**Proposition 1** 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  $\frac{Y_1}{Y_2} \leq \frac{8}{7}$ . (iii) If  $\frac{Y_1}{Y_2} > \frac{8}{7}$ , 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.** See Appendix. ■

It is straightforward to see from Proposition 1 that, for the laggard, the U-shaped relation is only given when  $c_1$  and  $c_2$  are sufficiently close.

## 2.2 The Investment Game

Consider now a two-stage game, where firms  $i = 1, 2$  first engage in cost-reducing investments and then compete in the product market. The inverse demand functions are given by (1). Initial marginal costs are denoted as  $c_i^0$  and corresponding efficiency levels as  $Y_i^0 \equiv a - c_i^0 > 0$ . In the following, we assume  $c_1^0 \leq c_2^0$ ; thus,  $Y_1^0 \geq Y_2^0$ . In the first stage, firms simultaneously choose investments  $y_i \in [0, c_i^0)$ , resulting in marginal costs  $c_i = c_i^0 - y_i$ . The efficiency level of firm  $i$  after the investment stage is given by  $Y_i = Y_i^0 + y_i$ . The investment costs are quadratic and given by  $ky_i^2$ , where  $k > 0$ . In the second stage, firms simultaneously choose quantities, that is, they compete à la Cournot.

According to (3), the net profit of firm  $i = 1, 2$  in the first stage of the game is given by

$$\Pi_i = \left( \frac{2(Y_i^0 + y_i) - b(Y_j^0 + y_j)}{4 - b^2} \right)^2 - ky_i^2, \quad i \neq j. \quad (6)$$

The maximization of (6) with respect to  $y_i$  leads to

$$\frac{\partial \Pi_i}{\partial y_i} = \frac{8(Y_i^0 + y_i) - 4b(Y_j^0 + y_j)}{(4 - b^2)^2} - 2ky_i \equiv 0. \quad (7)$$

The second-order condition is given by

$$\frac{\partial^2 \Pi_i}{\partial y_i^2} = \frac{8}{(4 - b^2)^2} - 2k < 0. \quad (8)$$

Note that (8) is fulfilled  $\forall b \in [0, 1]$  if  $k > \frac{4}{9}$ .

From (7), it follows that

$$y_i = \frac{4Y_i^0 - 2b(Y_j^0 + y_j)}{k(4 - b^2)^2 - 4}. \quad (9)$$

Relation (9) implies the following equilibrium investments:

$$y_i^* = \frac{(4 + 4b^2k - 16k)Y_i^0 + (8bk - 2b^3k)Y_j^0}{8k(4 - b^2) - k^2(4 - b^2)^3 - 4}. \quad (10)$$

Note that (10) is positive if  $Y_i^0$  and  $Y_j^0$  are sufficiently close.<sup>5</sup>

The difference between leader's and laggard's equilibrium investments is given by

$$y_1^* - y_2^* = \frac{2(c_1^0 - c_2^0)}{k(b - 2)(4 - b^2) + 2}. \quad (11)$$

Note that (11) is positive  $\forall c_1^0 < c_2^0$ ,  $\forall b \in [0, 1]$ , and  $\forall k > 0$ .<sup>6</sup> That is, the firm that is initially more efficient invests more than the other firm, implying that increasing dominance arises.

### 2.3 Choosing the Parameters

In this section, we consider a specific parameterization that we also use in the experiment. We first treat the asymmetric case. Let  $a = 50$ ,  $k = 1$ ,  $c_1^0 = 21$ ,  $c_2^0 = 25$ . For these parameters,

$$\frac{Y_1^0}{Y_2^0} = \frac{a - c_1^0}{a - c_2^0} = \frac{29}{25} > \frac{8}{7}. \quad (12)$$

For the leader, there is a U-shaped relation between intensity of competition and incentives to invest by Proposition 1. For the laggard, (12) implies strictly decreasing investments.<sup>7</sup> Figure 1 shows the plots of the leader's and laggard's equilibrium investments for  $b \in [0, 1]$ .

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<sup>5</sup>For instance, consider  $b = 1$  and  $k = 1$ . Then, (10) is positive if  $\frac{Y_i^0}{Y_j^0} > \frac{3}{4}$ .

<sup>6</sup>For  $c_1^0 = c_2^0$ , (11) is obviously zero.

<sup>7</sup>Actually, to ensure that laggard's investments are strictly decreasing, ex-ante marginal costs may be less close than stated in Proposition 1. This can be shown through the derivative of (10) for  $i = 2$  with respect to  $b$ ; (12) becomes  $\frac{Y_1^0}{Y_2^0} \geq \frac{124}{121}$ .

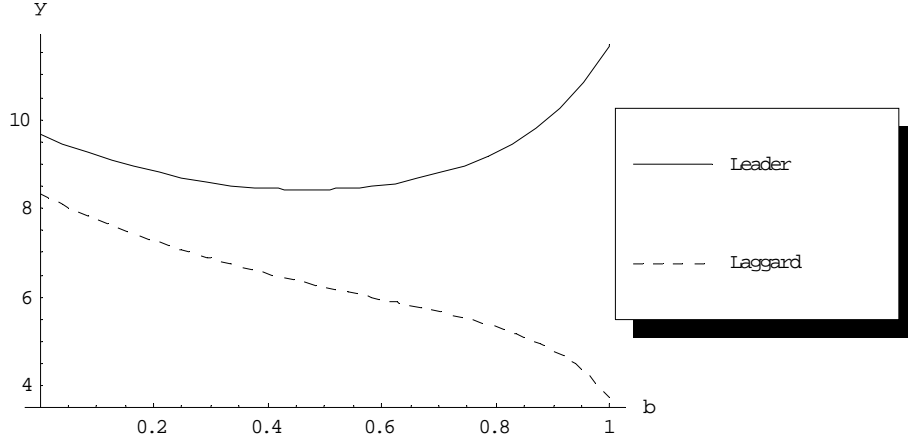


Figure 1: Leader's and laggard's investments.

In the experiment, we consider three cases for  $b$ , which correspond to different intensities of competition:  $b = 1/10$  (weak),  $b = 2/3$  (intermediate), and  $b = 1$  (strong). For the leader, the equilibrium investments are as follows:

$$\begin{cases} b = 1/10 \Rightarrow y_1^* = 9.18 \\ b = 2/3 \Rightarrow y_1^* = 8.68 \\ b = 1 \Rightarrow y_1^* = 11.70 \end{cases} . \quad (13)$$

For the laggard, we have:

$$\begin{cases} b = 1/10 \Rightarrow y_2^* = 7.75 \\ b = 2/3 \Rightarrow y_2^* = 5.75 \\ b = 1 \Rightarrow y_2^* = 3.70 \end{cases} . \quad (14)$$

Consider now the symmetric case. Figure 2 shows the plot of the equilibrium investments for  $a = 50$ ,  $k = 1$ ,  $c_1^0 = c_2^0 = 21$ , and  $b \in [0, 1]$ .

For the three values of the competition parameter  $b$ , the following equilibrium investments  $y_1^* = y_2^* = y^*$  arise:

$$\begin{cases} b = 1/10 \Rightarrow y^* = 9.09 \\ b = 2/3 \Rightarrow y^* = 7.75 \\ b = 1 \Rightarrow y^* = 8.28 \end{cases} . \quad (15)$$

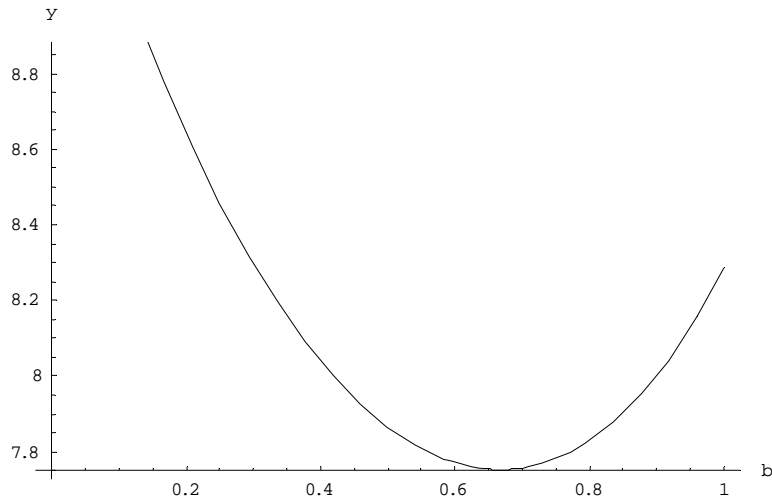


Figure 2: Investments of the symmetric firms.

For both firms, there is a U-shaped relation between intensity of competition and investments.<sup>8</sup>

## 3 The Experiment

### 3.1 Experimental Design and Procedures

The game implemented in the experiment is a reduced form version of the described two-stage game. To focus on investment choices which we restricted to  $y_i \in \{0, 1, \dots, 14\}$ , we reduced the game to the first stage, that is, to the investment stage. 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. This was a deliberate modeling choice ensuring that, whatever deviations from the equilibrium investments might arise, they do not result from anticipations of second-period deviations from the product market equilibrium.

In October and November 2007, we conducted eight experimental sessions at the University of Zurich. The participants were undergraduate students from various disciplines. In the first four sessions, we implemented the sym-

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<sup>8</sup>By Proposition 1, the minimum of the investment function lies at  $b = 2/3$ .

metric case; in the last four, the asymmetric case with the leader-laggard structure. Each session had 20 periods. In each session, there was a switch of the competition parameter after period 10. That is, participants played the game for one parameterization in the first ten periods and for the other parameterization in the second ten periods. In different sessions, we reversed the order of the parameterizations to allow for sequencing effects. Table 1 gives an overview of the sessions.

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

Table 1: Four symmetric and four asymmetric sessions.

In seven of eight sessions, there were 36 subjects.<sup>9</sup> This led to a total of 5640 investment observations. Moreover, in each period, subjects were asked to give a belief about the investment of the other group member.

In the asymmetric sessions, the roles of leader and laggard were randomly assigned and there was no switch over the 20 periods. No subject participated in more than one session. We built fixed matching groups of 6 people for statistical reasons. The participants were randomly matched into groups of size two within the matching groups. At the end of each period, subjects were informed about the investment level of the other group member and their own net profit for that period. 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 and laggards, respectively. In A3 and A4, leaders earned on average CHF 35 ( $\approx$ EUR 22); laggards CHF 24 ( $\approx$ EUR 15). Sessions lasted about 2 hours each. The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007).

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<sup>9</sup>In S3, there were 30 participants.

## 3.2 Results

In this section, we discuss the experimental results. To analyze the effects of varying the intensity of competition on the investment behavior, we consider three different parameterizations ( $b = 1/10, b = 2/3, b = 1$ ). First, we treat the asymmetric setting; second, the symmetric case.

### 3.2.1 The Asymmetric Setting

In the following, we analyze the first ten and the last ten periods of the four asymmetric sessions in turn. After that, to focus on sequencing effects, we compare A1 to A2, and A3 to A4; that is, we consider pairs of sessions which include the same values of  $b$ , but differ with respect to the order of the parameterizations.

**Investments in the two period ranges** The theoretical prediction is that leaders invest more than laggards. Further, for leaders, there is a U-shaped relation between intensity of competition and investment; for laggards, there is a negative relation. The experiment provides evidence for these predictions both for the first ten and for the last ten periods. However, the strength of the U-shaped relation is different for the two period ranges. We start with the first period range.

**Result 1** *In the first ten periods, leaders invest more than laggards. Leaders' investments are lowest for intermediate competition. Laggards' investments strictly decrease with increasing intensity of competition.*

Figure 3 reveals that increasing dominance arises. For all values of  $b$ , a regression over a constant and a Wilcoxon rank sum test show high significance ( $p < 0.01$ ) when considering the difference between leaders' and laggards' investments. Further, for leaders, there is underinvestment when competition is strong ( $b = 1$ ); for laggards, there is overinvestment when competition is intermediate and strong ( $b = 0.67, b = 1$ ). A regression over a constant shows that, for leaders, there is no significant difference between investments and Nash equilibrium for  $b = 0.1$  and  $b = 0.67$ . However, this result is not fully supported by a Wilcoxon rank sum test which yields significance at the 10%-level. On the other hand, the difference between actual and equilibrium investments is highly significant when competition is strong. For laggards,

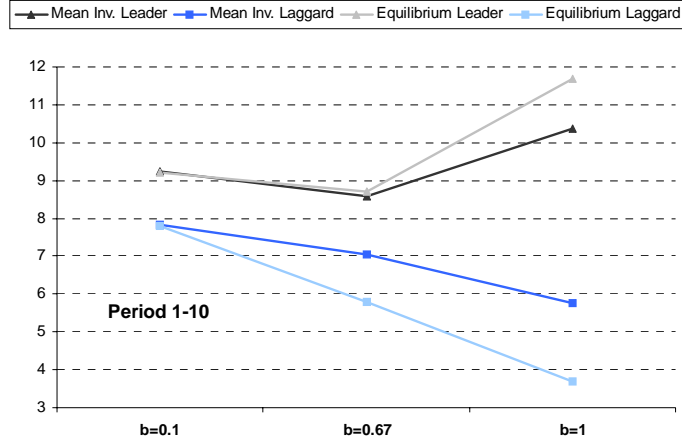


Figure 3: Leaders' and laggards' investment in period 1-10.

there is no significant deviation from the equilibrium for  $b = 0.1$ ; high significance is given for  $b = 0.67$  and  $b = 1$ . These deviations from the equilibrium can be explained through players' beliefs.<sup>10</sup>

Leaders believe that laggards invest more than they actually do. This is shown in Figure 4. Interestingly, given the wrong beliefs, leaders essentially choose the optimal investment level. In fact, the best response to the own beliefs almost coincides with actual investments; a regression over a constant and a Wilcoxon rank sum test yield no significant difference. Rather, laggards believe that leaders invest less than they actually do. This explains the overinvestment of the laggards. However, their investments are even higher than the best response to the wrong beliefs. The asymmetry between leaders and laggards – the former best-respond to their beliefs while the laggards do not – is astonishing. One explanation may be that laggards deliberately hurt leaders who have an exogenous advantage.

We consider now the last ten periods. The investment behavior is similar to that discussed above.

**Result 2** *In the last ten periods, leaders invest more than laggards. Leaders' investments are lowest for intermediate competition. Laggards' investments*

<sup>10</sup>Observe that own investments and beliefs about other players' investments are strategic substitutes.

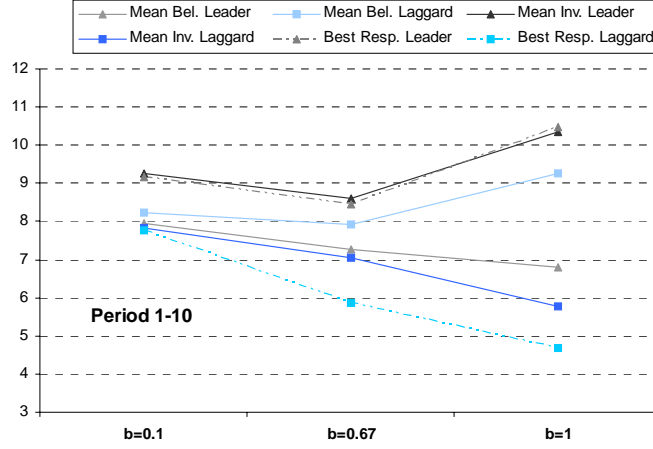


Figure 4: Leaders' and laggards' belief in period 1-10.

*strictly decrease with increasing intensity of competition.*

Figure 5 shows that, like in the first ten periods, increasing dominance emerges. The difference between leaders' and laggards' investments is highly significant for each parameterization.<sup>11</sup> Moreover, for leaders, there is slight overinvestment when competition is weak and intermediate, and striking underinvestment for strong competition. For laggards, there is overinvestment for all values of  $b$ . Regarding the deviation from the equilibrium, a regression over a constant and a Wilcoxon rank sum test yield high significance for each parameter value and player's role. Again, subjects' beliefs are helpful to understand the investment behavior.

Figure 6 reveals that, for leaders, the underinvestment for  $b = 1$  is related to wrong beliefs about laggards' investments. However, in contrast to the first ten periods, wrong beliefs do not fully explain the underinvestment behavior. In fact, investments of leaders are even lower than the best response to the own overestimated beliefs. Further, for laggards, the overinvestment results from underestimating leaders' investments. Like in the first ten periods, laggards invest even more than the best response to the wrong beliefs.

Results 1 and 2 have shown that, for leaders, a U-shaped relation emerges; for laggards, there is a negative relation. To test how strong these relations

<sup>11</sup>This is supported both by a regression over a constant and a Wilcoxon rank sum test.

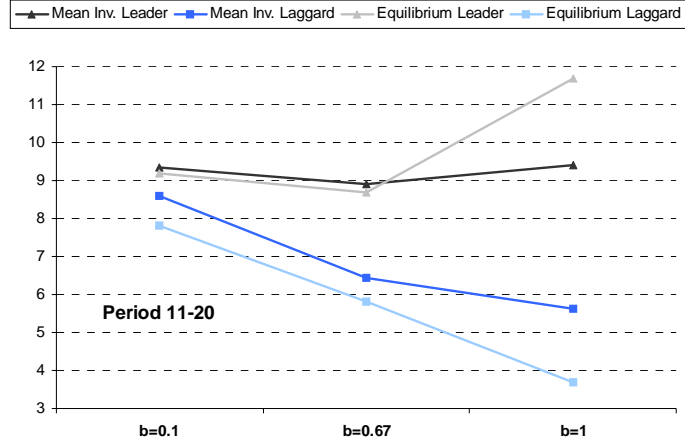


Figure 5: Leaders' and laggards' investment in period 11-20.

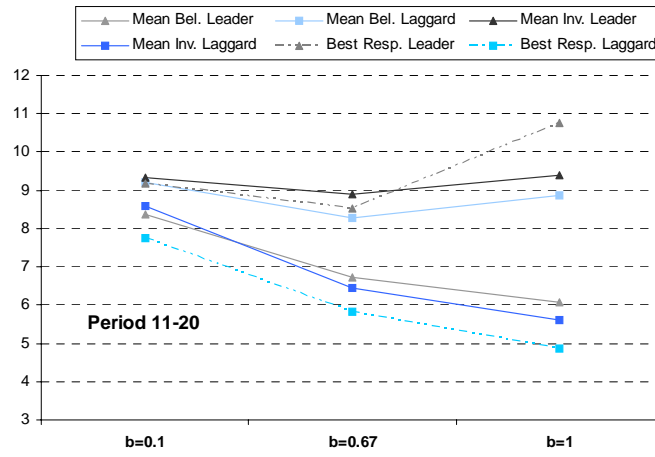


Figure 6: Leaders' and laggards' belief in period 11-20.

are, we consider the following random-effects model:

$$Y_{t,k}^i = \beta_0 + \beta_1 \delta_{weak,k}^i + \beta_2 \delta_{strong,k}^i + e_{t,k}^i + \mu_k^i, \quad (16)$$

where  $e_{t,k}^i$  is a residual term which is independent across groups  $k$ ;  $\mu_k^i$ , which captures the random effects, is uncorrelated with each explanatory variable in all time periods. The dummy variable  $\delta_{weak,k}^i$  takes the value 1 if the investment of subject  $i$  belonging to group  $k$  occurs in the first ten periods of A1 or in the last ten periods of A2, where the intensity of competition is weak. Otherwise, it takes the value 0. Similarly,  $\delta_{strong,k}^i$  takes the value 1 if  $b = 1$ .

Estimates are shown in Table 2. The reference variable is intermediate competition. First, consider leaders. For period 1 to 10, the coefficients related to *weak* and *strong* are positive and significant at the 5% and 1%-level, respectively. Investments for  $b = 0.1$  are 0.6611 units higher than for  $b = 0.67$ ; those for  $b = 1$  are 1.7666 units higher than for  $b = 0.67$ . This implies that the U-shaped relation is quite strong even though there is underinvestment for  $b = 1$ . Rather, in period 11 to 20, we denote a clearly weaker relationship. The coefficients for *weak* and *strong* are positive and significant at the 10%-level. Thus, for  $b = 1$ , underinvestment is more pronounced in the last ten periods. Second, consider laggards. The negative relation is substantial in each period range. The coefficients for *weak* are positive and significant at the 5% and 1%-level, respectively; those for *strong* are negative and significant at the 1% and 5%-level, respectively.

Table 2: Effects of the intensity of competition on the investment behavior.

	Period 1-10	Period 11-20	Period 1-10	Period 11-20
Variable	<i>Leader</i>	<i>Leader</i>	<i>Laggard</i>	<i>Laggard</i>
<i>const</i>	8.5944*** (0.2593)	8.8972*** (0.2694)	7.0333*** (0.2790)	6.4416*** (0.2539)
<i>weak</i>	0.6611** (0.4041)	0.4361* (0.4659)	0.7944** (0.3969)	2.1416*** (0.4657)
<i>strong</i>	1.7666*** (0.4367)	0.5027* (0.4898)	-1.2722*** (0.5254)	-0.8194** (0.4927)

Note: Random-effects GLS regression. \* denotes significance at the 10%-level, \*\* at the 5%-level, \*\*\* at the 1%-level. Robust standard errors in parentheses.

We can now summarize the findings related to Table 2 in the following result.

**Result 3** *For leaders, the U-shaped relation is stronger in the first ten than in the last ten periods. For laggards, the negative relation is strong no matter what period range is considered.*

**Sequencing effects** So far we have discussed the investment behavior in the two period ranges. In the following, we analyze whether sessions involving the same values of  $b$  but a different order of the parameterizations lead to similar results. To this end, we compare the investment distributions in A1 to those in A2. Analogously, for A3 and A4. Dealing with the investment distributions also allows us to highlight the heterogeneity of player behavior. We start with A1 and A2, where  $b = 0.1$  and  $b = 0.67$  are the relevant parameters.

**Result 4** *For A1 and A2, more intense competition shifts the leaders' and laggards' investment distribution to the left.*

According to prediction, leaders and laggards choose in both sessions higher investments when competition is less intense. This holds no matter what competition parameter is implemented first. For leaders, the investment distributions in A1 are shown in Figure 7.

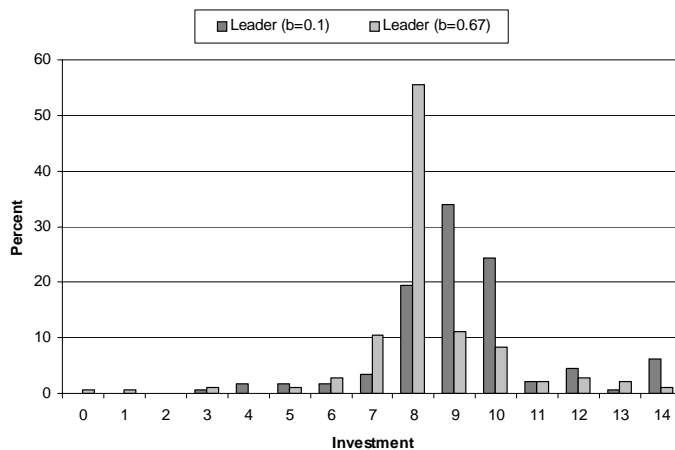


Figure 7: Leaders' investment distributions in A1.

Switching from weak to intermediate competition shifts the global maximum from 9 (34%) to 8 (56%). For laggards, the investment distributions in A1 are shown in Figure 8. More intense competition shifts the global maximum from 8 (47%) to 6 (54%).

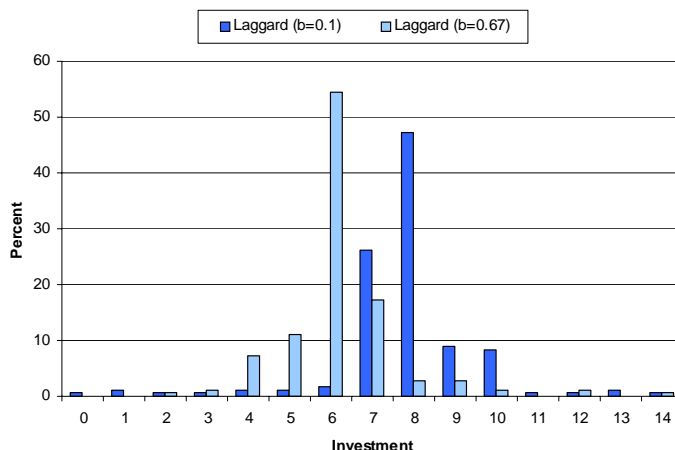


Figure 8: Laggards' investment distributions in A1.

The analysis of A2, where the parameterization order is reversed, leads to very similar results. We therefore omit additional considerations related to A2.

In the following, we investigate sessions A3 and A4, where the parameters involved are  $b = 0.67$  and  $b = 1$ .

**Result 5** *For A3 and A4, more intense competition shifts the laggards' investment distribution to the left; the shift of the leaders' distribution to the right is more pronounced in A4 than in A3.*

According to prediction, in both sessions laggards choose lower investments when competition is more intense. For leaders, there is a difference between A3 and A4. Consistent with Result 3, the distribution in A3 does not clearly shift to the right with increasing competition. The parameter switch in A4 has a greater impact on investments of leaders. Figure 9 shows the leaders' investment distributions in A4.

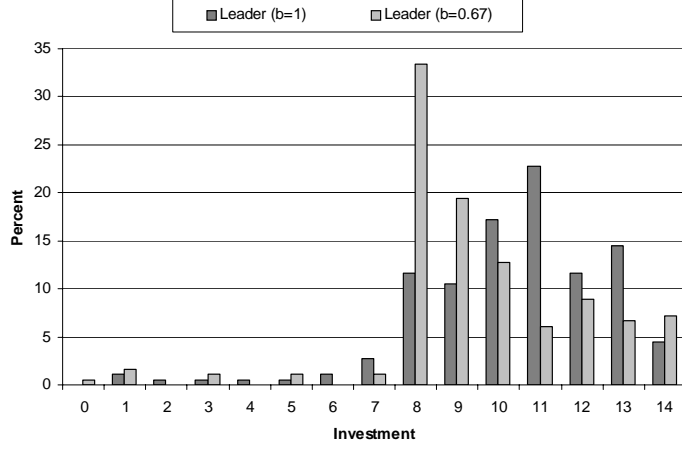


Figure 9: Leaders' investment distributions in A4.

The switch from strong to intermediate competition shifts the global maximum from 11 (23%) to 8 (33%). Figure 10 shows the investment distributions of laggards in A4. Less intense competition shifts the global maximum from 4 (19%) to 6 (27%).

### 3.2.2 The Symmetric Setting

In the following, we consider the symmetric case. Like in the asymmetric setting, we first analyze the investment behavior in the two period ranges, then the sequencing effects.

**Investments in the two period ranges** The theoretical prediction is that, for both players, there is a U-shaped relation between intensity of competition and investment. The experiment provides evidence for this prediction both for the first ten and last ten periods. Again, like in the asymmetric setting, the strength of the U-shaped relation is different for the two period ranges.

**Result 6** *In the first ten periods, investments are lowest for intermediate competition.*

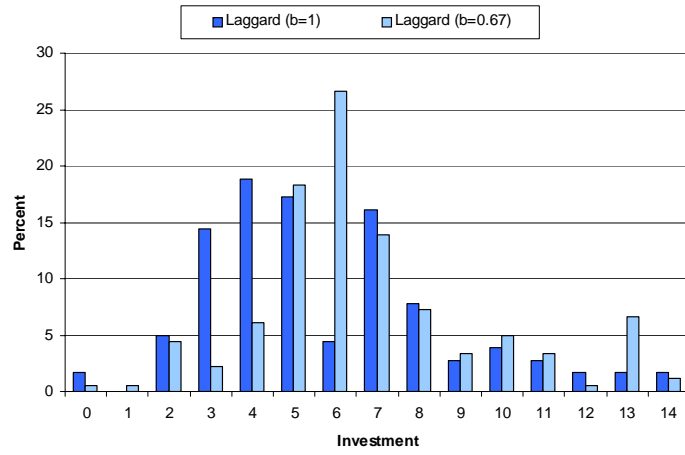


Figure 10: Laggards' investment distributions in A4.

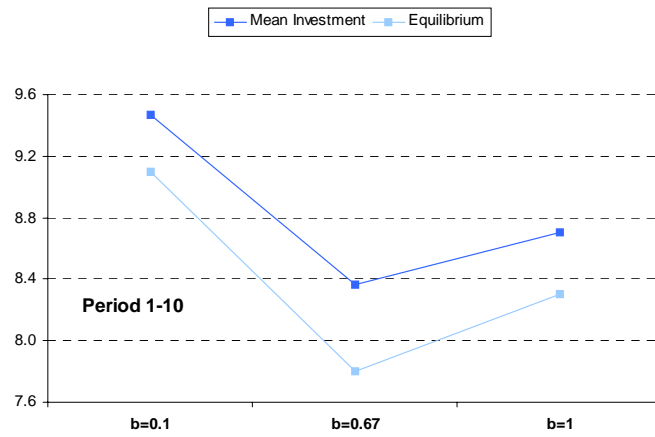


Figure 11: Mean investment in period 1-10.

Figure 11 reveals that there is overinvestment for all values of  $b$ . Both a regression over a constant and a Wilcoxon rank sum test show that the difference between observed and equilibrium investments is highly significant. The overinvestment behavior reflects underestimated beliefs.

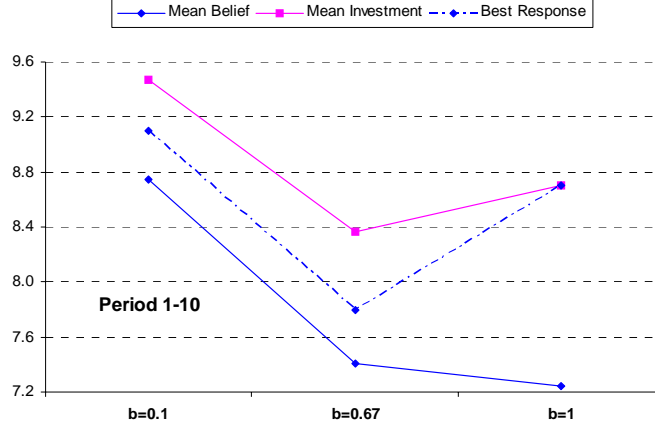


Figure 12: Mean belief in period 1-10.

Figure 12 shows that subjects believe that their group members invest less than they actually do. However, for  $b = 0.1$  and  $b = 0.67$ , mean investments are even higher than the best response to the wrong beliefs. For  $b = 1$ , mean investments exactly coincide with the best response to the underestimated beliefs.

Next, we consider the last ten periods, for which the investment behavior is similar to the other period range.

**Result 7** *In the last ten periods, investments are lowest for intermediate competition.*

For weak and intermediate competition, Figure 13 indicates overinvestment; for strong competition, there is slight underinvestment. For  $b = 0.1$  and  $b = 0.67$ , both a regression over a constant and a Wilcoxon rank sum test show that the difference between observed and equilibrium investments is highly significant. For  $b = 1$ , there is no significant difference.

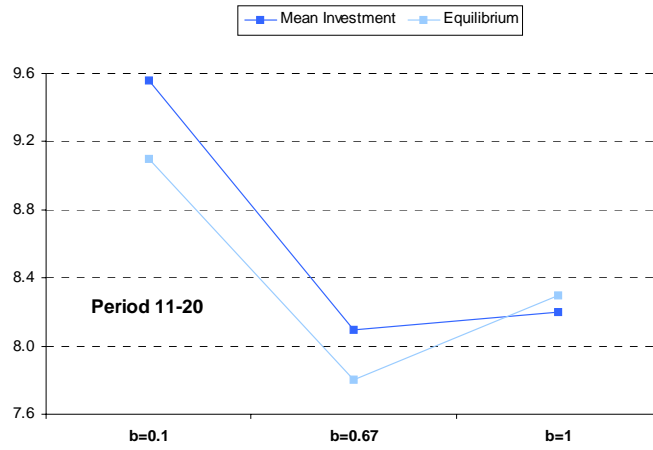


Figure 13: Mean investment in period 11-20.

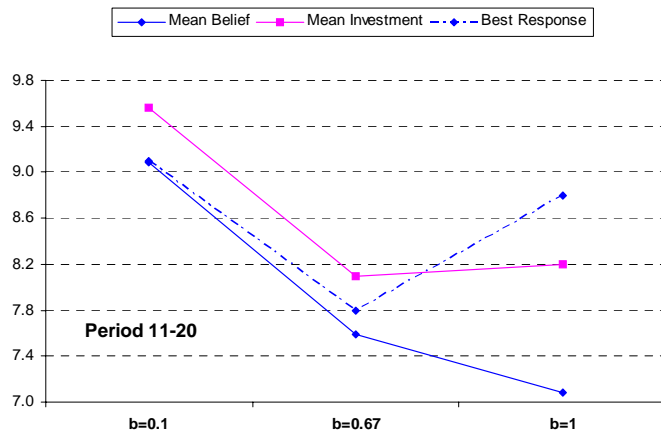


Figure 14: Mean belief in period 11-20.

For weak and intermediate competition, Figure 14 reveals that the overinvestment can be partly explained through the underestimated beliefs. However, mean investments are even higher than the best response to the wrong beliefs. For strong competition, the underestimated beliefs do not lead to overinvestment which would arise by best-responding.

To test the strength of the U-shaped relations shown in Result 6 and 7, consider the random-effects model given by (16). Estimates are shown in Table 3.

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

Variable	Period 1-10	Period 11-20
<i>const</i>	8.3590*** (0.1684)	8.0916*** (0.1644)
<i>weak</i>	1.1075*** (0.2384)	1.4666*** (0.2239)
<i>strong</i>	0.3436* (0.2715)	0.1050 (0.3502)

Note: Random-effects GLS regression. \* denotes significance at the 10%-level, \*\*\* at the 1%-level. Robust standard errors in parentheses.

For period 1 to 10, the coefficient related to *weak* is positive and significant at the 1%-level. The coefficient for *strong* is positive and significant at the 10%-level. This means that the decrease in investment is substantial when switching from weak to intermediate competition; the increase when switching from intermediate to strong competition is less pronounced. For period 11 to 20, the coefficient for *weak* is positive and significant at the 1%-level; the one for *strong* is positive but not significant. This implies that the decrease in investment is strong, the increase extremely weak. Summarizing we get Result 8.

**Result 8** *The U-shaped relation is stronger in the first ten than in the last ten periods.*

**Sequencing effects** In the following, we compare S1 to S2, and S3 to S4. We start with S1 and S2, where  $b = 0.1$  and  $b = 0.67$  are the relevant parameters.

**Result 9** *For S1 and S2, more intense competition shifts the players' investment distribution to the left.*

According to prediction, subjects choose in both sessions higher investments when competition is less intense. For the considered two sessions, the distributions look similar. Figure 15 concerns S1.

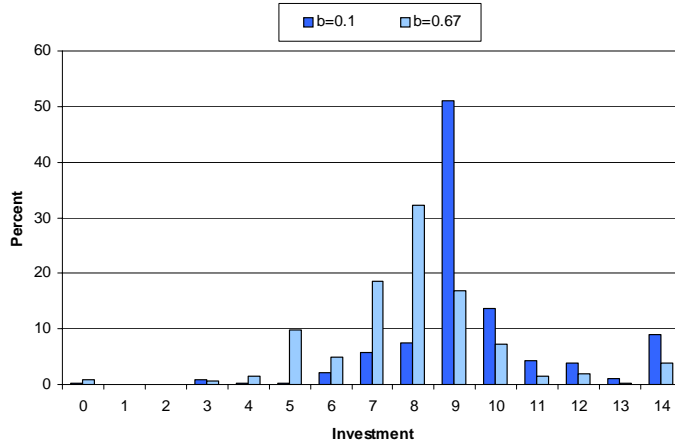


Figure 15: Investment distributions in S1.

For weak competition, the global maximum is at 9 and chosen in 51% of the cases. In fact, playing 9 represents a weakly dominant strategy.<sup>12</sup> Switching to intermediate competition shifts the global maximum to 8 (32%). The last considerations refer to S3 and S4, where  $b = 0.67$  and  $b = 1$  are the parameters involved.

**Result 10** *For S3 and S4, more intense competition does not unambiguously shift the players' investment distribution to the right.*

In contrast to prediction, higher intensity of competition does not clearly lead to higher investments. This is consistent with Result 8. Figure 16, which refers to S3, shows that the distributions are similar.

<sup>12</sup>In S1, we have eleven subjects choosing the investment level of 9 in each of the ten periods, sixteen subjects in at least eight periods. There are 28 subjects which invest on average between 8 and 10.

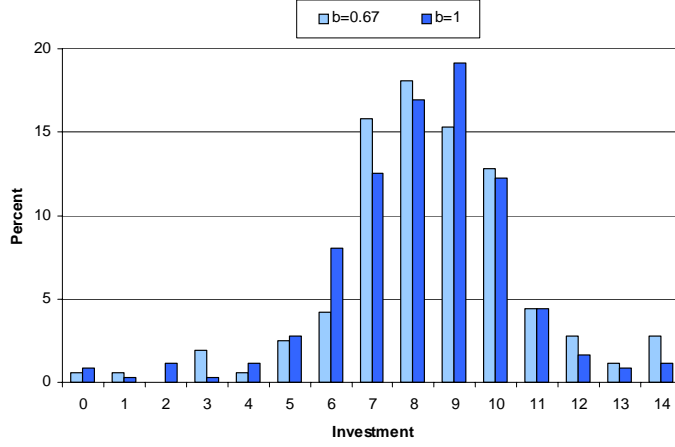


Figure 16: Investment distributions in S3.

## 4 Conclusion

We have analyzed the effects of varying the intensity of competition on investment incentives in an experiment, where we implemented a reduced form version of a two-stage game. In the first stage, duopolists choose cost-reducing investments. In the second stage, they choose quantities in a heterogeneous good market. Increasing competition corresponds to decreasing product differentiation.

We considered two settings: A symmetric and an asymmetric one. In the symmetric setting, firms' initial marginal costs are identical. In the asymmetric setting, there is a leader-laggard structure. The leader has lower marginal costs ex-ante. We have shown that, for symmetric firms and leaders, there is a U-shaped relation between the intensity of competition and investment. If the ex-ante cost difference between leader and laggard is sufficiently high, there is a negative relation for the laggard. Otherwise, the laggard also exhibits a U-shaped relation. Moreover, the leader invests more than the laggard; that is, increasing dominance arises.

The experimental sessions mostly support the theoretical predictions. For symmetric players and leaders, the U-shaped relation emerges; for laggards, as predicted, there is a negative relation. Moreover, leaders invest more than laggards, providing evidence for increasing dominance. However, in

both settings, there are deviations from the equilibrium. To a large extent, these deviations reflect best responses to wrong beliefs. In the symmetric setting, there is overinvestment no matter which intensity of competition is implemented. In the asymmetric setting, leaders underinvest under strong competition and laggards mostly overinvest.

## Appendix

### Proof of Proposition 1

(5) leads to the following results.

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, (5) has a unique zero  $\hat{b} \in (0, \frac{2}{3}]$ .  $\hat{b}$  is given by

$$\hat{b} = \frac{4 - 2\sqrt{-3Q^2 + 4}}{3Q}, \quad (17)$$

where  $Q = \frac{Y_2}{Y_1} \leq 1$ . Thus,  $Q^2 < \frac{4}{3}$  ensures the existence of  $\hat{b}$ . If  $\frac{Y_2}{Y_1} \rightarrow 1$ , 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 (17), where  $Q = \frac{Y_1}{Y_2}$ . We need  $Q^2 \leq \frac{4}{3}$  to ensure the existence of  $\tilde{b}$ , and  $Q^2 \leq \frac{64}{49}$  to ensure that  $\tilde{b} \in [0, 1]$ . If  $\frac{64}{49} < Q^2 \leq \frac{4}{3}$ , then  $\tilde{b} \in (1, \frac{2}{\sqrt{3}}]$ . If  $Q^2 > \frac{4}{3}$ , there is no  $\tilde{b}$ .

This yields statements (i) to (iv).

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