Cost-reducing investments – An experimental approach

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Abstract: This paper summarizes and discusses some recent experimental results on cost-reducing investments. I focus on the relation between competition and investments and on increasing dominance.

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1 Introduction

The analysis of cost-reducing investments in oligopolies has generated many interesting results.[1] Most of the insights can be generated in simple two-stage models where firms can take cost-reducing investments before they engage in some kind of oligopolistic interaction. For instance, the following issues have been addressed theoretically:

1. **The relation between competition and investment**: The literature has asked how increasing competition affects equilibrium investments.[2] Increasing competition can refer to several different changes in the environment, and the effects may well depend on the particular notion of competition.[3] Increases in the number of firms usually have clear negative effects on investments per firm. Changes in the nature of the strategic interaction for a given number of firms have more ambiguous effects (see, e.g. Schmutzler 2011), with the exact result depending on the specifics of the model. This is true for shifts from Cournot to Bertrand competition as well as for increasing substitutability of goods.

2. **Increasing dominance**: Several authors have asked whether market dominance has a tendency to be self-reinforcing, that is, whether firms with a high market share can increase their market share over time. Specifically, these authors usually consider a slightly different, but related question. Suppose in an oligopoly the firms have the opportunity to invest into reducing their marginal costs. Suppose their initial marginal costs (and thus their market shares) differ. Do leaders (with low marginal costs) reduce their costs more or less than laggards (with high marginal costs)? There is an obvious reason suggesting the latter outcome: Cost reduction may simply be more costly for firms that have

[1] The most common interpretation is that the cost reduction arises from investments in R&D. In most cases, however, the "investments" in the underlying models are sufficiently unspecific, so that they can be given many other interpretations. Cost reductions may arise from improvements in internal organization, hiring of qualified employees or training of the own staff, exerting pressure on suppliers, etc.

[2] Recent surveys include Gilbert (2006),Vives (2008) and Schmutzler (2009).

[3] See Boone (2008) for a discussion of different notions of increasing competition.

already reduced their costs more than others, because further progress may require cutting-edge research rather than just the application of off-the-shelf technology. However, there is a well-known countervailing effect: Firms that have low initial marginal costs have high margins and outputs and therefore benefit substantially from the increases in equilibrium outputs and margins that are typically brought about by cost reductions.[4] This can lead to *weak increasing dominance*, that is, firms that have lower initial marginal costs invest more.

3. **Spillovers**: It is often argued that an environment that secures property rights for the innovator increases innovation incentives. From the perspective of the individual investor, this indeed holds quite generally in standard oligopoly models: If a larger fraction of any amount of cost reduction spills over to the competitor, a firm will typically invest less, holding the investment level of the competitor fixed. There is, however, a countereffect on industry-wide investments: Firms anticipate that, whatever the investments of competitors are, if appropriability becomes smaller for all firms in the industry, own marginal costs for any given level of competitor investments decrease and own outputs and margins increase. Thus there are complementarities between own cost reductions and competitor cost reductions, so that reductions in the appropriability of the competitors' investments thus increase own investment incentives. The effects of a reduction in the overall appropriability of investments on equilibrium investments are thus not entirely straightforward, even though standard models predict a negative relation between appropriability and investment.[5]

4. **Initial heterogeneity and investments**: Some growth theory papers (e.g., Aghion et al. 2001 and 2005) argue that, in heterogeneous settings, where firms are initially far apart (a leader-laggard situation

[4] Most models on this topic use a multi-period setting which adds some complications to the simple two-stage analysis (see, e.g., Flaherty (1980) and Budd et al. 1993), but the underlying intuition for or against increasing dominance comes out quite clearly in two-period models (see, e.g., Athey and Schmutzler 2001, Halbheer et al. 2009).

[5] Leahy and Neary (1997).

with substantial cost differences) aggregate investments are lower than when firms are similar (neck-to-neck competition). The essence of this claim is derived in simple two-stage oligopolies. Nevertheless, the statement does not hold universally. For instance, in a linear Cournot model, average investments are not affected by a mean-preserving spread of the initial marginal costs; they depend only on the average initial cost level (Halbheer et al. 2009).

5. **Strategic investment incentives**: Building from the seminal work of Fudenberg and Tirole (1984) and Bulow et al. (1985), many IO papers have focused on the strategic incentives to invest, for instance, into R&D. According to the logic of these papers, players choose their long-term decisions taking the effects on future actions of the competitors into account. Depending on the nature of the strategic interaction in the product market (strategic complements or substitutes) and the type of investment ("soft" or "aggressive"), this leads firms to invest more or less than they would in the absence of such strategic effects.

In spite of the theoretical importance of these familiar ideas, it is hard to test them directly in the field. This paper therefore resorts to a discussion of some experimental papers that test specific models of cost-reducing investments. Such an approach clearly fails to resolve the issue of which of the many conceivable theoretical models are good approximations of specific real-world settings. However, it allows us to understand whether subjects who are asked to play according to a specific theoretical model actually perform according to the (subgame perfect Nash equilibrium) predictions of this game.

The following discussion draws heavily from earlier research that I conducted with various co-authors. The focus of this research and the following discussion is on the relation between competition and investment and on increasing dominance, but I also add some observations on the remaining topics. I put the results of this research into a common perspective; there is no claim of originality beyond that. I will only briefly touch upon the small number of contributions by other authors that deal directly with investment games in an experimental setting.

The relation between the number of firms and investment has been analyzed by Isaac and Reynolds (1988, 1992) in stochastic static and dynamic patent races. The authors identify a negative effect of greater competition. However, these authors did not study the effect in a standard oligopoly setting.

Cournot investment games have been studied by Suetens (2005), but only for duopoly markets. She focuses on the differences between investments and the Nash equilibrium, and specifically on the role of knowledge spillovers in this context. Suetens (2008) deals with RJVs and their effect on price collusion in Bertrand competition with product differentiation.

The paper is organized as follows. Section 2 introduces a general theoretical framework that contains all the models that I deal with experimentally as special cases. Section 3 briefly sketches the experimental approach that has been used in the papers under consideration. Sections 4 and 5 then deal with the specifics of the three main papers. Section 6 summarizes the main conclusions, and it points to possibilities for future research.

2 The theoretical framework

In the following, I present a general two-stage model which has several predecessors that have been introduced with different objectives in mind. Fudenberg and Tirole (1984) and Bulow et al. (1985) introduced a similar framework to show that the economic intuition of many papers on two-stage investment games can be reduced to a small set of basic principles. Athey and Schmutzler (2001) use a variant of the framework below (extended to many periods) to derive general results on the relative investment behavior of laggards, asking under which circumstances weak increasing dominance emerges. In Schmutzler (2011), I use a related framework to understand under which circumstances increasing competition leads to more investment.

There are $n \geq 2$ competitors in the market who are characterized by constant marginal costs $c_{i,0}$. Let $\overline{c}$ be some arbitrary reference cost level. Define the *ex-ante efficiency* of a firm as $Y_{i,0} = \overline{c} - c_{i,0}$. In period 1, each firm i can choose a cost reduction y_i at investment costs $K(y_i, Y_{i,0})$. This function is weakly increasing in both arguments. In addition, there may be spillovers from the investments of the competitors. Specifically, assume that, if $\mathbf{y}_{-i}$ is the vector of investments of the competitor and λ is a parameter measuring the strength of spillovers, then firm i benefits from an addional cost reduction $f(\mathbf{y}_{-i};\lambda)$. Here f is a function that is weakly increasing in each component of $\mathbf{y}_{-i}$ and in λ such that $f(\mathbf{y}_{-i};0)=0$; the simplest and most commonly used example is $f(\mathbf{y}_{-i};\lambda)=\sum_{j\neq i}\lambda y_j$. Thus, marginal costs of firm i are $c_i=c_{i,0}-y_i-f(\mathbf{y}_{-i};\lambda)$. Defining the *ex-post efficiency* level as $Y_i=\overline{c}-c_i^i$, we obtain $Y_i=Y_{i,0}+y_i+f(\mathbf{y}_{-i};\lambda)$.

In period 2, firms play an arbitrary oligopoly model with a unique product market equilibrium. Equilibrium outputs Q_i and margins M_i are allowed to depend on the ex-post efficiency levels, and on a competition parameter θ. The precise meaning of this parameter will depend on the context. In the experiments, it will correspond either to a substitution parameter or to the mode of competition (Bertrand vs. Cournot). Accordingly, equilibrium outputs and margins can be written as $Q_i\left(Y_i,\mathbf{Y}_{-i};\theta\right)$ and $M\left(Y_i,\mathbf{Y}_{-i};\theta\right)$, respectively. Gross profits (not deducting investment costs) are written as $\Pi_i^i\left(Y_i,\mathbf{Y}_{-i};\theta\right)$. Assuming that the second-period equilibrium is played, firm i thus has an objective function $\pi_i\left(y_i,\mathbf{y}_{-i};\theta\right)\equiv\Pi_i\left(Y_i,\mathbf{Y}_{-i};\theta\right)-K(y_i,Y_{i,0})$.

In specific examples of this setting, I will address the following questions:

1. How do the competition parameter θ and the number of firms n (which is also often interpreted as a competition parameter), influence equilibrium investments?

2. Does weak increasing dominance arise, i.e., does $Y_{i,0}>Y_{j,0}$ imply $y_i>y_j$?

3. What is the effect of increasing spillovers λ on equilibrium investments?

4. What is the effect of a mean-preserving spread of $\mathbf{Y}_{i,0}$ on aggregate investments, $\sum_{i=1}^{n}y_i$?

5. Are strategic effects of investment present, that is, do players bear in mind the induced effects on the future actions of other players when they take their investment decisions? Specifically, for instance, if investments are agressive, do strategic considerations lead to overinvestment

when the following product market game is characterized by strategic substitutes, as predicted by Fudenberg and Tirole (1984) and Bulow et al. (1985)?

3 The experimental approach

All the experimental papers I shall discuss below proceed by taking parameterized examples of the large class of games introduced in Section 2 to the lab. The games are framed in a way that is suggestive of an interaction in a market place. In all cases, subjects are asked to simultaneously choose investments from a set that can be discrete or continuous. The costs of the investment are always chosen as a function $K(y_i, \mathbf{Y}_{i,0}) = k\,(y_i)^2$.[6]

As to the effects of the investments in the product market, there are two different approaches. In *two-stage treatments*, the second stage of the model is explicitly played out in the lab. After the investment stage, subjects are given the information about the investments of other players; they therefore have complete information about the cost structure at the beginning of the product-market stage. They are then asked to choose prices or quantities simultaneously. To guide their decision, they are provided with information on the effects of their price and quantity choices on gross product market profits, that is, profits before deductions of investment costs. This information is typically given in the form of a payoff table; when choices are allowed to be continuous, subjects also receive calculators to determine profits for arbitrary product market choices.

Two-stage treatments appear to be most natural given the underlying model. However, they are potentially problematic for a simple reason. Suppose subjects deviate from equilibrium investments. Then, in a two-stage treatment, this could arise because they expect future deviations from equilibrium play that make higher or lower investments today advisable. For instance, in a Cournot setting, a player may plan to produce below-equilibrium output for some reason.[7] If so, he should respond to his expectation by re-

[6] Thus, the dependence of investment costs on Y_0^i is (deliberately) ignored. The reasons for this simplification and its implications will be discussed below.

[7] As outputs are typically strategic substitutes, this could arise because he expects his

ducing his investments, because low output makes cost-reducing investments less worthwhile. However, it is also possible that subjects deviate from equilibrium investments for reasons that have nothing to do with expected future deviations. For instance, as cost-reducing investments typically involve negative externalities for the competitors, subjects may refrain from such investments if they want to increase joint payoffs (see Engelmann and Strobel 2004 for related arguments). In a two-stage setting, it is hard to distinguish between such different sources of deviations.

Some papers therefore consider an alternative approach where the second stage is not played out in the lab. In such *one-stage treatments*, subjects are only asked to choose investments. In addition to the cost information, they are informed of the gross payoff for each combination of investment choices, which corresponds to the subgame equilibrium payoff for the resulting marginal costs. In this way, deviations from SPE investments can obviously not result from expected second-stage deviations, which rules out any explanations of first-period deviations which rely on the second stage actually being played out. Ideally, one-stage treatments and two-stage treatments should be juxtaposed to understand subjects' behavior better. Some of the papers below do this, others consider only one stage.

Another general design point concerns the possibility of reputation formation. Though the details of the designs differ, all the experiments mentioned below are set up so as to reduce the possibility of such reputation building, while making sure that there are sufficently many independent data points even so. Typically, matching groups are used where different subsets of players from one matching group play against each other in different periods, and the subjects cannot identify the player they are assigned to.

4 Competition and Investment

In this section, I focus in particular on the experimental analysis of the relation between competition and investment. In particular, I will deal with increasing substitutability, the number of firms and moves from Cournot to

rival to produce above-equilibrium outputs.

Bertrand competition. As some of the papers discussed explicitly juxtapose one-stage and two-stage treatments, they also allow some tentative conclusions about the (non-)existence of strategic investment behavior in the lab. In addition, we will obtain some conclusions on the existence of weak increasing dominance.

4.1 Homogeneous Goods Models

Several papers rely on homogeneous goods markets with linear demand functions $D(p) = a - p$ (where $a > 0$ is an exogenous parameter and p is the price), initial constant marginal costs $\overline{c}$ and quantity or price competition. Investment costs are given as $k\,(y_i)^2$.

Defining $\alpha \equiv a - \overline{c}$ and using the notation of Section 2, the equilibrium output and margin for the second-stage Cournot subgame become[8]

$$Q_i = M_i = \left(\frac{\alpha - nc_i + \sum_{i \neq j} c_j}{n+1} \right). \tag{1}$$

Using this result, equilibrium investments can easily be calculated as

$$y^C = \frac{\alpha n}{k(n+1)^2 - n}$$

The Bertrand case is less straightforward. Ignoring the possibility that marginal costs in the second stage are so far apart that one firm becomes the monopolist and assuming limit pricing in the second-stage, margins become $M_i = c^m_{-i} - c_i$, where $c^m_{-i} = \min_{j \neq i} c_j$. Equilibrium outputs correspond to the demand function evaluated at the costs of the second-best firm, so that $Q_i = D(c^m_{-i})$. Thus gross profits are

$$\Pi_i = \max \left\{ (c^m_{-i} - c_i), 0 \right\} D(c^m_{-i}).$$

The equilibrium structure of the homogeneous Bertrand investment game has been analyzed in detail by Sacco and Schmutzler (2008). Intuitively, investments can only be worthwile if the competitors do not invest, because

[8] This is a standard result; see for instance Belleflamme and Peitz 2010, p. 55.

only the better firm obtains a positive profit. Thus, the model is akin to an all-pay auction, except that the prize (the gross product profit) depends negatively on the investment of the competitors. Therefore, it is immediately clear that symmetric pure-strategy equilibria cannot exist. Asymmetric pure-strategy equilibria where only one firm invests exist whenever the investment cost function is sufficiently convex. Moreover, the game has a symmetric mixed-strategy equilibrium where firms mix between no investment and all investment levels up to the positive investment level in the asymmetric pure-strategy equilibrium.[9]

The Bertrand investment game represents a case of very intense product market competition due to the winner-takes-all nature of the game. The obvious disadvantage is that there is no straightforward equilibrium investment prediction. Coordination on asymmetric pure-strategy equilibria in a symmetric game is notoriously difficult and symmetric mixed-strategy equilibria are also not extremely appealing in games with a small number of players.[10]

Average investments are always lower under Cournot competition than under Bertrand competition, except for two players and large investment costs ($k > 2$). Considering an alternative benchmark of competition, (average) investments are decreasing in the number of players for Cournot as well as Bertrand competition. Thus, increasing competition (more players or moving from Cournot to Bertrand) almost always leads to lower investments, except for the above qualification.

Darai et al. (2010) consider Bertrand and Cournot investment models to test comparative statics (effects of moving from Cournot to Bertrand for 2 or 4 players and of moving from 2 to 4 players under Cournot and Bertrand competition, respectively. In addition, for each of these four cases, both a one-stage and a two-stage treatment were considered. Players were allowed to choose from a discrete set of investments. Parameters were chosen as $\alpha = 30$ and $k = 3$.

Figure 1 summarizes the observations. In all cases, increasing the num-

[9] In addition, there usually are asymmetric mixed-strategy equilibria, which I shall ignore in the following.

[10] For the specific parameterization we considered the mixed-strategy equilibrium and the asymmetric pure-strategy equilibrium yield very similar expected investment levels.

ber of players has a negative effect on investments, no matter whether the Cournot or the Bertrand case is considered. More strikingly, moving from Cournot to Bertrand competition has a positive effect on investment, independent of whether one-stage or two-stage treatments are used. This is true even for $n = 4$, where expected Bertrand investments are predicted to be lower than for Cournot. It turns out, however, that the positive effect of moving from Cournot to Bertrand competition is more pronounced for two-stage treatments than for one-stage treatments. A more thorough econometric analysis corroborates this impression by revealing that, whereas investments in the Cournot case essentially correspond to the equilibrium, (i) overinvestment arises for Bertrand competition, and (ii) this overinvestment is more pronounced in the two-stage treatments.

Conceivable explanations that apply to one-stage as well as two-stage treatments involve joy of winning, efficiency considerations (à la Engelmann and Strobel 2004), reputation effects, confusion and optimism about the choices of others. In view of the fact that the overinvestment becomes smaller over time, confusion and excessive optimism about the strategic behavior appear to play a role, whereas joy of winning at least cannot completely explain the observations, because there should be no reason why such joy of winning would disappear over time. A particularly interesting issue concerns the distinction between one stage and two-stage treatments. Darai et al. (2010) argue that the following explanation is consistent with the data. The value of a firm's investment clearly depends on its expectations about the future price of the competitor. If a firm is optimistic in that it expects a competitor to set high prices, it will expect to win even it does not set very low prices itself. It will therefore also put high probability on the event that it can serve the entire market, so that cost reductions are likely to be worthwhile. Thus, we should see firms who invest a lot set high prices. Indeed that is what happens.

Finally, I briefly mention some related research. The unpublished work of Sacco and Schmutzler (2008) considers the reduced one-stage version of the Bertrand investment game. It shows that overinvestment is substantial. Such overinvestment has also been observed in related settings, for instance in all-pay auctions where the winner's prize is independent of the effort levels.[11] Darai et al. (2011) also observe overinvestment in two-stage treatments with price competition, but they focus on the effects of political instruments (subsidies and patent protection) on investment rather than the effects of increasing competition.

4.2 Differentiated Goods Models

Using models of product differentiation, one can analyze the effects of the degree of substitution on cost-reducing investments. Consider, for instance, a standard Cournot duopoly with inverse demand $p_i = a - q_i - \theta q_j$ for firms $i = 1, 2$; $j \neq i$, where $a > 0$ the competition parameter $\theta \in [0, 1]$ measures the degree of substitution. It is well-known that, in the Nash equilibrium of this Cournot game

$$Q_i = M_i = \left(\frac{2\,(a - c_i) - \theta\,(a - c_j)}{4 - \theta^2} \right).$$

Using this expression, equilibrium investments can be derived explicitly in a two-stage investment game with cost functions $K(y_i) = (y_i)^2$. The following results are straightforward to derive; see the illustration in Figure 2.[12]

1. In the symmetric case, equilibrium investments are decreasing for low levels of competition ($\theta < 2/3$), increasing for higher levels.

2. A U-shaped relation still holds for leaders and for laggards that do not have much higher initial costs than the competitor.

3. For firms that lag far behind, the effect of the competition parameter is strictly negative.[13]

4. Weak increasing dominance holds, that is, leaders always invest more than laggards.

[11] Most closely related is Gneezy and Smorodinsky (2006) who consider symmetric all-pay auctions with 4, 8, and 12 players and also observe overinvestment. Like Darai et al., these authors obtain overbidding that diminishes over time, but remains substantial even in later periods. See also Davis and Reilly (1998).

[12] See Sacco and Schmutzler (2011).

[13] When one firm lags very far behind, there will typically be an asymmetric equilibrium where only the leader invests.

The U-shape of the relation between competition and investments for leaders is rather striking, because the view that the relation should have an inverse-U shape is more common.[14] The intuition comes from the interaction of two countervailing effects which typically arise in standard models (see Schmutzler 2011). On the one hand, competition reduces equilibrium margins for arbitrary cost structures. This reduces the incentives of firms to increase equilibrium outputs by investing into cost reductions. On the other hand, an increase in competition increases the positive effect of investments on equilibrium output, which increases investment incentives. The presence of two countervailing effects suggests why a non-monotone relation is possible. The intuition is strengthened by the fact that the negative margin effect becomes weaker as competition falls, which works in favor of a convex relationship.

It should be emphasized that the U-shape is by no means a general feature of the relation between increasing substitutability and investment. It simply is an interesting possibility that has largely gone unrecognized in the literature.[15]

Sacco and Schmutzler (2011) analyze the above four hypotheses experimentally, using the parameterization corresponding to Figure 2. The parameter a was chosen as 50 in all cases. To test the U-shape of the relation between competition and investment for symmetric firms and leaders, the authors considered three different values of the competition parameter, low competition ($\theta = 0.1$), intermediate competition ($\theta = 2/3$) and intense competition ($\theta = 1$). They also distinguished between a symmetric case (where both firms have initial marginal costs of 21 and an asymmetric case where the leader has initial marginal costs of 21 and the laggard has initial marginal costs 25).

Most comparisons were only conducted for one-stage treatments. However, to obtain a better understanding of the predicted positive effect of moving from intermediate ($\theta = 2/3$) to high competition ($\theta = 1$) for symmetric firms, the authors also looked at two-stage treatments for this specific

[14] See, for instance, the above-mentioned papers by Aghion (2001, 2005).

[15] In Schmutzler (2011), I provide examples where the relation is monotone increasing, decreasing or independent of the degree of substitutability for symmetric firms.

case.

The results for the one-stage case are broadly in line with the theoretical predictions. For the symmetric case, investments are indeed lowest for intermediate competition, but the positive effect of investment is insignificant. Moreover, there is some overinvestment, the extent of which is quite similar for all parameter values. For the asymmetric case, the negative effect for laggards comes out clearly, whereas the U-shape for laggards is again confirmed only weakly (in the sense that the move from intermediate to intense competition has a positive, but insignificant effect). On a related note, there is underinvestment for leaders and overinvestment for laggards. Even so, it is still true that leaders invest more than laggards, so that weak increasing dominance is confirmed.

In the symmetric two-stage treatments, the picture changes dramatically. First, instead of overinvestment, there is underinvestment. Second, the positive effect of moving from intermediate to intense competition disappears completely.

It is not obvious how the deviations in the one and two-stage treatments can be explained. Some insights can be obtained by looking more carefully at the output subgames in the two-stage treatments. While average outputs in the two-stage treatments are lower than in the subgame perfect equilibrium, they are close to the average outputs in the equilibria of the subgames corresponding to the investments that are actually chosen. This suggests that the players' underinvestments reflect expected downward deviations in the output game: Players are planning to produce lower than equilibrium outputs, so that lower equilibrium cost reductions make sense. Also, the reactions of outputs to investments are not in line with theory. While the reactions of outputs to own investment are significantly positive and roughly of the expected size, the expected negative effect of competitor investments on own outputs is not significant. This strongly suggests that the well-known logic of strategic investment in the Cournot game may not play the predicted role. If subjects do not condition their behavior on the investment of competitors, then players should also not take their investments with a view towards the future reaction they are inducing. In fact, the observed underinvestment is at least consistent with such considerations. Rather than behaving like a "top dog", that is, investing a lot so as to induce lower future outputs of competitors, players appear to choose lower investments, arguably focusing more on the effects of investments on their own costs.

An alternative explanation is that subjects do actually react directly to the investments of competitors, but that there are two confounding effects that happen to cancel out: On the one hand, players might realize perfectly well that, on purely materialistic grounds, they should respond to lower competitor costs by reducing their own outputs. On the other hand, they might regard cost reductions of the competitor as an unfriendly act to which they want to respond unkindly by increasing their own outputs. Either way, firms that doubt that higher investments trigger output reductions might reduce their investments relative to the SPE prediction.[16]

In its analysis of strategic effects, the paper is related to others. There are experimental treatments of the strategic trade policy model of Brander and Spencer (1985) by Engelmann and Normann (2007), the delegation game of Ferschtman and Judd (1987) by Huck et al. (2004a) and the Brander-Lewis (1986) model of debt choice by Oechssler and Schuhmacher (2004). In all these papers, first-period actions (government subsidies, incentive schemes fo managers, debt choices) are aggressive in that they induce second-period actions (higher own firm outputs) that impose negative externalities on opponents. As in Sacco and Schmutzler (2011), investments thus should trigger desirable behavior of opponents because outputs are strategic substitutes. The results in the three experimental papers just mentioned confirm that first period-actions are not as high as in equilibrium in the three examples just managed. Compared to this literature, however, Sacco and Schmutzler (2011) makes an additional contribution: By allowing for a clean comparison of the two-stage game with the reduced one-stage version where there is overinvestment, it becomes transparent that the absence of overinvestment in the two-stage game actually results from anticipated effects on second-period behavior.

[16]Darai (work in progress) has designed several experiments specifically to analyze strategic effects. Preliminary results confirm that they are absent when second-stage actions are strategic substitutes, but they exist (and are quite strong) for complements.

5 Increasing Dominance

I now move towards the analysis of increasing dominance, ignoring the effects of increasing competition. For this reason, I fix the number of players, the mode of competition (Cournot) and the degree of substitution (only homogeneous goods). For linear demand $D(p) = a - p$, second-period outputs and mark-ups are given by (1). With a cost function $K(y_i) = (y_i)^2$, costs do not depend on the initial efficiency of the firm. This rules out the possibility that leaders invest less than laggards simply because it is more expensive for them to reduce costs.

Halbheer et al. (2011) provide an experimental analysis of weak increasing dominance in a variant of this standard investment game that allows for spillovers, which are modeled as usual by assuming that a fraction λ of each cost reduction also accrues to each competitor. Contrary to games without spillovers, investments now can have positive externalities, that is, they increase the equilibrium profits of competitors if λ is sufficiently large ($\lambda > 0.5$). Further it is straightforward to show that investments are strategic substitutes only if they exert negative externalities; for $\lambda > 0.5$ they are strategic complements.

The paper starts by providing theoretical results for the specific model which relate to well-knowns general theoretical results on weak increasing dominance and spillovers (see, e.g. Leahy and Neary 1997 and Athey and Schmutzler 2001).

1. The model satisfies weak increasing dominance: Good firms invest more than bad firms.

2. The average investment level is determined only by the average initial efficiency; that is, starting from a symmetric situation, the effects of reducing the efficiency of some firms and increasing the efficiency of other firms by the same total amount exactly cancel out.

3. Quite generally, an overall increase in the spillover parameter reduces equilibrium investments. Appropriability concerns dominate over the

complementarities between investments.[17]

4. For $\lambda < 0.5$, investments are higher than required for joint profit maximization; for $\lambda > 0.5$, they are lower. Intuitively, as low spillovers correspond to negative externalities of investments, investments are excessively high; conversely for high spillovers.

To test these four hypotheses, the authors choose a six-player setting. In the central asymmetric treatments, there are three types of players, two leaders (with low costs), two followers (with intermediate costs) and two laggards (with high costs). To explore the second hypothesis, the authors introduce symmetric treatments where all players have identical initial marginal costs that are identical to the average costs in the corresponding asymmetric treatments. They also distinguish between treatments with no spillovers ($\lambda = 0$) and treatments with high spillovers ($\lambda = 0.6$). Finally, as a robustness exercise, scenarios with high-cost (average costs 11) and low cost (average costs 5.5) are introduced.

Generally speaking, the predictions of the (subgame perfect) Nash equilibrium are confirmed surprisingly accurately. Though there is some small overinvestment, the weak increasing dominance hypothesis comes out very clearly in all cases. The remaining hypotheses are also essentially correct. As predicted, average investments do not depend on the distribution of the initial marginal costs, only on the average level. Average investments with spillovers are significantly higher than without. The relation between observed investments and joint-profit maximization needs slightly more consideration. As one would expect, average investments are inefficiently high for no-spillover treatments. With spillovers, average investments are approximately efficient in symmetric treatments, but inefficently low for asymmetric treatments. While the latter observation is consistent with the expectations, the efficiency in the symmetric case is more surprising. It should probably not be given too much weight, however, because the spillover parameter $\lambda = 0.6$ is relatively close to $\lambda = 0.5$ where the Nash equilibrium maximizes joint

[17] As sketched above, complementarities arise because, with higher λ, any given investment of competitors results in lower own costs and therefore higher markups and outputs, thus making higher outputs and markups (and thus investments) more desirable.

profits. Thus, even slight overinvestment relative to the Nash equilibrium results in behavior that is close to joint profit maximization.

6 General lessons

Deriving general lessons on investment games from a small set of experiments is obviously problematic. Nevertheless, the papers presented above suggest some tentative conclusions. These conclusions are subject to a general methodological qualification, which is in itself based on the observations of the experiments. The above analysis shows that the behavior in one-stage and two-stage treatments can differ considerably. Specifically, in the two-stage treatments of Darai et al. (2010) and Sacco and Schmutzler (2011), subjects appear to deviate from equilibrium investments because they are planning to deviate from equilibrium (outputs and prices) in the second stage.

Competition and investment: The extent to which the effects of competition on investment correspond to theoretical predictions depends on the particular competition parameter:

1. There is clear support for a negative effect of the number of firms on investments (Darai et al. 2010).

2. The effect of increasing substitutability on the investments of laggards is clearly negative (Sacco and Schmutzler 2011) as predicted.

3. The effect of increasing substitutability on the investments of symmetric firms and leaders does not fully confirm the predicted U-shape (Sacco and Schmutzler 2011); in particular, in the two-stage treatments there is no evidence of the upward-sloping part.

4. The effect of moving from homogeneous Cournot to homogeneous Bertrand competition is clearly more positive than predicted (Darai et al. 2010).

As argued above, the last observation is in line with the more general observation that winner-takes-all situations attract excessive investments. However, such observations have typically been made in situations where the prize of winning is high even when the investments of competitors are similar. In the Bertrand investment game analyed by Darai et al., the prize can become arbitrarily small if investments are similar.

Increasing Dominance: In the one-stage treatments of Halbheer et al. (2009) and Sacco and Schmutzler (2011), weak increasing dominance arises quite clearly. However, the hypothesis has not been tested in two-stage treatments. In view of the considerable behavioral differences between the two types of treatments, the robustness of the result therefore needs to be taken with a grain of salt.

Spillovers: The experiments of Halbheer et al. (2009) also provide support for the hypothesis that spillovers reduce investment incentives. An interesting related point is that in treatments with spillovers, the deviation of subjects from equilibrium can be qualified as cooperative, whereas it is non-cooperative in the case without spillovers: In both cases, there is overinvestment relative to the Nash equilibrium, which is good for the competitors with spillovers, but bad without spillovers.

Initial heterogeneity and investment: The paper of Halbheer et al. (2009) shows that in a specific setting where the inital cost heterogeneity of firms has no impact on aggregate investment, there is indeed no such effect.

Strategic investments: Subjects do not appear to condition their second-stage behavior on investments of competitors in a way that is consistent with standard theory. This does not necessarily imply that they actually ignore the information on competitor investments; it could also mean that the "materially optimal" adjustment to greater investments and behavioral effects such as reciprocity cancel out. The more systematic approach of Darai (work in progress) should shed some more light on these issues.

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8 Appendix: Figures and Tables

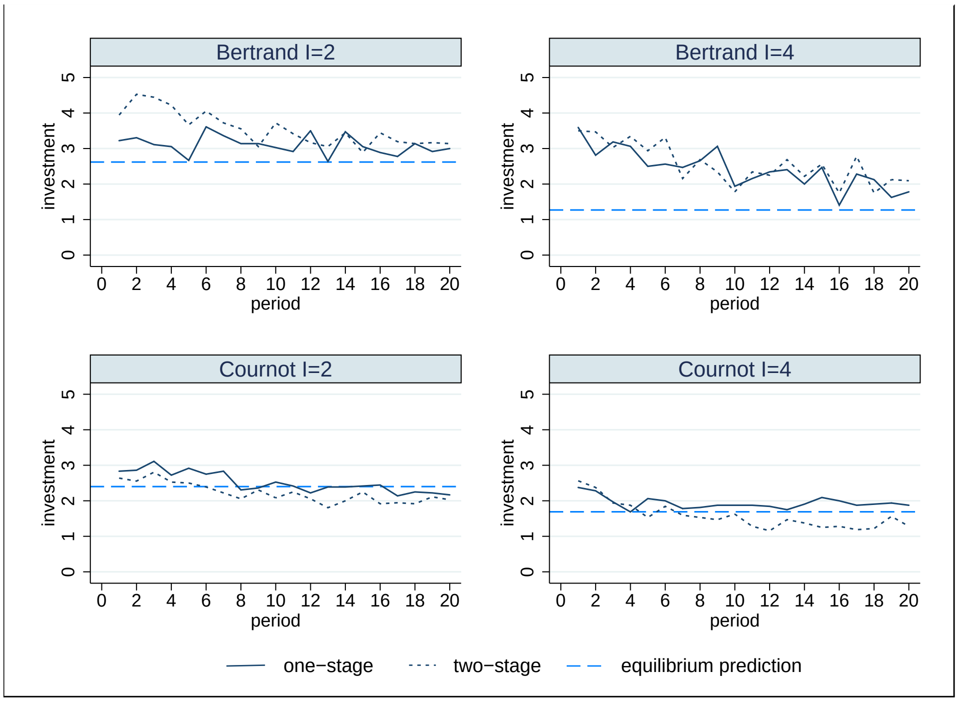

Figure 1: Average investment per period (Darai et al. 2010)

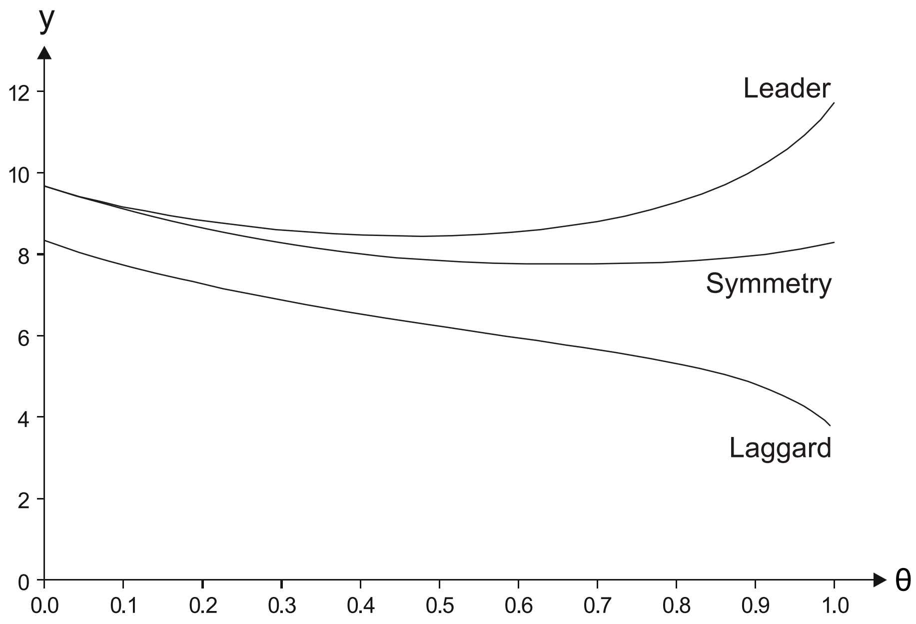

Figure 2: Equilibrium investments (Sacco and Schmutzler 2011)