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Competition and Innovation: An Experimental Investigation*

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ABSTRACT: The paper analyzes the effects of competitive intensity on firms' incentives to invest in process innovations through an experiment based on two-stage games, where R&D investment choices are followed by product market competition. An increase in the intensity of competition is modeled as an increase in the number of firms or as a switch from Cournot to Bertrand. The theoretical prediction is that more intense competition is unfavorable to investments for both cases. In the experiment it turns out that the way of modeling the intensity of competition is essential. The theoretical prediction is confirmed for the number effects. On the other hand, the comparison of Cournot and Bertrand shows that more intense competition is beneficial for investments.

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1 Introduction

There is broad agreement among economists that R&D is an important driver of economic growth. Some authors like Arrow (1962) claim that without competitive pressure there are little incentives to invest in R&D. Others like Schumpeter (1943) argue that some degree of monopoly power is necessary for innovative activities.

In this paper we use specific notions of increasing competition from industrial organization to derive predictions about the effects of competitive intensity on the incentives to innovate. The predictions obtained in this fashion are tested experimentally.

The obvious candidate for defining the intensity of competition is given by the number of firms. However, the intensity of competition has an influence on the decisions of firms to enter a market. Due to this endogeneity problem it seems reasonable to consider alternative concepts. For example, one can model the intensity of competition through the distinction between Cournot and Bertrand, where the Bertrand case represents more intense competition. Another possibility is given by the substitutability of products; that is, the intensity of competition is higher when goods are closer substitutes. Further measures are the ease of entry or the market size; that is, the easier to enter a market or the smaller the market size the higher the intensity of competition. Boone (2000) developed a unifying concept. He showed that all the mentioned parametrizations of competition have a feature in common, namely that a rise in competition increases the profits of a firm relative to the profits of a less efficient firm.

In this paper we deal with two measures of competitive intensity. First, we consider the number of firms for a given type of product market competition. Second, we compare Cournot and Bertrand competition for a given number of firms. The Bertrand case represents more intense competition because it will turn a winner-takes-all structure. This means that only the most efficient firm gets a positive profit. The ratio between the profits of the most efficient firm and the laggards is infinite under Bertrand competition, and therefore larger than in the Cournot case, where it is finite; according to Boone (2000), competition is thus more intense in the former case.

The theoretical literature on the subject is typically about patent races. For instance, Lee and Wilde (1980) and Delbono and Denicolò (1991) study the effects of the number of firms on investments in such a framework. The former analyze games of R&D competition between symmetric firms in a

Bertrand setting. They deal with dynamic investment races and show that the R&D effort per firm grows as the number of firms increases. Delbono and Denicolò (1991) work in a similar setting as Lee and Wilde (1980), except that product market competition is of a Cournot type. Therefore, with non-drastic innovations, even losers in the innovation race earn positive profits. Delbono and Denicolò (1991) show that an increase in the number of firms results in a decrease of both the R&D investment of each firm and the total investment. In a stochastic patent race preceding product market competition, Delbono and Denicolò (1990) directly compare investments for Cournot and Bertrand competition. In the Bertrand case investment is unambiguously higher than in the Cournot case. This effect is driven by the fact that, with more intense competition, outputs tend to be larger, so that cost reductions are more valuable. There are also papers that investigate the robustness of this argument with respect to the extent of product differentiation. Bester and Petrakis (1993) show that, with sufficiently large horizontal product differentiation, the innovation incentive is higher under Cournot competition than under Bertrand competition.[1]

The empirical work on the subject also comes to ambiguous conclusions. The early literature regarded market structure as an explanatory variable. This is shown in the survey of Cohen and Levin (1989). However, the causality might run in the opposite direction. Innovation may affect market structure because R&D involves fixed costs or because it affects the pattern of firm growth in an industry. Innovation can also affect market structure indirectly, by increasing or decreasing the efficient scale of production. This endogeneity problem has been analyzed by the more recent literature, for example by Aghion et al. (2005), where an inverted-U relationship between intensity of competition and investments arises. However, due to the fact that the empirical analysis is still inconclusive, it seems reasonable to use experiments as a complementary strategy because of the flexibility when choosing variables as exogenous or endogenous according to theoretical needs.

Contrary to the theoretical literature, there are only few experimental studies which deal directly with the linkage between intensity of competition and R&D investments. Isaac and Reynolds (1988, 1992) consider the number effects. They deal with stochastic static and dynamic patent races and show that an increase in the group size lowers investment per firm and raises

[1] Bonnano and Haworth (1998) come to an even starker conclusion regarding vertical product differentiation.

aggregate investment. Concerning the comparison of Cournot and Bertrand competition there is the paper of Sacco and Schmutzler (2006), where a deterministic investment game has been analyzed and it has been shown that greater competition induces higher investments.

This study extends the analysis of Sacco and Schmutzler (2006) by treating a further measure of the intensity of competition, namely the number of firms. Thus, we can examine whether different modeling methods lead to the same theoretical and experimental results. The analysis is based on deterministic two-stage games, where investment decisions are followed by product market competition. In the first stage identical firms producing homogenous goods simultaneously invest in R&D, which yields a decrease in marginal costs. In the second stage firms simultaneously choose quantities (Cournot) or prices (Bertrand).[2] The theoretical model predicts that more intense competition is unfavorable to investments, no matter whether increasing competition corresponds to an increase in the number of firms or to the shift from Cournot to Bertrand. In the experiment it turns out that the way of modeling the intensity of competition is relevant. An increase in the number of firms yields lower investments. On the other hand, a shift from Cournot to Bertrand leads to higher investments, even though this is inefficient when considering the joint profit maximization.

The paper is structured as follows. Section 2 contains the theoretical framework. Section 3 describes the experimental results. Section 4 concludes.

2 The Model

We analyze static two-stage games, where firms $i = 1, ..., I$ first invest in R&D and then compete in the product market. The demand function for the homogenous product is given by $D(p) = a - p$, with $a > 0$. All firms i are identical ex ante with constant marginal costs $c > 0$. In the first stage firms simultaneously choose R&D investments $Y_i \in [0, c)$, resulting in marginal costs $c_i = c - Y_i$.[3] The cost of R&D is given by kY_i^2, where $k > 0$. In the second stage firms simultaneously choose quantities (Cournot) or prices (Bertrand). We refer to the Cournot case as soft competition (SC); to the Bertrand case as intense competition (IC).

[2] The set-up corresponds to Sacco and Schmutzler (2006).

[3] Even though agents are restricted to finite choice sets in the experiment, the theoretical analysis is much more transparent if the choice set is a continuum.

2.1 Soft Competition

For SC, that is, if firms compete in quantities in the second stage, backward induction shows that the net payoff function of firm i in the first stage is given by

$$\Pi_i(Y_1, ..., Y_I, \alpha, k) = \left(\frac{\alpha + IY_i - \sum_{i \neq j} Y_j}{I+1} \right)^2 - kY_i^2, \tag{1}$$

where $\alpha \equiv a - c$ represents the demand parameter.

It is easy to see that the first term on the right-hand side of (1), namely the gross payoff of firm i, depends positively on its own investment and the demand parameter, and negatively on the investments of the other firms. Competition is soft in the sense that, even investing less than the others, a firm achieves a positive gross payoff, as long as the numerator of the gross payoff term is positive.

The maximization of (1) with respect to Y_i yields

$$\frac{\partial \Pi_i(\cdot)}{\partial Y_i} = \frac{2I(\alpha + IY_i - \sum_{i \neq j} Y_j)}{(I+1)^2} - 2kY_i \equiv 0. \tag{2}$$

The assumption in the following is that the second order condition holds, that is,

$$\frac{\partial^2 \Pi_i(\cdot)}{\partial Y_i^2} = \frac{I^2}{(I+1)^2} - k < 0, \tag{3}$$

which is fulfilled for arbitrary $I \geq 2$ if $k > 1$.

The equilibrium follows immediately from (2).

Proposition 1 *Under SC the symmetric pure strategy Nash equilibrium investment levels are*

$$Y^{SC} = \frac{\alpha I}{k(I+1)^2 - I}. \tag{4}$$

It is straightforward to check from (4) that the equilibrium investment levels are increasing in the demand parameter α, and decreasing in the cost parameter k and in the number of firms I.

2.2 Intense Competition

For IC, that is, if firms compete in prices in the second stage, it results from backward induction that the net payoff function of firm i in the first stage is given by

$$\Pi_i(\cdot) = \begin{cases} (Y_i - Y_{-i}^m)D(c - Y_{-i}^m) - kY_i^2, & \text{if } Y_i > Y_{-i}^m \\ -kY_i^2, & \text{if } Y_i \leq Y_{-i}^m \end{cases}, \tag{5}$$

where $Y_{-i}^m = \max_{j \neq i} Y_j$.

Competition is intense in the sense that a firm can achieve a positive gross payoff only by investing more than the highest investment of the others.

If $Y_i > Y_{-i}^m$, the maximization of (5) with respect to Y_i leads to

$$\frac{\partial \Pi_i(\cdot)}{\partial Y_i} = D(c - Y_j^m) - 2kY_i \equiv 0. \tag{6}$$

If $Y_i \leq Y_{-i}^m$, then clearly $Y_i = 0$ holds. If firm i does not invest more than the highest investment of the others, it gets a negative net payoff. In such a case the deviation to $Y_i = 0$ is profitable.

Note that the concavity condition is fulfilled for $k > 0$. The equilibrium is characterized as follows.

Proposition 2 *Under IC, for $k > \frac{1}{2}$, there are multiple asymmetric equilibria with one firm investing $Y_i^{IC} = \frac{\alpha}{2k}$ and firms $j \neq i$ investing $Y_j^{IC} = 0$.*

Proof. If firms $j \neq i$ invest $Y_j^{IC} = 0$, then according to (6) the best response of firm i is $Y_i^{IC} = \frac{\alpha}{2k}$ for any $k > 0$. If firm i invests $Y_i^{IC} = \frac{\alpha}{2k}$, then the best response of the other firms is $Y_j^{IC} = 0$ for $k > \frac{1}{2}$. That is, firm j does not have an incentive to exceed the investment of firm i by choosing $Y_j^{IC} = \frac{\alpha}{2k} + \Delta$, where $\Delta > 0$. The value $\Delta = \frac{\alpha}{4k^2}$ maximizes $\Pi_j(\cdot)$ which is negative for $k > \frac{1}{2}$. This concludes the proof. ■

The non-existence of symmetric pure strategy equilibria for IC makes it unlikely that agents coordinate on an equilibrium. Nevertheless, we chose the set-up because it is a particularly clear way of modeling intense competition.

It is easy to see from Proposition 2 that the average equilibrium investment level is given by

$$\overline{Y}^{IC} = \frac{\alpha}{2kI}, \tag{7}$$

which is increasing in the demand parameter, and decreasing in the cost parameter k and in the number of firms I.

2.3 The Effects of Increasing Competition

By defining the intensity of competition through the number of firms we have seen that more intense competition has a negative effect on the incentives to invest.

Corollary 1 *For a given type of product market competition, SC or IC, the average equilibrium investments are decreasing in* I.

In analogy to that, comparing (4) to (7), the following result arises.

Corollary 2 *Suppose that (3) holds and* $k > \frac{1}{2}$. *The average equilibrium investment for SC is higher than the average investment in each asymmetric pure strategy equilibrium for IC if and only if* $I \geq 3$ *or* $I = 2$ *and* $k < 2$.

We therefore have that for a given number of firms, except for the case with $I = 2$ and $k \geq 2$, a switch from SC to IC reduces average investments. Again, an increase in competition is unfavorable to the incentives to invest.

3 The Experiment

3.1 Choosing the Parameters

We conducted four experimental sessions: Two of them correspond to SC and two to IC. For both SC and IC there was a session with two-player groups (SC2 and IC2) and one with four-player groups (SC4 and IC4). Further, we chose the parameters $\alpha = 30$ and $k = 3$. In the case of SC with continuous investment choices the equilibria $(2.4, 2.4)$ and $(1.69, 1.69, 1.69, 1.69)$ arise for SC2 and SC4, respectively. On the one hand, according to Proposition 1, investment per firm decreases in the number of firms; it is maximal in the monopoly case. On the other hand, total investment increases if competition is more intense. According to Proposition 2, there are asymmetric equilibria for IC with continuous investment choices, each with one firm investing 5 and the other firm(s) investing 0.

However, in the experimental sessions, we restricted the investment choice set to $Y_i \in \{0, 1, ..., 9\}$. Under SC, it can be shown that the equilibria of the game with the discrete choice set are $(2, 2)$ and $(2, 2, 2, 2)$ for SC2 and SC4, respectively. Under IC, equilibrium investments are not affected by the change of the choice set.

These four sessions allow to analyze the effect of the intensity of competition on the incentives to invest in R&D in two different ways. First, according to Corollary 1, for a given type of product market competition we can look at the effect of increasing the number of players on investments. Second, according to Corollary 2, for a given number of players we can examine changes in the investment behavior by considering the switch from SC to IC.

3.2 Experimental Design and Procedures

The experimental sessions were conducted in June and November 2006 at the University of Zurich. The participants were undergraduate students.[4]

The games implemented in the experiment are reduced form versions of the described two-stage games. To focus on investment choices, we reduced the games to the first stage, that is, to the investment stage. We did not model the product market stage explicitly, avoiding the chance of an influence of the second stage on the first one. For each investment profile, players earned the unique Nash equilibrium payoffs of the corresponding subgame.

In the first two sessions we implemented the IC treatments, in the last two the SC treatments. In each session there were 20 periods and in two of four sessions 36 subjects.[5] This led to a total of 2760 investment observations. No subject participated in more than one session. The participants were randomly matched into groups of size two or four after each period. This corresponds to a Stranger design.[6] At the end of each period subjects were informed about the investment level of the other group member(s) and their own net payoff for that period. In each session participants received an initial endowment of CHF 35 (≈US$ 28).[7] Average earnings including the endowment were CHF 31 (≈US$ 25) and CHF 32.50 (≈US$ 26) for IC2 and IC4, respectively. The amounts were CHF 49 (≈US$ 39) and CHF 39 (≈US$ 31) for SC2 and SC4, respectively. Sessions lasted about 90 minutes each. The experiment was programmed and conducted with the software z-Tree (Fischbacher, 1999).

[4] We did not exclude any disciplines. We had students of law, engineering, psychology, economics etc.

[5] In the SC4 and IC2 sessions there were 32 and 34 participants, respectively.

[6] Observe that through the choice of a Stranger design the experimental analysis is based on one-shot considerations.

[7] The instructions are available upon request.

3.3 Results

In this section the number effects are first analyzed. That is, for a given type of product market competition we consider the effects of increasing the number of players on investments. The analysis of the SC treatment precedes that of the IC treatment. Second, for a given number of players, we take the switch from SC to IC into account.

3.3.1 Soft Competition

Given SC, we analyze the effects of increasing the number of players from $I = 2$ to $I = 4$ on the investment behavior. The theoretical prediction based on the discrete choice set is that each firm chooses the investment level of 2. That is, the mean investment level for SC2 is the same as for SC4 ($\overline{Y}^{SC2} = \overline{Y}^{SC4} = 2$). The experiment does not provide evidence for this prediction.

Result 1 *Mean investments are higher for SC2 than for SC4.*

<Figure 1 here>

Considering all periods, both a regression over a constant and a Wilcoxon rank sum test show that the difference between the two treatments is highly significant ($p < 0.01$). This also holds in the last five periods. That is, the mean investment level under SC2 does not converge to that under SC4.

Figure 1 reveals that there is overinvestment for SC2 and underinvestment for SC4. In the SC2 treatment the difference between investments and Nash equilibrium is highly significant over all periods. This also holds in the last five periods. In the SC4 treatment the difference with respect to the prediction is likewise highly significant throughout the 20 periods. Interestingly, this also holds in the last five but not in the first five periods. It is important to note that, even though the experiment does not provide evidence for the prediction based on the discrete choice set, it does considering the continuous choice set. The fact that theoretically the two-player case yields higher per capita investments than the four-player case ($2.4 > 1.69$) emerges experimentally.

A further interesting aspect concerns the heterogeneity of player behavior. One way to analyze heterogeneity is to consider the spread of investment choices. This is shown in Result 2.

Result 2 *The spread of the investment choices, defined as the difference between the maximum and the minimum investment level within a group, is higher on average for SC4 than for SC2.*

<Figure 2 here>

Inspection of Figure 2 shows that with exception of period 11 and 14 the mean spread is higher when competition is more intense. Both under SC2 and SC4 the difference to the equilibrium spread of 0 is highly significant over all periods.

Another way to analyze heterogeneity is to consider the investment distribution. Over all periods the properties for SC2 and SC4 are summarized in Result 3.

Result 3 *For SC2 the following holds: The equilibrium investment level of 2 is the most chosen, followed by 3.*

For SC4 the following holds: 2 is the most chosen investment level, followed by 1.

<Figure 3 here>

The investment distributions are highly concentrated. Figure 3 reveals that in the SC2 treatment the investment level of 2 is played in 43% of the cases and that 3 is chosen in 34% of the cases. The Nash equilibrium with both subjects in a group investing 2 arises in 59 of the 360 one-shot games.[8] Further, one fourth of the subjects plays 2 in at least 16 of the 20 periods; four participants choose 2 in each period.

In the SC4 treatment the investment level of 2 is played in 47% of the cases and 1 is chosen in 33% of the cases. The Nash equilibrium with each

[8] 20 periods times 18 groups per period yields 360.

subject investing 2 arises in 12 of the 160 one-shot games.[9] Moreover, one fourth of the subjects plays 2 in at least 15 of the 20 periods.

The properties contained in Result 3 also hold in individual periods. Under SC2 the investment level of 2 is chosen most often in 17 periods, followed by 3. In the remaining three periods 3 is the most frequently played investment level, followed by 2. Under SC4, again in 17 periods, 2 is mostly chosen, followed by 1. In the other three periods 1 is mostly played, followed by 2.

To analyze if the heterogeneity is due to individual investment patterns, one can examine the distribution of the average investments per subject.

<Table 1 here>

For each interval of length 1, Table 1 gives the number of subjects whose average investment is in the interval, both under SC2 and SC4. We see that the high concentration of the investment distributions is clearly due to individual patterns. For SC2 there are 28 subjects of 36 whose mean investment over the 20 periods lies between 2 and 3. For SC4 there are 20 subjects of 32 with a mean investment that lies between 1 and 2.

3.3.2 Intense Competition

Given IC, the effects of increasing the number of players from $I = 2$ to $I = 4$ on investments are considered. The theoretical analysis shows that there are asymmetric equilibria, each with one firm investing 5 and the other firm(s) investing 0. That is, the mean investment level for IC2 ($\overline{Y}^{IC2} = 2.5$) is higher than for IC4 ($\overline{Y}^{IC4} = 1.25$). The experiment provides evidence for this prediction.

Result 4 *Mean investments are higher for IC2 than for IC4.*

<Figure 4 here>

[9] 20 periods times 8 groups per period yields 160.

Both a regression over a constant and a Wilcoxon rank sum test show that the difference between the two treatments is highly significant over all periods. Figure 4 reveals that the mean investment level under IC2 does not approach the one under IC4. Like in the case involving all periods the difference between the two treatments is highly significant when taking into account either the last ten periods or the last five.

According to Corollary 1, the experimental analysis confirms the fact that, both for SC and IC, mean investments are decreasing in the number of agents. This has been shown in Result 1 and 4. This contrasts the findings of other settings like those discussed by Huck et al. (2004) for which cooperative behavior is more likely when the number of players is small; one might therefore expect in our context where investments have negative externalities on the other players less incentives to invest in the two-player than in the four-player case. Though, one must keep in mind that, due to the choice of a Stranger design, it is unlikely that cooperative behavior arises. However, by looking at the IC treatment another effect seems to dominate. Under IC2 subjects invest more because of a risk argument. That is, the probability of getting a positive gross payoff by investing more than the other(s) is higher for IC2 than IC4.

Figure 4 also shows that, both under IC2 and IC4, the mean investments over the 20 periods always lie above the Nash equilibrium values of 2.5 and 1.25, respectively.

In the IC2 treatment the difference between investments and Nash equilibrium is highly significant throughout the 20 periods. This still holds when considering either the last ten periods or the last five. That is, there is no convergence to the Nash equilibrium value of 2.5, even though the investments in the first ten periods are significantly higher than those in the last ten periods (Wilcoxon rank sum test, $p = 0.016$).

In the IC4 treatment, considering all periods, a regression over a constant shows that the difference between investments and Nash equilibrium is highly significant. In contrast to that, a Wilcoxon rank sum test indicates high significance only in the first five periods ($p = 0.01$). However, the investments in the first ten periods are not significantly higher than those in the last ten periods (Wilcoxon rank sum test, $p = 0.146$). Again, there is no convergence to the Nash equilibrium value of 1.25. Considering the last five periods a Wilcoxon rank sum test shows significance at the 4%-level.

Another way to analyze the overinvestment feature is to look at the percentage deviation from the Nash equilibrium in both treatments.

<Figure 5 here>

Inspection of Figure 5 shows that the percentage deviations from the theoretical predictions are similar in most periods. In certain periods the deviation is higher for IC4 but there is no significant difference. We can therefore claim that in both treatments there is the same investment behavior in relation to the Nash prediction.

The next three results refer to the heterogeneity of player behavior.[10]

Result 5 *The spread of the investment choices is higher on average for IC4 than for IC2.*

<Figure 6 here>

By considering Figure 6 we see that with few exceptions the mean spread for IC4 lies between 4 and 6 and that for IC2 between 2 and 4. Under IC4 the mean spread is below the equilibrium spread of 5 in 15 of the 20 periods. Over all periods the difference is highly significant.

Due to the coordination problem related to the asymmetric equilibria, it is interesting to look at the investment distributions. The properties when considering all periods are summarized in Result 6.

Result 6 *For IC2 the following holds: The investment distribution exhibits a global maximum at 5. There is a local maximum at 0.*

For IC4 the following holds: The investment distribution exhibits a global maximum at 0. There is a local maximum at 5.

<Figure 7 here>

[10] This heterogeneity explains why the result for IC4 regarding the difference between investments and Nash equilibrium obtained by a regression over a constant is not supported by a Wilcoxon rank sum test.

The prediction for IC2 is that the investment levels of 0 and 5 are played in 50% of the cases, respectively. Inspection of Figure 7 reveals that in the IC2 treatment 5 is chosen in 24% of the cases and that 0 is played in 15% of the cases. The Nash equilibrium with one subject investing 5 and the other 0 arises in 24 of the 340 one-shot games.[11]

The prediction for IC4 is that the investment level of 0 is played in 75% and that of 0 in 25 % of the cases. Figure 7 shows that in the IC4 treatment 0 is chosen in 44% of the cases; thereby one fourth of the participants plays 0 in at least 15 of the 20 periods. Three subjects play 0 in every period. The distribution over the other investment levels exhibits another local maximum at 5 which is chosen in 17% of the cases. The Nash equilibrium with one subject investing 5 and the others 0 arises in 14 of the 180 one-shot games.[12]

It is important to note that, though the frequency with which 0 and 5 are played is lower than predicted, the subjects understand the incentives of the IC game. For example, under IC4, the investment level of 0 is chosen in almost half of the cases, which shows that the participants are aware of the low probability of getting a positive gross payoff.

Surprisingly, in spite of the coordination problem, the properties summarized in Result 6 also hold in individual periods. This is shown in Result 7.

Result 7 *For IC2 the following holds: In 19 periods the investment distribution exhibits a global maximum at 4 or 5. In 15 periods there is a local maximum at 0.*

For IC4 the following holds: In each period the investment distribution exhibits a global maximum at 0. In each period there is a local maximum at 4 or 5.

The next observation refers to the distribution of the average investments per subject.

<Table 2 here>

By considering Table 2 we see that for IC4 the heterogeneity reflects individual behavioral patterns. Except for the fact that the global maximum

[11] Observe that 20 periods times 17 groups per period yields 340.

[12] 20 periods times 9 groups per period yields 180.

arises in the interval $[1, 2)$ and not in $[0, 1)$, the distribution of the average investments is similar to the distribution shown in Figure 7. For IC2 the same holds. Except the interval $[0, 1)$, where a local maximum does not emerge, the distribution is similar to that of Figure 7.

The last point concerns the investments of the leaders, that is of those with the highest investment within a group. Because of the asymmetric equilibria it is interesting to look at this aspect.

<Figure 8 here>

Figure 8 shows that both for IC2 and IC4 the mean investments of the leaders are close to 5 throughout the 20 periods, which is consistent with the prediction.

3.3.3 Soft versus Intense Competition

In the following we analyze the effects of switching from SC to IC on the investment behavior for a given number of players. We first treat the two-player case. Theoretically, the mean investment level for SC2 ($\overline{Y}^{SC2} = 2$) is lower than for IC2 ($\overline{Y}^{IC2} = 2.5$). The experiment provides evidence for this prediction.

Result 8 *Mean investments are higher for IC2 than for SC2.*

<Figure 9 here>

Over all periods the difference between the two treatments is highly significant. Figure 9 shows that the mean investment level under IC2 does not approach the one under SC2. Even in the last five periods the difference remains highly significant.

The overinvestment feature both for IC2 and SC2 has already been discussed. In addition to that, it is relevant to point out that the deviation from the equilibrium is more pronounced under IC2.

<Figure 10 here>

As revealed in Figure 10, in each period the mean investment level in the IC2 treatment exceeds the corresponding equilibrium value more than the mean investment level under SC2 does. The difference is highly significant when taking into account either all periods or the last five periods.

The next result concerns the heterogeneity aspect.

Result 9 *The spread of the investment choices is higher on average for IC2 than for SC2.*

<Figure 11 here>

Over all periods the difference is highly significant. The diversity regarding the investment distributions is shown in Figure 12.

<Figure 12 here>

The last results are related to the four-player case. The theoretical prediction is that the mean investment level for SC4 ($\overline{Y}^{SC4} = 2$) is higher than for IC4 ($\overline{Y}^{IC4} = 1.25$). The experiment does not provide evidence for this prediction.

Result 10 *Mean investments are higher for IC4 than for SC4.*

<Figure 13 here>

By considering Figure 13 we see that with exception of period 18 and 19 the mean investment level is higher if competition is more intense. Taking into account all periods a regression over a constant shows that the difference between the two treatments is highly significant. Contrary, a Wilcoxon rank sum test indicates significance at the 10%-level only in the first ten periods. The mean investment level under IC4 seems to converge to that under SC4. However, a regression over a constant and a Wilcoxon rank sum test lead to different results. Considering the last five periods, the former shows no significant difference between the two treatments, whereas the latter exhibits significance at the 4%-level.

The important aspect of Result 8 and 10 is the fact that, by defining the intensity of competition through the switch from SC to IC instead of the number of agents, the experimental results are reversed. That is, in contrast to Result 1 and 4, more intense competition leads to higher mean investments. This is driven by the fact that in the IC treatment only investing more than the others leads to positive gross payoffs.

Last, the heterogeneity of subjects' investment behavior is briefly discussed.[13]

Result 11 *The spread of the investment choices is higher on average for IC4 than for SC4.*

<Figure 14 here>

The difference is highly significant when considering either all periods or the first five periods. It is interesting to note that mean spreads are higher when competition is more intense in each of the considered cases.

Further, Figure 15 shows the investment distributions.

<Figure 15 here>

Concluding, it is important to observe that all results regarding SC4 and IC4 confirm the findings of Sacco and Schmutzler (2006). There, for the four-player case, the intensity of competition is modeled through the comparison of Cournot and Bertrand competition.

[13] Again, due to the heterogeneity of the investment choices, the statistical analysis regarding Result 10 is not unique.

3.3.4 Investments' Efficiency

We have seen that, with the exception of SC4, all treatments have an overinvestment feature in common. An interesting point to analyze is to what extent behavior deviates from efficiency. One way to do that is to relate the joint net payoffs realized in the experimental sessions to the maximal joint net payoffs. For IC the maximal joint net payoff is given by equilibrium. Due to the fact that the equilibrium strategy has one player investing and considering that this player maximizes his own net payoff by choosing the investment level of 5, it follows that also the joint net payoff is maximal. On the other hand, under SC, the equilibrium case with all players investing 2 does not maximize the joint net payoff. For SC2 it can be shown that the maximal joint net payoff arises when the two players choose the investment level of 1; under SC4 when one player chooses 1 and the others 0.

To look at the investments' efficiency the following measure called efficiency rate (ER) can be used:

$$ER = \frac{Mean\ Joint\ Net\ Payoff}{Maximal\ Joint\ Net\ Payoff}.$$

The ER considers the joint net payoff over all periods and groups in relation to the maximal joint net payoff. For IC negative values emerge, which signalize inefficiency. Under IC2 a value of -0.69 arises; under IC4 -0.87. That is, the overinvestment feature does not have beneficial effects on net payoffs. The participants made losses over the 20 periods. In the IC2 treatment, 22 of the 34 subjects earned a negative net payoff in at least 14 periods. In the IC4 treatment, 13 of the 36 subjects earned a negative net payoff in at least 13 periods. No subject earned more than the initial endowment at the end of the IC sessions. On the other hand, the SC cases are relatively efficient. The SC2 treatment leads to an ER of 0.91. For SC4 the value is 0.77. Each participant earned more than the initial endowment.

4 Conclusion

This paper has analyzed the effects of increasing the intensity of competition on investment incentives in an experiment where a reduced form version of a simple two-stage R&D model has been implemented. In the first stage firms whose marginal costs are identical ex-ante simultaneously invest in R&D.

The investment leads to a decrease in marginal costs. In the second stage of the game firms simultaneously choose quantities or prices in a homogenous good market.

The intensity of competition has been modeled in two ways. First, as an increase of the number of firms for a given type of product market competition. The theoretical prediction is that, both for SC and IC, an increase in the number of agents yields lower mean investments. This fact is confirmed by the experimental results. Mean investments are higher for a smaller number of players. Even though investments have a negative externality on the other agents, there is no cooperative behavior in the two-player case. With exception of the SC4 treatment the other three sessions have led to overinvestments which are in the IC case inefficient when considering the joint profit maximization.

Second, the intensity of competition has been modeled through the comparison of Cournot and Bertrand for a given number of players. Thereby, Bertrand competition has a winner-takes-all structure and therefore represents more intense competition. Again, it results theoretically that, with exception of a particular case, higher intensity of competition is unfavorable to investments. The experimental results are interesting because they reverse the ones obtained in the case which refers to the number of players as a measure of the intensity of competition. That is, mean investments are higher for intense competition than for soft competition. This holds both for two and four players.

Interestingly, both for SC and IC the heterogeneity of the investment distributions largely reflects the one across individuals. Even in the IC treatment where the coordination on equilibria is obviously difficult due to the choice of a game with multiple asymmetric equilibria, stable behavioral patterns emerge early on.

Robustness checks are conceivable. For example one could model increasing competition through increasing substitutability and see what experimental results arise. Further, it would also be interesting to test a model like that of Aghion et al. (2005) which predicts an inverted-U relationship between intensity of competition and investments.

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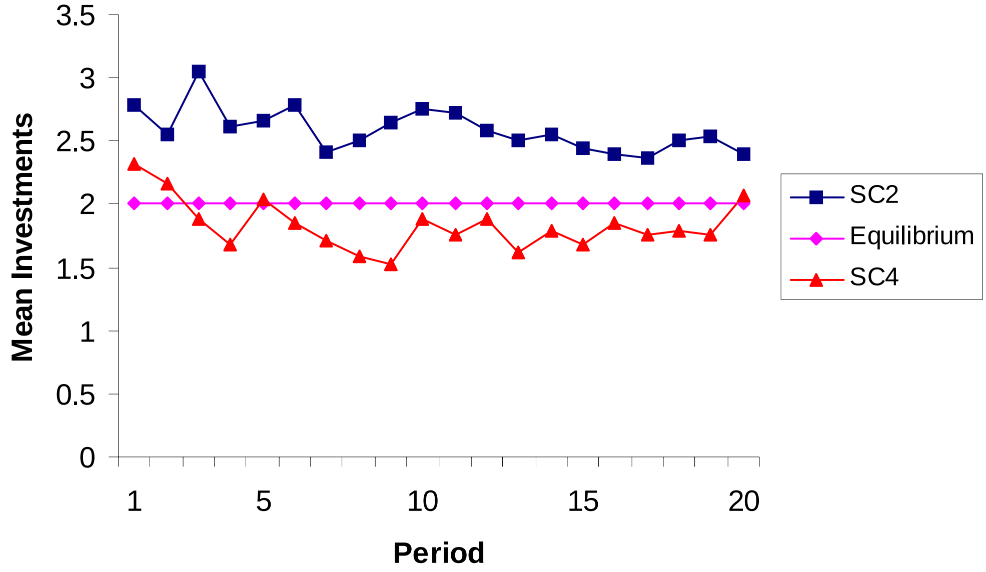

Figure 1: Mean investments.

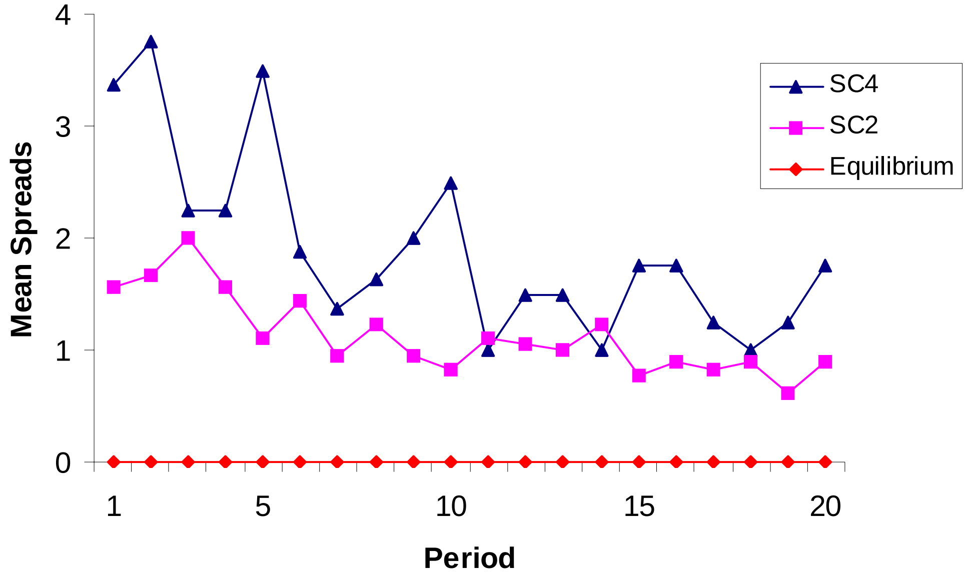

Figure 2: Mean spreads.

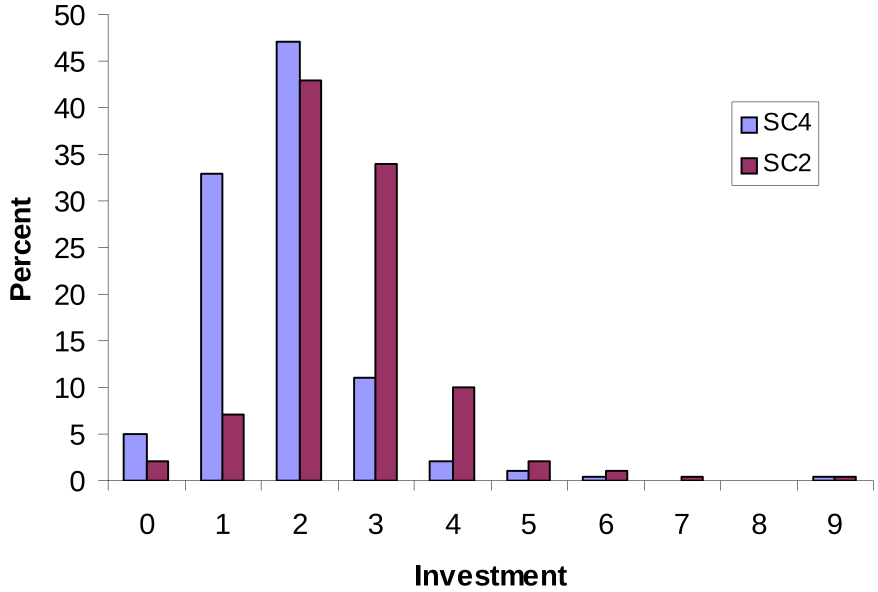

Figure 3: Investment distributions.

Interval	$[0,1)$	$[1,2)$	$[2,3)$	$[3,4)$	$[4,5)$	$[5,6)$	$[6,7)$	$[7,8)$	$[8,9)$
SC2	0	1	28	6	1	0	0	0	0
SC4	2	20	9	1	0	0	0	0	0

Table 1: Subject distributions.

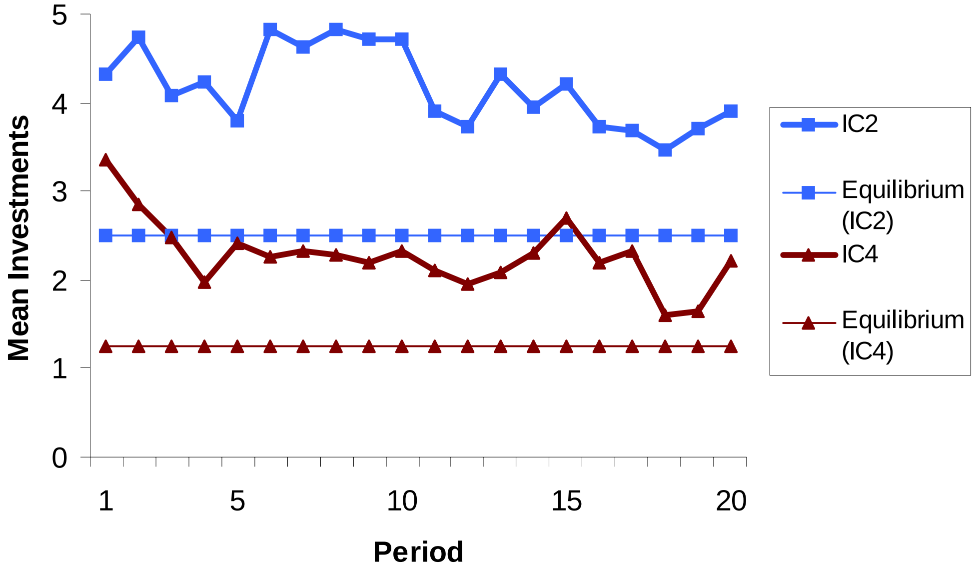

Figure 4: Mean investments.

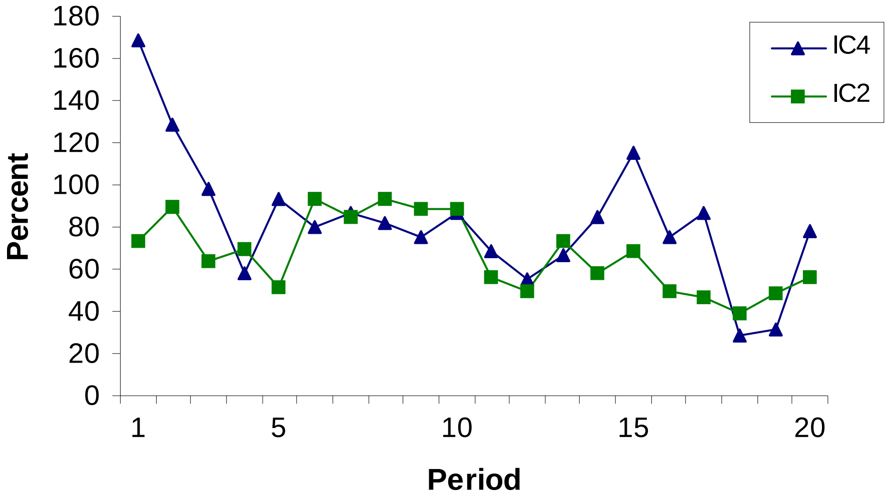

Figure 5: Deviation from the equilibrium.

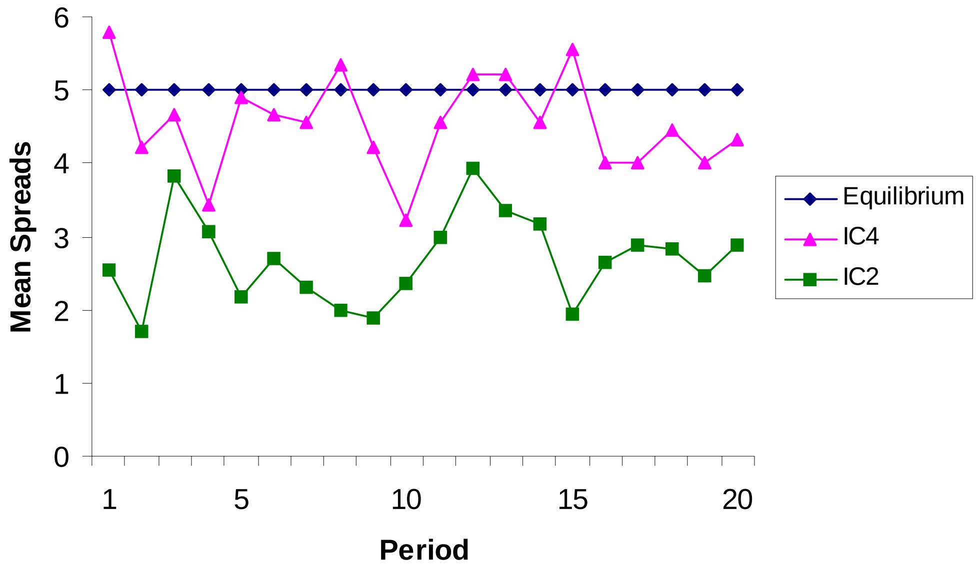

Figure 6: Mean spreads.

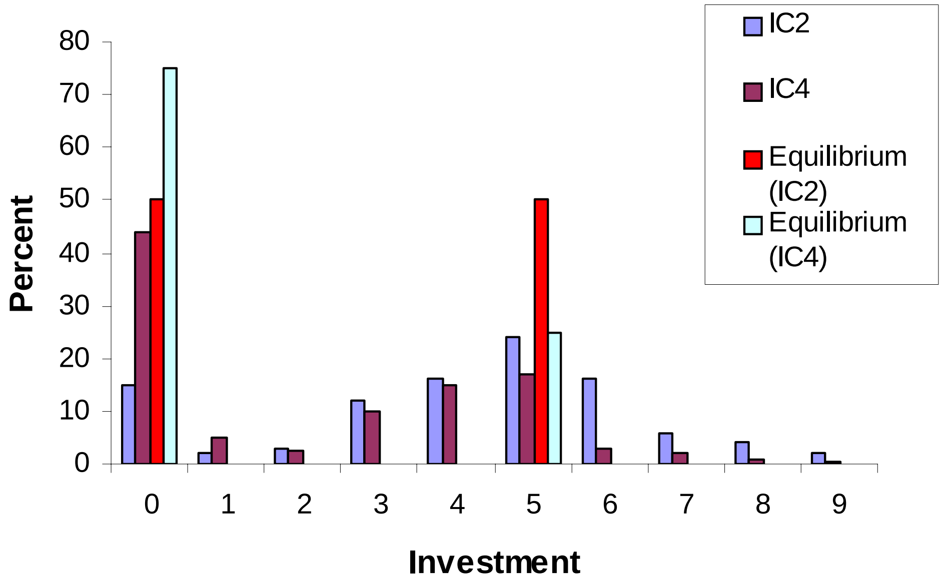

Figure 7: Investment distributions.

Interval	$[0,1)$	$[1,2)$	$[2,3)$	$[3,4)$	$[4,5)$	$[5,6)$	$[6,7)$	$[7,8)$	$[8,9)$
IC2	1	1	6	6	11	6	2	1	0
IC4	8	9	7	4	7	1	0	0	0

Table 2: Subject distributions.

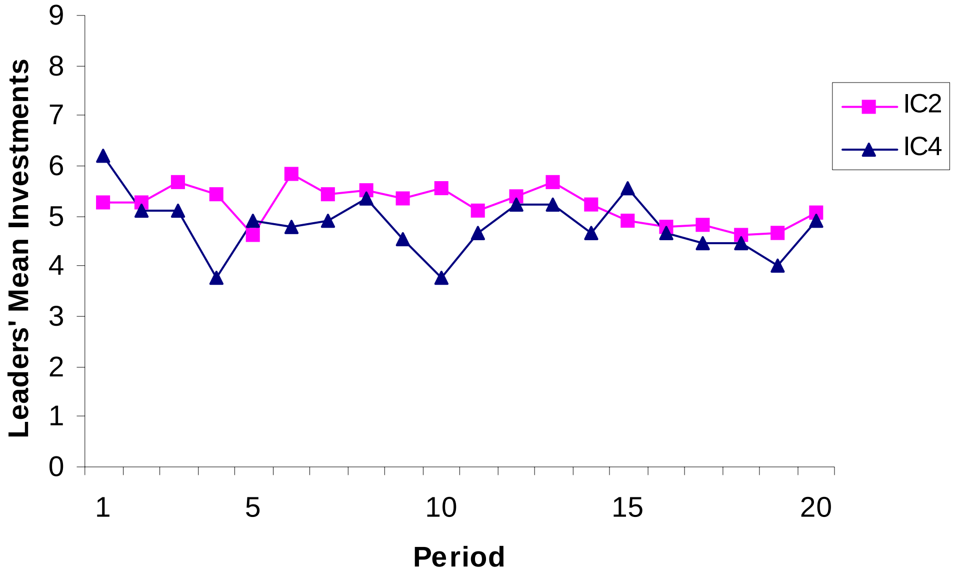

Figure 8: Leaders' mean investments.

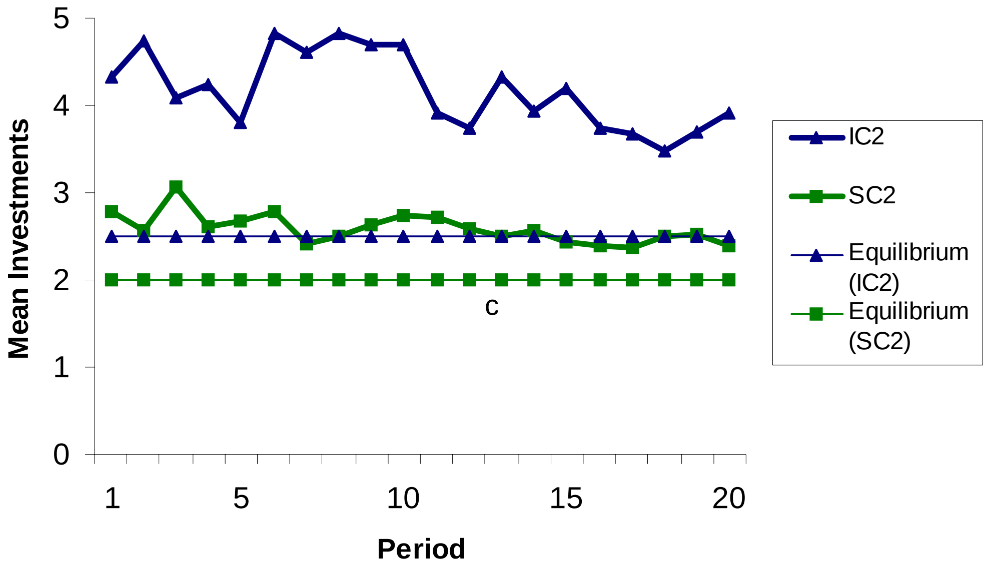

Figure 9: Mean investments.

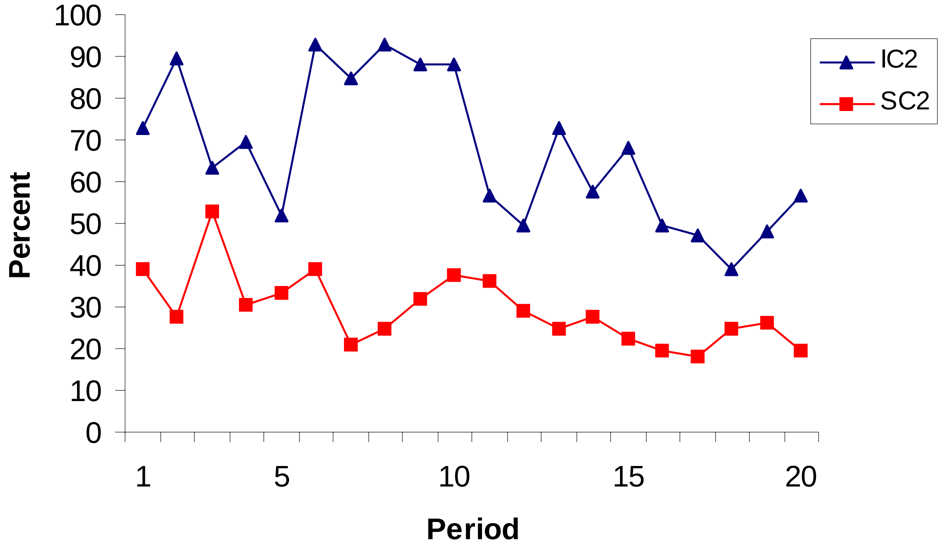

Figure 10: Deviation from the equilibrium.

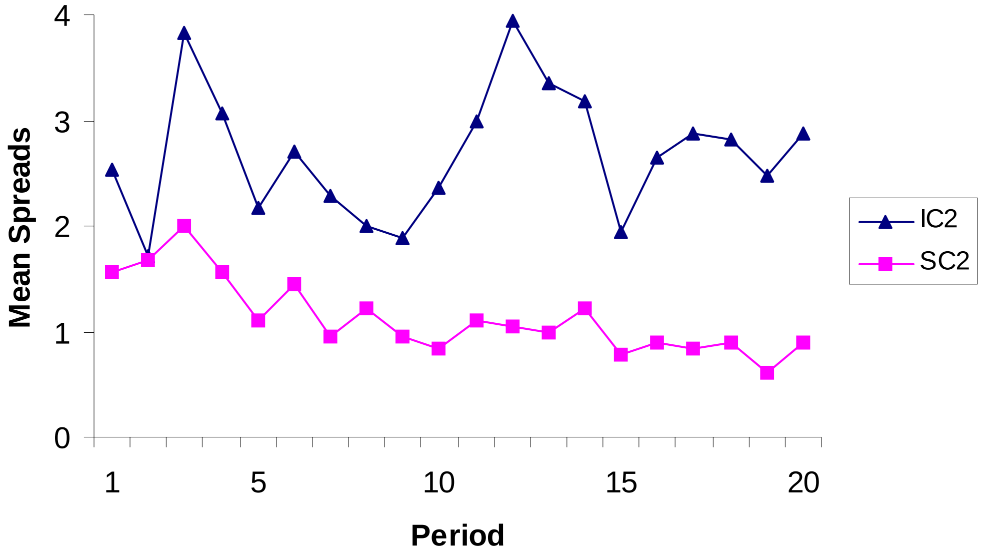

Figure 11: Mean spreads.

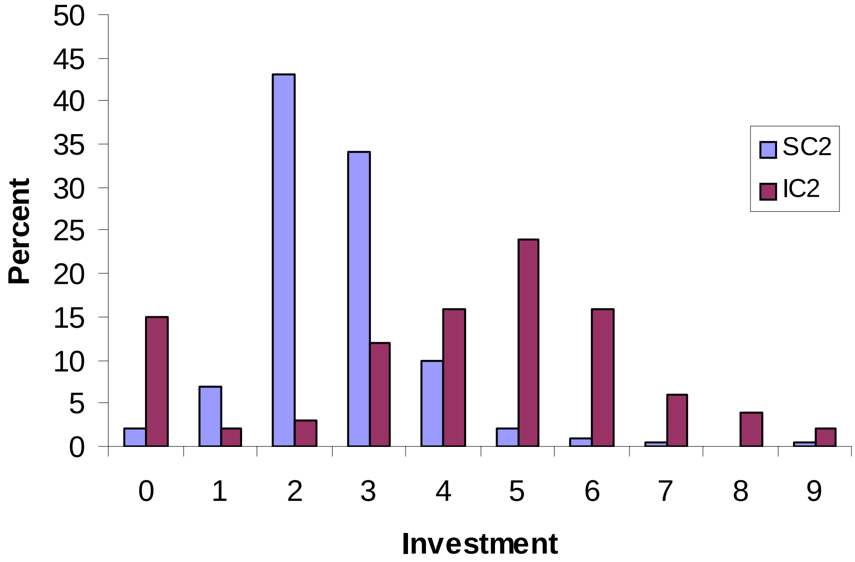

Figure 12: Investment distributions.

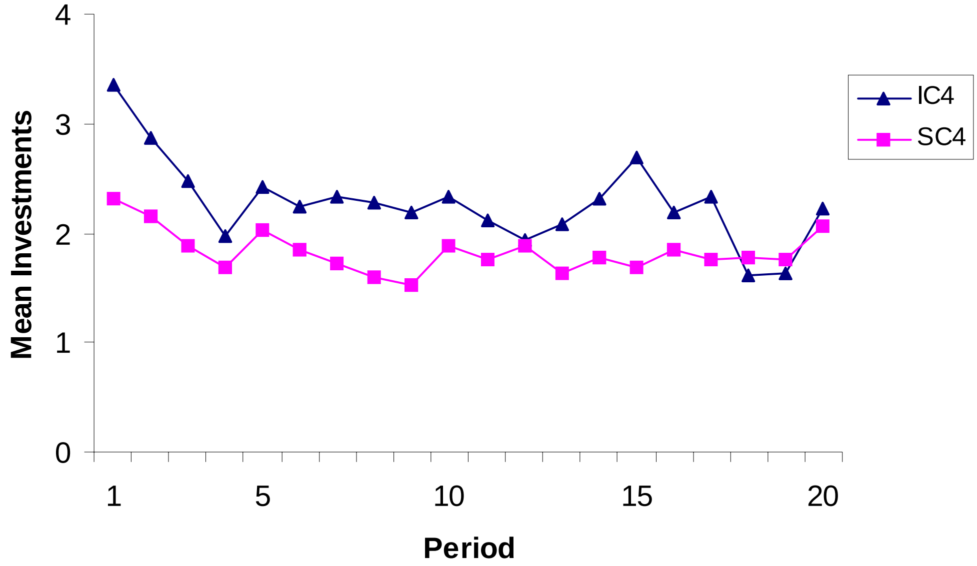

Figure 13: Mean investments.

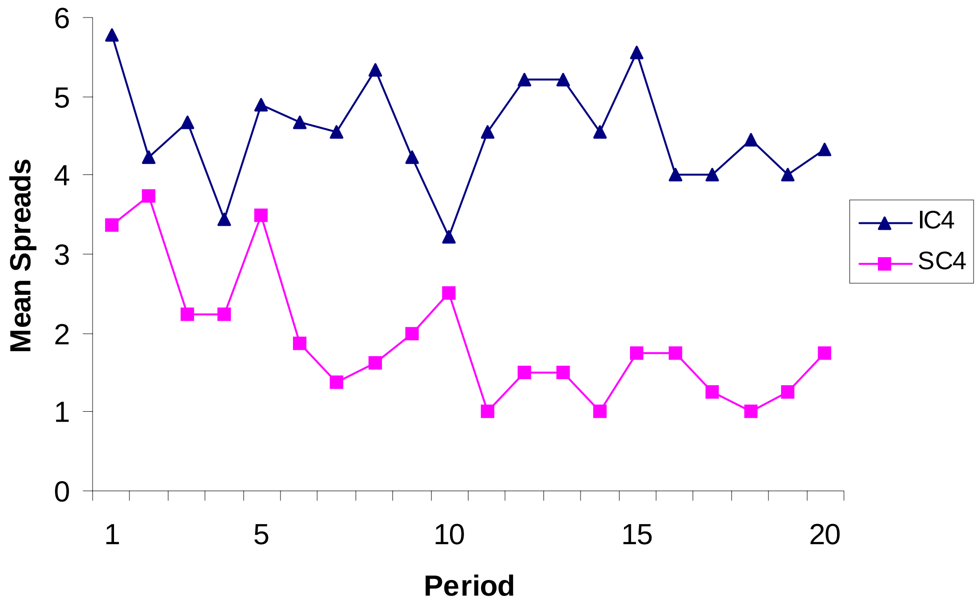

Figure 14: Mean spreads.

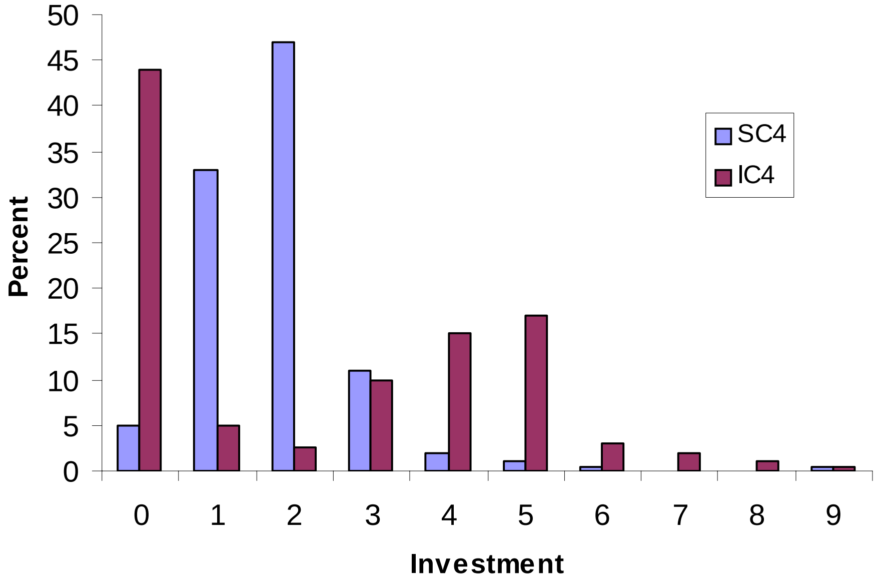

Figure 15: Investment distributions.

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