Innovation races: An experimental study on strategic research activities

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Abstract

In an experimental setting, firms in a duopoly market engage in a patent tournament and compete for profit-enhancing product advancements. The firms generate income by matching exogenously defined demand preferences with an appropriately composed product portfolio of their own. Demand preferences are initially unknown and first need to be revealed by an investigation of the possible product variations. The better firms approximate demand preferences, the higher their profits. In the ensuing innovation race, firms interact through information spillovers resulting from the imperfect appropriability of research successes. In the random period of the experiment, the continuity of the search process is disturbed by an exogenous shock that affects both the supply and demand side and again spurs research competition. Firms may henceforth explore an enlarged product space in attempting to match the equally modified demand preferences. In our analysis, we explore the behavioral regularities of agents who are engaged in innovation activities. As a key element we test to what extend relative economic performance exercises a stimulating effect on the implementation of innovation and imitation strategies.

Keywords: Innovation, Imitation, Patent Tournament, Trial and Error Process

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1 Introduction

In a world of perfect information, economic innovation is exclusively achieved on the basis of optimal investment calculations of all market participants. Assuming that the success rate of a given research activity is stochastically predictable, the complexity of a firm's decision to invest in R&D is reduced to decision-making under risk, with the objective of profit maximization (Friedman, 1953). Consequently, primarily those firms should invest that have the strongest economic incentive to innovate (Harris & Vickers, 1987, Katz & Shapiro, 1987).

Yet the assumption of perfect information is a strong one, which does not adequately depict reality. In the majority of cases, the prediction of the entire set of outcomes and the economic success of R&D activities is impossible. Rather, economic markets are characterized by dynamic changes and uncertainty (Winter, 1964). Therefore, it seems important to us to analyze the strategic interaction – in terms of R&D activities – of firms that compete on markets with changing consumer preferences. There exists a large body of empirical literature on the influence of economic parameters on innovative success (e.g., Cohen & Klepper, 1996). In particular, the empirical analysis of Acs & Audretsch (1988) showed that market concentration has a negative influence on the total number of innovations. To the contrary, aggregate R&D expenditures in a market are positively correlated with innovative output, though the relationship need not be of a linear type. Nevertheless, the question, how market concentration influences R&D expenditures cannot be convincingly answered. Empirical studies of this particular question are rare, and do not expose certain market structures that particularly promote innovative activities (e.g., Lerner, 1997). One could argue that incumbent firms invest larger funds in the pursuit of innovations while they strive to maintain their superior economic position in the market (Dasgupta & Stiglitz, 1980a). Alternatively, one may equally claim that new market entrants have stronger incentives than their larger competitors to build up a competitive edge on the basis of successful innovations (Reinganum, 1983). By means of this experimental study, we aim at exploring this relation in detail. We believe that this issue has to be discussed in a broader perspective. Innovations are heterogenous with respect to their strategic implications on a particular market. In one case, innovations may simply complement already established technologies, whereas, in another case, innovations may render existing technologies obsolete. Introducing both types of innovation in an experimental setting allows us to investigate the relation between firm size and R&D activities.

This paper is structured as follows. Section 2 discusses the theoretical aspects of competition and innovation in greater detail and highlights their coherence. In section 3, we describe the market model – in which competition is exclusively a matter of product improvements – and formulate our expectations concerning the strategically motivated timing of product innovations. In section 4, the experimental design and results are introduced. Section 5 summarizes the main findings.

2 Competition and Innovation

The traditional economic view on innovations relies on the existence of temporary asymmetric information that provides firms with an opportunity to establish monopolies. The latter may only be sustained for a prolonged period of time if property rights can be credibly enforced by the legal system or if competitors are able to perfectly absorb the economic benefits of their own research. This may occur if the firm disposes of large amounts of tacit knowledge which prevents diffusion. In such a setting, competing firms are prevented from incorporating external knowledge through spillovers and imitation. Models of technological competition typically rely on the above-mentioned award structure (Tirole, 1989). Thus, they ignore the fact that knowledge spillovers – via imitation or licensing of improvements – play a central role in the diffusion of innovations, as they have a profound impact on aggregate economic growth (Reinganum, 1982, Katz & Shapiro, 1987).

Imitation may be considered a viable strategy in industries in which R&D investments tend to be highly capital-intensive and risky. There is a large body of literature on patent races, discussing the tension between innovation and imitation. Yet those studies either rely on agents that are perfectly aware of the profitability of their activities (e.g., Vickers, 1986, Beath, Katsoulacos & Ulph, 1990), or they presume perfect patent protection so that the winner of the race appropriates all benefits (e.g., Isaac & Reynolds, 1988, 1992, Zizzo 2002).

In this article, we want to relax both preconditions. In particular, we experimentally analyze patent races in an environment of incomplete information about the economic consequences of innovative activities. In this respect, we are especially interested in observing behavioral regularities of agents making investment decisions, while they are at the same time unable to deduce the optimal innovation strategy. Moreover, imitation may equally prove to be a viable strategy in this setting, since we assume the duration of the patent protection to be finite. In our theorizing, we can build up on an earlier series of experiments, in which we showed that an environment of intense competition – which is identified by a relatively small distance in the capital wealth of competitors – significantly stimulates risky R&D investments (Cantner et al, 2004).

However, in the earlier study, we applied a rather general notion of innovation. In principle, innovations can be categorized according to their strategic implication and their economic impact on a given market. In the following, we will distinguish between two types of innovations, namely incremental and fundamental innovations. Incremental innovations primarily add to an existing technology in the sense of enhanced product functionality and style. Yet the overall production process in terms of applied technologies is typically only marginally rearranged. In contrast, fundamental innovations are characterized by a profound reorganization of a product's entire value chain. Commonly, the actuated reorganization leads to the introduction of new and more efficient technologies. This replacement effect invariably renders a set of previously existing technologies and income sources obsolete (Katz & Shapiro, 1987). Therefore, fundamental innovations are burdened with considerable opportunity costs. On this basis, we claim that market participants do not share a uniform economic incentive to strive for incremental and fundamental product improvements.

More generally, one may ask whether firm size is an important determinant in promoting investments for both types of innovations. The economic literature offers two principal ideas in this respect (Nelson & Winter, 1982, Schumpeter, 1942). In one case incremental innovations are mainly promoted by larger firms in an industry. These firms feature a large capitalization and a persistently dominant market share over a prolonged period of time. Over the years these firms are able to accumulate substantial amounts of capital. This enables them to allocate large funds to risky and capital-intensive research projects with the objective of protecting their economically superior market position. However, fundamental innovations that replace existing technologies impose the burden of high opportunity costs on well-established firms. In the other case, small firms are said to excel in economic competition due to their increased flexibility and lower opportunity costs. Although they face a more severe budget constraint than their larger counterparts, they may take over the leading market position by means of risky, but eventually successful fundamental innovations. At the same time, the incumbent may be restrained by organizational rigidity and technological lock-in effects. Of course, one can also think of the opposite approach. Only incumbent firms with large financial resources are able to afford the cost of developing fundamental innovations.

To analyze this question in detail, we will introduce both types of innovations in our experiment. We consider a simple duopoly market in which two firms compete exclusively in terms of risky product improvements. In case of success, a research project undertaken by the firm yields a marketable innovation that enjoys temporary patent-protection. In a first phase, subjects will be able to perform solely those innovations which are incremental in nature, since the invalidating effect of succeeding technologies on preceding technologies is intentionally omitted. In the ensuing second phase of the experiment, subjects will then be able to generate fundamental innovations with a depreciating effect on preceding technologies, as well.

3 Sequential search for product improvements

We consider a simple duopoly market. Initially, two firms enter the market as symmetric competitors. Both firms receive an identical capital endowment and do not yet possess a portfolio of marketable products. In the first phase of the experiment, firms are free to design their own product portfolio and to modify that portfolio subsequently. The firm generates profits if it successfully specifies a product in such a way that the product coincides with an exogenously defined demand preference, whereby the ideal specification is not known to the firm beforehand. In all other instances, the firm is not able to derive any profit from the vainly offered product. Given this incentive structure, firms have a strong motivation to carry out search investments in order to establish a product portfolio that increasingly matches the demand preferences.

At a point of time which is not specified to the subjects, the first phase of the experiment is terminated by an exogenous shock. Essentially, the exogenous shock can be equated with an external effect that expends the action set of suppliers and modifies the demand characteristics of buyers. Consequently, firms face a wider range of strategic options in the second phase of the experiment. As in the first phase, firms are free to make the generic choice if they want to actively offer a set of products or if they want to remain passive. In contrast to the preceding phase, they may henceforth also attempt to differentiate themselves from the competitor by further refining their product portfolio. The incentive to invest is maintained because successfully refined products yield higher revenues than standard products.

At the start of the second phase of the experiment, firms will most likely have experienced differing histories of research successes and economic outcomes. Thus, the game model is suitable for allowing the market structure to evolve endogenously. The strategic interaction among competitors in the first phase typically brings about heterogeneity in the size of the two firms, whereby the latter figure is expressed in terms of the firm's accumulated profits. The above-mentioned differences mainly result from diverging competitive efforts and the unequal innovative success of firms.

3.1 First generation product improvements

In this section, we observe the first stage of a patent race in a duopoly market similar to the preceding study (Cantner et al, 2004). Our motivation for incorporating this phase is to let the two initially identical firms differentiate into one large and one small firm (both in terms of their accumulated capital).[1] Of course, one may argue that asymmetry in firm size could also be introduced by simply assigning varying initial endowments. However, we prefer the chosen approach, because we assume that an exogenously imposed market structure is less suitable than an endogenously grown structure for stimulating innovative activities.

Let us assume that each firm manages a portfolio that is comprised of n independent products.[2] In order to exclusively concentrate on product innovations, consider the absence of any kind of price competition. The economic success of a firm is solely determined by the accordance of her products' characteristics to specified demand preferences. Unlike price competition, product attractiveness in our model is not determined on a cardinal scale. Thus, the employed notion of quality competition does not correspond to reverse price competition in the sense of "the-more-the-better". Rather, quality competition in this setting should be interpreted as a dichotomic variable.

[1] As accumulated capital, we define the sum of accumulated profits and the endowment.

[2] Imagine, for example, two software manufacturers offering different software packages.

For each of the $i = 1, \dots, n$ products in the firm's portfolio, there exist m_i possible specifications, which all represent feasible variations of the same product. Thus, for each product $i = 1, \dots, n$, one has an unordered set

$$a_i \in \left\{a_i^{10}, \dots, a_i^{m_i 0}\right\} \quad \text{with } m_i \geq 2 \tag{1}$$

of m_i alternative specifications. We randomly designate one specification for each product as the consumers' ideal specification a_i^{*0}. The two firms, X and Y, are free to select a certain variation of each product $x_1, \dots, x_n$, respectively $y_1, \dots, y_n$. Whenever a selected variation matches the corresponding ideal specification by the choice $x_i = a_i^{*0}$, or $y_i = a_i^{*0}$, X, respectively Y, sells one unit of the product in that period. Therefore, a firm may at most realize a sales volume of n, if it is able to sell its entire product portfolio. More specifically, one can define the conformity of any x_i^t, respectively y_i^t, with a_i^{*0} in period t as

$$\delta_i\left(z_i^t, a_i^{*0}\right) = \begin{cases} 1 & \text{if } z_i^t = a_i^{*0} \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

for $z \in \{x, y\}$.

Furthermore, several general provisions apply. The interaction between the two firms always lasts for T periods with $t = 1, \dots, T$ $(T \geq 1)$. Any technological change initiated by a firm – in the sense of a firm selecting a new specification for product i – is associated with a fixed one-time expenditure, known as switching costs γ_i^j.

Assuming negligible production costs, the two firms, X and Y, realize (undiscounted) profits of π_z^t for $z \in \{x, y\}$ in periods prior to the occurrence of the exogenous shock in period t'. For all periods t with $t < t' \leq T$, the following profit function applies:

$$\pi_z^t = \sum_{\tau \in \{1, \dots, t\}} \sum_{i \in \{1, \dots, n\}} \delta_i(z_i^\tau, a_i^{*0}) - \sum_{i \in \{1, \dots, n\}} \sum_{j \in \{1, \dots, m_i\}} \gamma_i^j(z_i^t), \tag{3}$$

with switching costs

$$\gamma_i^j(z_i^t) = \begin{cases} 1 & \text{if } z_i^\tau = a_i^{j0} \text{ for some } \tau = 1, \dots, t \\ 0 & \text{otherwise.} \end{cases} \tag{4}$$

Hence, the incurred switching costs equal one sales unit and are deducted each time one of the n different product aspects is changed to another product variation that has not previously been selected.

We assume that each product that is supplied by a firm can be perfectly observed by the firm's competitor. It is hereby insignificant whether that product coincides with demand preferences or not. Additionally, we presume that both firms are informed about their own and the competitor's product choices and economic success. Consequently, each firm may rapidly imitate a successful product variation of the competitor at the marginal cost of one sales unit. Imperatively, in a such environment of high spillovers, the incentive to engage in costly research with the aim of achieving product improvements must be weak. Therefore, we introduce property rights in the form of a patent protection in order to promote risky investments. If firm X is the first to discover the optimal i-th product a_i^{*0} by $x_i^h = a_i^{*0}$ in period h, then the firm's competitor cannot choose $y_i^\tau = a_i^{*0}$ in periods $\tau = h + 1$ to $\tau = h + k$ with $k(\geq 1)$. Similarly, if the firm's competitor is the first to find a_i^{*0} by $y_i^t = a_i^{*0}$, then firm X cannot choose a_i^{*0} for k periods thereafter. If both firms independently identify a_i^{*0} at the same time, both can freely choose a_i^{*0} afterwards.

Undoubtedly, in this experimental setting, we do not observe innovative behavior in terms of individual creativity or problem solving. Instead, we arbitrarily define demand preferences and investigate which heuristics subjects commonly apply to reveal these preferences and by which factors their actions are stimulated. The focus of this study is on the strategic interaction of rivaling decision-makers, who may pursue product innovations to improve their relative position. In this respect, it is important to recall that successful product improvements in the first phase of the experiment have the character of incremental innovations, insofar as they improve the preceding product without depreciating any preexisting technology.

3.2 Second generation product improvements

In a randomly selected period (denoted as period *t'*), an exogenous shock takes place and modifies several parameters which affect both the suppliers' action set and the buyers demand preferences. Subjects may henceforth conduct additional costly research in order to refine their product portfolio. In the context of the model, "product refinement" translates into the attempt of a firm to bring her portfolio into conformity with a set of previously identified demand preferences.

The existence of an improved product coincides with a refinement in demand preferences. Both effects are intended to intensify research competition once again. This time, however, the market structure has significantly changed, since firms henceforth feature asymmetric capital endowments. As previously stated, we favor the setting in which firm heterogeneity evolves endogenously as the result of the subjects' interaction as opposed to a setting in which an asymmetric market structure is imposed by means of varying the firms' initial endowment.

The exogenous shock that takes place in the randomly determined period *t'* increases the set of possible specifications of each product by $m_i \times p_i$ additional items. Therefore, from period *t'* onwards, each product $i = 1, \ldots, n$ features an unordered set

$$a_i \in \left\{a_i^{10}, a_i^{20}, \ldots, a_i^{m_i 0}, a_i^{11}, \ldots, a_i^{m_i p_i}\right\} \quad \text{with } m_i, p_i \geq 2 \tag{5}$$

of $m_i \times (p_i + 1)$ alternative specifications.

The calculation of the attained sales volume in the second experiment phase is similar to the revenue function that applies in the periods preceding period *t'*. Whenever a product specification of firm X (Y) coincides with the ideal first generation specification by the choice $x_i = a_i^{*0}$ ($y_i = a_i^{*0}$), X (Y) sells one unit of the product in that period. Once the exogenous shock has occurred, X (Y) is able to sell two units of a product in that period whenever the specification of that product conforms to the newly discovered ideal second generation specification by the choice $x_i = a_i^{**}$ ($y_i = a_i^{**}$). The switching costs γ_i amount to one sales unit, remain constant during the entire experiment, and are charged whenever a new product specification is selected. However, the opportunity costs a subject incurs while modifying a product specification may exceed the sheer switching costs. This situation arises if the subject already generates revenues from the properly selected first generation product.

Due to the fact that potential product improvements are investigated in a sequential order, subjects are able to reduce the magnitude of the searchable product space by continuously eliminating invalid branches of the search tree. Note that the ideal second generation specification is directly linked to the specification of the preceding ideal first generation improvement. Thus, firms ought to adopt the search heuristics of identifying the ideal first generation specification of the product in the first place, and they should only then move on to find out the ideal second generation specification. Any attempt to search for the ideal second generation specification in some part of the search tree other than the branch of the ideal first generation product will inevitably come to nothing.

Thus, one can define the proximity of any x_i, respectively y_i, to a_i^{**} after period *t'* as

$$\delta_i\left(z_i^t, a_i^{**}\right) = \begin{cases} 2 & \text{if } z_i^t = a_i^{**} \\ 1 & \text{if } z_i^t = a_i^{*0} \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

for $z \in \{x,y\}$. Consequently, the maximal total market size increases to *2n* for each firm for all periods $t' \leq t$. We can define the profit π_z^t for $z \in \{x,y\}$ of firm X and Y, respectively, in a period $t \leq T$ as follows

$$\pi_z^t = \sum_{\tau \in \{1,\ldots,t\}} \sum_{i \in \{1,\ldots,n\}} \delta_i(z_i^\tau, a_i^{**}) - \sum_{i \in \{1,\ldots,n\}} \sum_{\substack{j \in \{1,\ldots,m_i\} \\ k \in \{0,1,\ldots,p_i\}}} \gamma_i^{jk}(z_i^t), \tag{7}$$

with switching costs

$$\gamma_i^{jk}(z_i^t) = \begin{cases} 1 & \text{if } z_i^\tau = a_i^{jk} \text{ for some } \tau = 1, \ldots, t \\ 0 & \text{otherwise.} \end{cases} \tag{8}$$

Similar to the granting of patents for first generation improvements, here a patent is also awarded to the firm that first reveals the ideal second generation improvement. Note that patents on first generation improvements are not affected by the exogenous shock and remain valid until they expire after a predefined length of time. However, any patent on a first generation improvement is overridden as soon as the corresponding second generation improvement has been identified.

3.3 Hypotheses

Due to the complexity in predicting all possible outcomes of this game, which would require enormous Bayesian reasoning on one's own and the competitor's investments, we assume that individual decisions are not based on optimal investment calculus. Therefore, we will not provide optimal innovation strategies for this environment. We expect that investments, nonetheless, follow certain regularities. Since economic interactions take place in a complex setting, which ultimately approximates decision-making under uncertainty, we maintain that subjects will search for reference points that assist them in making sensible investment decisions. We claim that firms evaluate the success of risky R&D investments not exclusively in terms of absolute profits, but also in comparison with the performance of their competitors. Consequently, we assume that subjects do perceive the modelled competition for innovation leadership as a tournament. Therefore, we suggest that the concept of the relative performance of firms is suitable for providing such a reference point.[3] If one firm is able to establish temporal monopolies for certain products, then the intensity of the competitive threat to the remaining market participants will increase significantly.

The latter will find their own relative strength diminishing, which is evidenced by a decline in their sales volume and profitability. Therefore, in contradiction to the ideas presented in the earlier literature on innovation, it is not the absolute size of firms that promotes the intensity of research activities, in the sense of a positive correlation between firm size and aggregate research investments. Rather, research propensity is determined by the relative positioning of firms with respect to their size, and it reaches its maximum when competing firms are of identical size.

In line with this reasoning, Schotter & Weigelt (1992) observe in earlier tournament experiments, in which competitors are endowed with unequal cost structures, that disadvantaged players discontinue their effort investment and drop out of competition during later periods of the experiment. Thus, we assume for the first phase of product improvements that a small distance compared to the competitors' accumulated profits promotes risky investments. Conversely, a larger relative distance in terms of the accumulated profits of the two firms decreases the rate of investment. In accordance with earlier findings (Cantner et al., 2004), we will analyze investments with respect to the following hypothesis:

> **Hypothesis 1**: In the first phase, those subjects who resemble each other in terms of their accumulated capital exhibit a higher probability of investing in

[3] In contrast to absolute income motivation for workers, Stark (1990) introduces the concept of relative deprivation in the discussion of labor tournaments. In this context, workers feel relatively deprived if their own individual income is lower than the average income of a reference group. Consequently, workers invest an additional effort in order to minimize the income difference between themselves and the reference group.

risky incremental innovations than those who are either far ahead or far behind their competitor in terms of their accumulated capital.

Although second generation product improvements are more profitable than first generation improvements, the opportunity costs for investigating a new alternative do increase. In the setting of this experiment, this can be equated with the existence of an outside option that guarantees a positive rent. Thus, the opportunity cost in the second phase of the experiment amounts to two sales units if the specification of the preceding first generation product is known to the firm.[4] Note in this respect that second generation product improvements have the character of fundamental product improvements, since they replace first generation product specifications. Consequently, due to the increased costs of search, it seems reasonable to test for the hypothesis:

> **Hypothesis 2.1**: The mean of the aggregated research investments of all subjects in first generation improvements will be higher than the corresponding mean of research investments in second generation improvements.

Yet the question arises whether all firms are identically affected by the increased opportunity costs. There are good reasons for both groups, leading or lagging firms, to pursue research in second level improvements. Of course, one could assume that economically leading firms expedite investments in second generation product improvements since they face a less severe budget constraint. According to this rationale, leading firms which can afford R&D expenditures invest in research with a higher intensity than their counterparts. Note that this claim corresponds to the empirical finding that R&D expenditures positively influence the number of innovations (Acs & Audretsch, 1988). Therefore, we will analyze investments for second generation improvements in hypothesis:

> **Hypothesis 2.2**: (Economically) Leading firms at the time of the exogenous shock will consecutively invest more than the corresponding (economically) lagging competitors.

On the other hand, the earlier literature favors the idea that lagging firms in particular promote fundamental innovation (Nelson & Winter, 1982). Firms face the problem that fundamental innovations replace existing technologies, and as such existing sources of income. In particular, leading firms would be asked after the exogenous shock to surrender those product improvements that laid the foundation for their superior economic position. In contrast, fundamental innovations give lagging firms the opportunity to surpass the competitor and, if still existing, to devalue the competitor's first generation patent while imposing a new patent on the market herself. Again, we would like to point out that this claim is consistent with the empirical result that market concentration negatively affects the number of innovations (Acs & Audretsch, 1988). For these reasons, we test for hypothesis:

[4] An opportunity cost of one sales unit is incurred due to active searching in contrast to abstaining from search. Moreover, declining a risk-free rent adds another sales unit to opportunity costs.

Hypothesis 2.3: (Economically) Lagging firms at the time of the exogenous shock will consecutively invest more than the corresponding (economically) leading competitors.

Finally, we want to ask whether the perception of opportunity costs is affected by the competitive threat. This context seems particularly relevant for firms that are only slightly ahead or behind their competitor in terms of relative capital. The decision to invest in research is influenced by the idiosyncratic weighting of potential losses and gains. If the focus is on potential losses, the following reasoning applies. If an effected research investment fails, it will invariably deteriorate the initiating firm's relative competitive position. A firm that had thus far outperformed its competitor by a slim margin may actually lose its leading position. Likewise, a lagging firm may further aggravate its competitive disadvantage by deliberately forfeiting a risk-free rent in terms of sales that it could have appropriated otherwise. If the focus is, however, on potential gains, then firms that are in a disadvantageous economic position in comparison with their competitor – prior to the exogenous shock – may consider the introduction of the second generation of product specifications as a chance to improve their relative position and invest largely. Therefore, we deduce that only those pairs of players that feature a clear-cut difference in their accumulated capital do exhibit a substantial propensity to invest in research. Thus, the data is analyzed in the following hypothesis:

Hypothesis 2.4: In the second phase, those subjects who resemble each other in terms of their accumulated capital exhibit a lower probability of investing in risky fundamental innovations than those who are either far ahead or far behind their competitor in terms of their accumulated profits.

4 Experimental results

We tested our set of hypotheses in a series of experiments. Altogether, 60 subjects participated in four sessions that were conducted in February and June of 2004.[5] Subjects were mostly students with a major in economics and business administration who had already completed two years of studies. At the beginning of a session, written instructions were handed out to each participant. The same instructions were subsequently read out aloud by the experimenter. In order to ensure that all participants had fully understood the experimental rules, all of the subjects were required to take a quiz about the rules before they were allowed to commence with the experiment. After each period, subjects were informed about their success in finding product specifications that coincided with demand preferences (i.e., whether they gained a patent), their own period income, the competitor's choice of product specifications, and the competitor's success in terms of patents and pe-

[5]To recruit subjects, we used the software package ORSEE (Greiner, 2004).

riod income. Subjects were provided with pen and paper so that they could take notes. The majority of participants did take notes.

The entire experiment lasted for 15 periods and consisted of two phases which were separated by the exogenous shock. In the course of the experiment, subjects were free to modify their product portfolio in every single period. The portfolio always consisted of $n = 8$ independent products. Initially, all products were unspecified. Prior to the exogenous shock, each subject was able to select one out of a set of distinct variations of the same (first generation) product specifications $m_i, i = 1, \ldots, 8$, with $m_i = 6$ for each of the eight products. If a subject preferred to leave a certain product unspecified, she was free to do so, as well. However, in this case, demand for this product invariably decreased to zero. At the beginning of the experiment, it was pointed out to all subjects that the exogenous shock would occur at a randomly determined point of time between period seven and ten (bounds included). Subjects were free to maintain their current first generation product specification (yielding a demand of 1 for this product) or to specify the products in greater detail (if successful, yielding a demand of 2 for this product). For each of the eight (first generation) specifications, subjects could choose one out of a set of distinct variations of the same (second generation) product specifications $p_i, i = 1, \ldots, 8$, with $p_i = 6$. As for convenience, the search space of variations for second generation products was kept manageable by the automatic elimination of evidently unsuccessful branches of the search tree. Thus, only those product variations were available for selection which had not already been falsified through own or the competitor's previous search attempts. The remaining product variations that logically could still contain the optimal variation for the second generation improvements were then listed for each of the eight independent products. Therefore, in case the suitable variation of the first generation product were found before the exogenous shock, subjects had the choice among not specifying a product, selecting the suitable variation of the first generation, or engaging in further research in second generation improvements. If that subject was the first to discover the respective demand preference, she was awarded a patent, as well. The duration of patent protection was arbitrarily set to six periods for the first level product and to three periods for the second level product.

Subjects needed approximately 65 minutes – including the time spent for instruction and solving the quiz – to complete the 15 periods of the experiment. They earned 9.81 Euros on average, with payoffs ranging from 4.20 Euros to 13.70 Euros. Subjects received an initial endowment of 30 ECU (experimental currency units). At the end of the experiment, both the endowment and the proceeds from the experiment were summed up and converted at the exchange rate of 1 ECU = 0.10 Euros. Theoretically it was possible for subjects to go bankrupt in the experiment. This, however, never occurred. As all subjects were provided with pen and paper to enable them to take notes, unwise investment decisions such as unnecessary redundant research (i.e., selecting a product specification which had previously already been unsuccessfully explored by the competitor) occurred only rarely.[6] Another investment inefficiency resulted from the fact that a set of subjects did not invest into research projects in situations in which they reasonably should have invested. In these cases, the decision to invest was not associated with any risk, since the product's demand preference had already been revealed by the competitor. All there was for the subjects to do was to select that very specification.[7] At large, we can infer that the subjects' individual search behavior was altogether quite systematic, since the large majority of all subjects successfully exploited emerging profit opportunities and avoided costly research inefficiencies.

4.1 First generation product improvements

First, we want to analyze the subjects' economic performance while competing for first generation product improvements. Before the exogenous shock is introduced in period eight or nine (depending on the session), 29 out of 30 groups have already found all eight first generation product improvements. In all of these groups, one subject clearly outperforms the other group member in terms of accumulated capital. The winner in the period preceding the exogenous shock shall hereafter be denoted as the leader, the other subject as the follower. Only for one group does the first phase of the experiment end in a draw.[8] The average accumulated capital of leaders surpasses the accumulated capital of followers from period 3 onward. Figure 1 shows the development of average closing accounts (measured in ECU) for leaders and followers.

As one possible explication, one can argue that the gap between the accumulated capital of leaders and followers can also result from diverging initial investments in product improvements. However, there is not a significant difference between the magnitude of investments of leaders and followers. Leaders invest 6.34 ECU while followers invest 5.97 ECU on average in period 1. In an earlier study, we presented another explanation (Cantner et al, 2004). In a series of experiments on patent races in an uncertain environment, we showed that subjects' willingness to invest in product improvements is dependent on the relative performance of competitors. We already introduced the idea that subjects who are in a group with a smaller gap in account balances exhibit a higher probability of investing in risky product innovations than subjects who are either far ahead or far behind in terms of their accumulated capital (**Hypothesis 1**).

In order to test **Hypothesis 1**, we analyze the effected first generation investments in a logit analysis of each individual investment decision.[9] In the fitted model, the dependent variable assumes the value of 1 if the player carries out a risky investment for a potential

[6] 0.7% (4.3%) of all effected investments in the first (second) phase feature this type of error.

[7] In the worst-performing period, aggregated sales of all subjects could have been 8% (5%) greater if all riskless profit opportunities had been exploited.

[8] In this particular case, we denote the firm that outperforms the competitor in the second last period as the leader, and the other firm as the follower.

[9] A fixed-group effects-panel data estimation is applied.

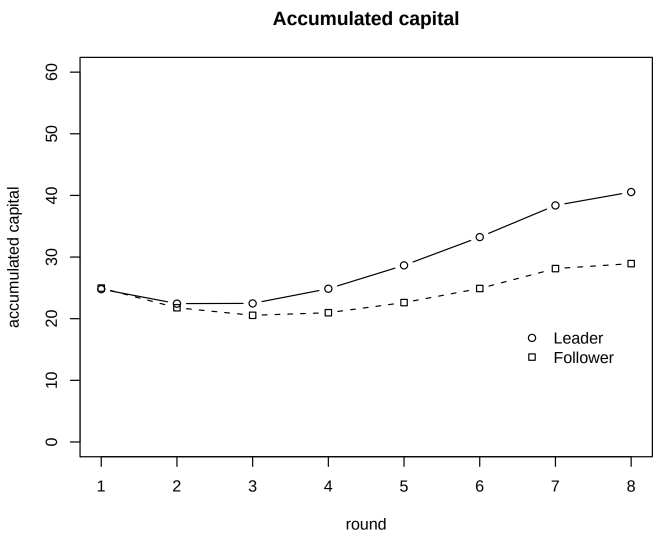

Figure 1: Mean accumulated capital of leaders and followers

first generation product improvement and assumes 0 otherwise.[10] Of course, subjects face the problem of scarce investment resources in the first phase of the experiment. A higher number of investment opportunities lowers the investment probability for each individual one. Hence, we introduce the variable *NoOp*, which accounts for the number of further reasonable risky investment options ($NoOp \in [0{,}7]$), where we assume that *NoOp* has a negative influence on investments. Results are summarized in Table 1 as model OBJ.

In addition, we test for the influence of the absolute size of the accumulated capital (*ownAccount*) in period t on the probability of carrying out a risky investment in period t. Results are reported as model ABS. We then define a measure for the relative capital (denoted as *relAccount*) as the difference between one's own accumulated capital and the competitor's accumulated capital in period t, divided by the sum of the two. With respect to **Hypothesis 1**, we expect that subjects who feature a negative relative account balance at the time of the investment decision will have a higher probability of conducting further search investments for increasing *relAccount*. To the contrary, for those subjects who surpass their competitor in terms of their relative capital at the time of the investment decision, we presume a negative relation between the relative capital *relAccount* and the probability to invest in a product improvement.[11] We mark those subjects who had a positive relative capital *relAccount* with the dummy variable δ_{pos} so that we can test for the interaction $relAccount \times \delta_{pos}$. Results are reported as model REL. Estimated parameters of the fitted logit models are reported in Table 1. Standard errors are provided in parenthesis, goodness of fit is reported by the Akaïke information criterion (AIC), and stars indicate

[10]We exclude all those by no means risky investments from the analysis in which the ideal specification is already known (and so there is no reason to further explore the remaining search space for this product) or in which only one alternative is still remaining (so that the investment is no longer risky).

[11]Note that *relAccount* is negative for subjects who dispose of less accumulated capital than their competitor, while it is positive for subjects who dispose of more capital than their counterpart.

model	OBJ	ABS	REL
constant	2.41^{***}	1.28^{***}	2.57^{***}
	(0.269)	(0.416)	(0.388)
NoOp	-0.128^{***}	-0.151^{***}	-0.151^{***}
	(0.034)	(0.044)	(0.052)
ownAccount		0.017	
		(0.02)	
relAccount			-0.758^{*}
			(1.921)
$relAccount \times \delta_{pos}$			-1.803^{*}
			(3.414)
AIC	1434	1442	1434

Table 1: Logit models for risky first generation investments

levels of significance.[12]

The results of our estimation support the assumption that the variable *NoOp* has a significant negative effect on the probability of investing. To the contrary, the variable *ownAccount* does not significantly affect the investment propensity. Yet the interaction of $relAccount \times \delta_{pos} + relAccount$ shows a significant negative effect of the leader's relative capital on her probability to invest. Thus, the logit estimation confirms **Hypothesis 1**, insofar as the greater the subject's relative capital becomes, the lower is her probability of engaging in risky investments. By contrast, we cannot confirm **Hypothesis 1** for followers. Firms that exhibit a negative relative capital significantly deviate from our prediction insofar as a decreasing value of *relAccount* does not lower the follower's probability to invest, whereas we expected a positive correlation between these variables. One can explain this result by the fact that, in contrast to earlier experiments on patent races (Cantner et al, 2004), subjects anticipate that, subsequent to the end of the first phase, the patent race will continue for second generation improvements. Thus, followers also persistently search for ideal first generation improvements, knowing that those will be the prerequisites for further product development in the second phase.

4.2 Second generation product improvements

In the second phase, subjects typically do not explore the entire set of product alternatives as thoroughly as they did in the first phase of the experiment. Only 16 out of 30 groups are able to identify all eight second generation product improvements. Apparently, this results from a lower investment intensity in the first three periods following the exogenous shock, as compared to the corresponding periods in the first phase. Figure 2 compares the mean investment levels for first and second generation product improvements.

Indeed, a statistical comparison of the average investment levels of the first eight periods

[12]* significant on a 10% level; ** significant on a 5% level; *** significant on a 1% level.

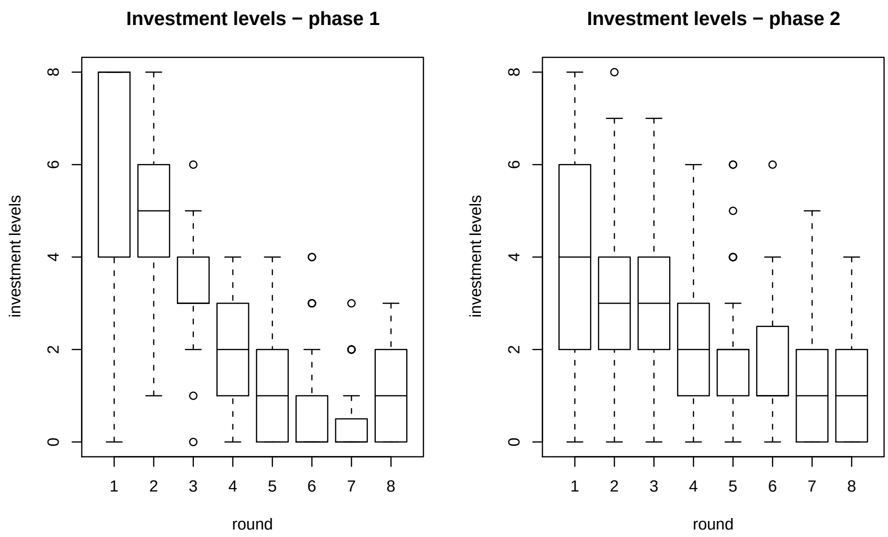

Figure 2: Boxplot of investments in product improvements

and their corresponding counterparts after the exogenous shock shows that investment levels in the first phase start out at higher levels, but decline more rapidly over the course of that phase, as well. However, investment intensity in the second phase of the experiment is more balanced (mean of 1.96 for each product, standard deviation of 1.96) when compared with the first phase (mean of 2.18, standard deviation of 2.41).[13] The overall intensity of search investments is not significantly lower, but it is less pronounced in the early periods. Thus, we have to reject **Hypothesis 2.1**. Consequently, the increased opportunity costs do not lead to lower search activities per se, but they attenuate the time pressure under which the subject has to make an investment decision. This could be the consequence of increased opportunity costs, but could also reflect the greater profitability of successful search attempts, which encourages investments even in the concluding periods of the second phase.

Still, so far we have not yet identified the type of firm that preponderantly invests in product improvements. Is it the leading firm that is backed by her strong economic position or is it rather the lagging firm that has the ambition to improve her relative economic standing after the exogenous shock? A comparison of the mean investment levels for the groups of leaders and followers does not point out any significant difference.[14] As a consequence, we cannot identify any regularity with regard to the investments of leaders and followers. Therefore, we can neither confirm **Hypothesis 2.2** that firms with superior market power in an established market do promote innovations (Schumpeter, 1942), nor can we affirm **Hypothesis 2.3** that less established firms actively attempt to exploit a

[13]The difference in means of investment levels for phase 1 and 2 is noticeable, but it is not significant (p=0.101, t-test, two-sided). The difference in variance, though, is clearly significant ($p < 0.001$, F-test, two-sided).

[14]In each of the periods of the second phase, the corresponding test (t-test, two-sided) remains insignificant.

competitive opportunity (Nelson & Winter, 1982).

Rather, we analyze the subjects' propensity to invest in relation to their relative capital at the time of the exogenous shock (**Hypothesis 2.4**). With this in mind, we form four groups of subjects (*a, b, c,* and *d*). Group *a* includes all those subjects who exhibit relative capital (*relAccount*, as defined in the previous section) of $relAccount < -0.15$ at the time of the exogenous shock. Subjects of group *b* feature relative capital in the range of $-0.15 < relAccount < 0$, while group *c* comprises all subjects with relative capital in the range of $0 < relAccount < 0.15$. Finally, group *d* includes all the subjects with relative capital of $relAccount > 0.15$. This partitioning is based on the following deliberation: The subjects of group *a* represent distant followers who are very unlikely to catch up. Their own accumulated capital equals less than 75% of their competitor's accumulated capital. The subjects of group *b* are slightly more fortunate. Their accumulated capital is still lower than that of their competitors, but they possess at least 75% of the latter's accumulated capital. Similarly, the subjects of group *c* feature higher accumulated capital than their competitor, but exceed the competitor's accumulated capital by at most 35%. Finally, group *d* comprises all the subjects who have more than 35% more of their own accumulated capital than the other. Thus, one can state that the relative position of each of the four groups[15] is quite different. An analysis of the overall sum of investments in second generation product improvements – which is carried out at the level of the previously defined groups – exhibits the structure that is shown in Figure 3. Due to the fact that the exogenous shock occurs in different periods – which depended on the session – we have to correct for the fact that, for some subjects, the second experiment phase lasts for 9 periods, while, for others, it only lasts for 8 periods. We fix the issue by truncating the data for the former group after the completion of period 14. Thus, in terms of our analysis, all subjects face a second experiment phase of uniform duration.

Indeed, the relative competitive position of a subject has a direct implication on her investment behavior, which confirms **Hypothesis 2.4**. A comparison of the average sum of investments illustrates a significantly greater investment intensity for group *a* (17.57 ECU) than for group *b* (12.40).[16] Investment levels for groups *b* (12.40) and *c* (15.56) vary insignificantly.[17] In a comparison between group *c* (15.56) and *d* (17.20), the latter group features a greater, albeit insignificant, mean investment.[18]

It seems that subjects who find themselves in a disadvantageous economic position relative to their competitor (group *a*) prior to the exogenous shock consider the introduction of the second generation of product specifications as a chance to improve their relative position, and they thus invest largely. This result supports the claim that less established firms are active promoters of innovations. To the contrary, subjects who fare somewhat

[15]Please note that both groups *a* and *d* (groups *b* and *c*) are composed of 14 firms (16 firms, respectively).

[16]The mean of investments of group *a* is significantly greater than the mean of group *b* ($p = 0.028$, t-test, one-sided).

[17]The equality of means of investments for both groups cannot be rejected ($p = 0.317$, t-test, two-sided).

[18]It cannot be confirmed that mean investments of group *d* exceed those of group *c* ($p = 0.324$, t-test, one-sided).

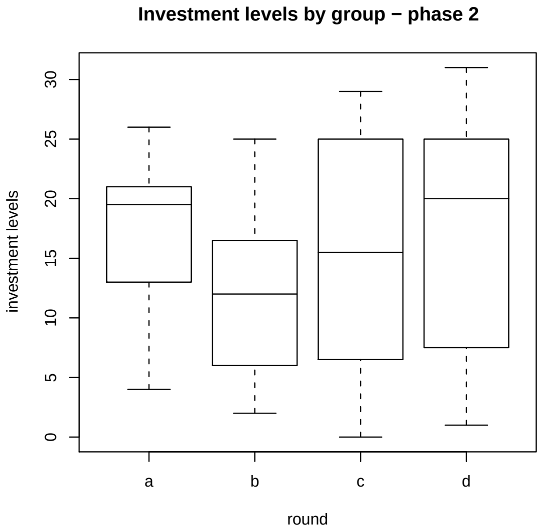

Figure 3: Total investments in second generation product improvements

better in terms of their relative capital (group b), but who are nevertheless still economically behind in a direct comparison with their competitor, perceive the introduction of the second generation of product aspects rather as a threat than as an opportunity. As soon as attempts for further product improvement entail positive opportunity costs, then subjects in bitter competition with their competitor no longer promote innovations that depreciate former investments and render existing products obsolete. In this situation, the majority of subjects prefer to fully exploit the given profit opportunities first before moving on to conduct new and risky search investments. The same is true for subjects who gain the leading position in the market, but do so by only a slim margin (group c). They invest less than firms who dominate their market – with respect to their far superior accumulated capital. Nonetheless, subjects in group d act rather irregularly, which is pointed out by the high variance of the group's investments levels. While some subjects seem to be highly motivated and eager to defend their dominant economic position, others invest only moderately. Yet the mean of investments roughly equals the mean investment of the economically worst performing group.[19]

For further interpretation, we estimate another logit model of each risky investment into second generation improvements.[20] The dependent variable equals 1 if the risky investment occurred, and 0 otherwise. In contrast to the first experiment phase, we must state that the product space which subjects are facing after the exogenous shock is not entirely homogeneous. For numerous groups, some patents on first generation products are still in effect at the time of the exogenous shock. Evidently, a subject's opportunity costs amount to zero for those products that the competitor is holding a patent to. From a strategic point of view, subjects shall favor investments in exactly these products, since a success-

[19]A t-test (two-sided) for the equality of means remains insignificant (p=0.906).

[20]Again, a fixed-group effects-panel data estimation is applied.

model	OBJ	ABS	REL	A&R
constant	-0.771^{***}	-0.113^{**}	-0.891^{***}	1.033^{***}
	(0.097)	(0.157)	(0.102)	(0.292)
comPat	0.543^{***}	0.464^{**}	0.571^{***}	0.546^{***}
	(0.0889)	(0.09)	(0.0907)	(0.0913)
ownAccount		-0.012^{***}		-0.043^{***}
		(0.0031)		(0.0049)
relAccount			0.113^{*}	2.081^{***}
			(0.339)	(0.512)
$relAccount \times \delta_b$			1.773^{***}	1.815^{***}
			(0.866)	(1.063)
$relAccount \times \delta_c$			-1.65^{**}	-2.12^{***}
			(0.883)	(1.066)
$relAccount \times \delta_d$			0.056^{*}	-0.804^{*}
			(0.638)	(0.85)
AIC	3259	3227	3261	3183

Table 2: Logit models for risky second generation investments

ful second generation product improvement will not only increase one's own turnover, but will equally devalue the competitor's monopoly. Therefore, we introduce the independent variable *comPat*, which equals 1 if the competitor holds the patent on the first generation product at the time of investment, and 0 otherwise. We expect *comPat* to have a positive influence on investment. Table 2 summarizes the results as model OBJ.

Again, we conduct an analysis of the influence of the absolute size of the accumulated capital (*ownAccount*) in period t on the probability of carrying out a risky investment in period t (results are reported as model ABS). Next, we analyze the influence of the relative account on the probability to invest. We already showed previously that the total investment levels are different for the groups *a, b, c,* and *d.* Thus, we introduce the variable *relAccount* and three dummy variables as dependent variables, which interact with the variable *relAccount* ($relAccount \times \delta_b$, $relAccount \times \delta_c$, and $relAccount \times \delta_d$). The latter three variables show deviations with respect to the influence of the variable *relAccount* on the propensity to invest for subjects that belonged to group *b, c,* and *d.*[21] Table 2 shows the results of the estimation as model REL. Standard errors are provided in parenthesis, goodness of fit are reported by the Akaïke information criterion (*AIC*), and stars indicate levels of significance.[22]

The results of our estimation show the significant positive influence that the existence of a competitor-held patent exercises on one's own investment probability. As it turns out, *ownAccount* has a significant influence on investment, as well. In contrast to the analysis of first generation investments, we find a significant saturation effect in the second model, as

[21] Recall that *relAccount* is negative for subjects belonging to groups *a* and *b*, while positive for subjects belonging to groups *c* and *d*.

[22] * significant on a 10% level; ** significant on a 5% level; *** significant on a 1% level.

the coefficient of *ownAccount* is significantly negative. This result seems reasonable since all subjects know for sure that the experiment will end after the second phase. Therefore, we finally provide a model (reported as model A&R) that incorporates *ownAccount* and *relAccount* as explanatory variables.

With respect to the variable *relAccount*, the results of the REL and the A&R model indicate a significant difference between the investment behavior of groups *a*, *b*, *c*, and *d*. Within each group, the results for groups *a*, *b*, and *c* support **Hypothesis 2.4**. Here, a smaller relative distance with respect to relative capital increases the probability to invest in second generation product improvements. However, the result is not true for group *d* (i.e., $relAccount \times \delta_d + relAccount > 0$). Remember that those firms are already in the comfortable position such that their relative capital exceeds that of the competitor by at least 35% in the period in which the exogenous shock occurs. Therefore, from the leader's perspective, the competitor's accumulated capital may no longer provide a valid reference point for guiding investments into product improvements. As a result, subjects of group *d* seem to be only marginally affected in their investment behavior by their relative competitive position.

5 Conclusion

In this study, we experimentally investigated prominent investment patters of firms that strategically interact in a duopoly market and compete for economically successful product innovations. The experiment is modelled so as to allow for a scenario of sequential innovations, in which both incremental as well as fundamental innovations may be pursued. Our research aims at identifying possible economic factors that exhibit a direct impact on the subjects' decision to invest or to refrain from investing in costly research. To this effect, we propose several logit models that provide explicit and consistent results. We want to emphasize three main findings. First, we observe a significant effect of the subject's relative economic position on her propensity to carry out search investments for incremental innovations. If the competitive threat is high – which is indicated by a small difference in the subjects' accumulated capital – then subjects exhibit a significantly higher propensity to invest. Second, we can show that, depending on their relative competitive position, subjects also pursue distinct investment strategies for fundamental innovations. If the competitive threat is low – which is indicated by a wide gap between the subjects' accumulated capital – then subjects exhibit a significantly higher propensity to invest in fundamental innovations than in situations in which competitors posses equal capitalization and the competitive threat is substantial. In the latter environment, the likelihood that the subjects will effect further investments is significantly reduced. As the third finding, the impact of increased opportunity costs on investments in innovations has to be differentiated. The direction of the effect significantly depends on the relative positioning of competitors in terms of their capitalization. Yet the experimental evidence provides little support for the hypotheses that either leading firms or lagging firms primarily promote further innovative investments. Consequently, the results of our experimental analysis confirm earlier empirical findings (e.g. Lerner, 1997). Throughout the experiment, investment levels of leading and lagging firms – if treated as a group – do not differ significantly at any time. Rather, the difference in investment levels between leaders and followers is motivated by the subject's relative economic position with respect to the direct competitor.

References

[1] Acs, Z.J. & D.B. Audretsch (1988), Innovation in large and small firms: An empirical analysis, *American Economic Review* **78 (4)**, 678-690.

[2] Beath J., Y. Katsoulacos & D. Ulph (1988), Strategic innovation. In M.A.H. Dempster (editor.) *Mathematical Models in Economics*, Oxford: Oxford University Press.

[3] Cantner, U., W. Güth, A. Nicklisch & T. Weiland (2004), Competition in innovation and imitation: A theoretical and experimental study, Papers on strategic interaction, 2/2004, Jena: Max Planck Institute for Research into Economic Systems.

[4] Cohen, M.W. & S. Klepper (1996), Firm size and the nature of innovation within industries: The case of process and product R&D, *The Review of Economics and Statistics*, **78 (2)**, 232-243.

[5] Dasgupta, P. & J. Stiglitz (1980a), Uncertainty, industrial structure and the speed of R&D, *The Bell Journal of Economics* **11 (1)**, 1-28.

[6] Friedman, C. (1953), *The methodology of positive economics: Essays in positive economics*, Chicago: University of Chicago Press.

[7] Greiner, B. (2004), An online recruitment system for economic experiments. In K. Kremer & V. Macho (editors) *Forschung und wissenschaftliches Rechnen 2003, Bericht der Gesellschaft für wissenschaftlichen Datenverarbeitung Göttingen* **63**, 79-93.

[8] Harris C.J. & J. Vickers (1987), Racing with uncertainty, *Review of Economic Studies* **49**, 372-387.

[9] Isaac, R.M. & S. Reynolds (1988), Appropriability and market structure in a stochastic invention model, *The Quarterly Journal of Economics* **103**, 647-671.

[10] Isaac, R.M. & S. Reynolds (1992), Schumpeterian competition in experimental markets, *Journal of Economic Behavior and Organization* **17**, 59-100.

[11] Katz, M.I. & C. Shapiro (1987), R&D Rivalry with licensing or imitation, *American Economic Review* **77**, 402-420.

[12] Lerner, J. (1997), An empirical exploration of a technology race, *The Rand Journal of Economics* **28 (2)**, 228-247.

[13] Nelson, R.R. & S.G. Winter (1982), *An evolutionary theory of economic change*, Cambridge: Harvard University Press.

[14] Reinganum, J.R. (1982), A dynamic game of R&D: Patent protection and competitive behavior, *Econometrica*, **48**, 671-688.

[15] Reinganum, J.R. (1983), Uncertain innovation and the persistance of monopoly, *American Economic Review* **73**, 741-748.

[16] Schumpeter, J.A. (1942), *Socialism, Capitalism, and Democracy*, London: Unwin.

[17] Schotter, A. & K. Weigelt (1992), Asymmetric tournaments, equal opportunity laws, and affirmative action: Some experimental results, *The Quarterly Journal of Economics* **107**, 511-539.

[18] Stark, O. (1990), A relative deprivation approach to performance incentives in career games and other contests, *Kyklos* **43**, 211-277.

[19] Tirole, J. (1989), *The Theory of Industrial Organization*, Cambridge: MIT Press.

[20] Vickers, J. (1986), The Evolution of market structure when there is a sequence of innovations, *Journal of Industrial Economics* **35**, 1-12.

[21] Winter, S.G. (1964), Economic 'natural selection' and the theory of firms, *Yale Economic Essay* **4**, 225-272.

[22] Zizzo, D.J. (2002), Racing with uncertainty: a patent race experiment, *International Journal of Industrial Organization* **20**, 877-902.

Appendix: Instructions

Thank you very much for participating in this experiment. From now on, we kindly ask you to refrain from any public announcements and attempts to communicate directly with other participants. If you violate this rule, we will have to exclude you from this experiment. If you do have any questions, please raise your hand, and an experimenter will come to your place and answer your questions. In the experiment, you will repeatedly interact with one other participant who has received the same instructions as you have.

In this experiment you are asked to manage a large technology company. In each period, you have to decide whether you want to engage in research activities in eight different research fields (e.g., in motor engines, cellular telephones, etc.). For each research field, you and the other participant can choose from six alternative technologies (e.g., for the cellular telephones wap-technology, gps-technology, etc.), which we denote as "tech 1.0", "tech 2.0", etc. . For the entire duration of the experiment, we randomly set an ideal technology in each of the eight research fields. Your task is to specify the technology fields such that they meet those ideal technologies. Whenever you choose the ideal technology, you receive one ECU (experimental currency unit). Whenever you do not choose the ideal technology, you receive no ECU. In total, you receive in each period t the sum of all earnings from all eight technology fields (we denote them as D_t). In the first period, for instance, you can receive at most eight ECU – if you meet all eight ideal technologies. In the worst case, you earn nothing – if you miss all eight technology fields. You can also leave one or more fields unspecified. However, if you do so, you will definitely not receive any ECU in those fields for the given period.

If for any technology field you are the first, say in period t, to find the ideal technology, you obtain a patent for the next six periods in this technology field, and the other participant is not allowed to choose the ideal technology in the meantime. Similarly, if the other is first in finding the ideal technology, you cannot choose the ideal technology for the next six periods. After the patent has expired, both you and the other participant can choose the ideal technology (which remains unchanged in the course of the experiment). If both of you find the ideal technology in the same period, you can both choose the ideal technology afterwards. It is important to note that you have to pay one ECU for trying a new technology. This rule does not apply to the research of technologies that you had already tried in earlier periods. Leaving fields unspecified does not incur any costs, either.

In total, this experiment lasts for 15 periods. In a random period *t'*, between period seven and ten, the following happens: The remaining technologies in all technology fields unfold into six sub-technologies; that is, if the ideal technology is already found prior to that period, only this technology splits into sub-technologies. If you or the other participant had already tried a technology unsuccessfully, this technology is not split into sub-technologies, but disappears.

Example: You found the ideal technology "tech 2.0" in the field "cellular telephones".

Then, only technology “tech 2.0” is divided into “tech 2.0”, “tech 2.1”, ..., “tech 2.6”. If you and the other only found that the ideal technology is either “tech 2.0” or “tech 3.0” (i.e., you both tried all other alternatives unsuccessfully), the two technologies will have been divided into “tech 2.0”, “tech 2.1”, ..., “tech 3.0”, ..., “tech 3.6”.

Still, for the specification “tech .0”, you receive one ECU in period *t’* and later if the selected technology is ideal. If the patent for the ideal technology has not yet expired in *t’*, it remains in effect for the sub-technology “tech .0” until the patent duration has elapsed (however, this is not the case for the other sub-technologies “tech .1”, ..., “tech .6”). If one of you is the first find the ideal technology “tech .0” even after period *t’*, this person obtains a patent for the next six periods.

Within the ideal technology (and only there), there exists an ideal sub-technology. If you identify the ideal sub-technology, by choosing it, you receive two ECU. If you choose the wrong sub-technology, you do not receive any ECU.

Example: You found prior to period *t’* that the ideal technology in the field “cellular telephones” has to be either “tech 2.0” or “tech 3.0”. Suppose “tech 2.0” is the ideal technology. Then you receive one ECU for choosing “tech 2.0” after period *t’*. For your choice “tech 3.0”, or “tech 3.1”, or ... “tech 3.6”, you definitely do not receive any ECU. We assume that “tech 2.6” is the ideal sub-technology. Then you receive two ECU for choosing “tech 2.6”, while you do not earn any ECU for choosing “tech 2.1”, or “tech 2.2”, or ... “tech 2.5”.

If, for any technology field, you (or the other participant) are the first to find the ideal sub-technology, you obtain a patent for the next three periods in this technology field (and the other participant is not allowed to choose the ideal sub-technology for that time). Such a patent on the ideal sub-technology devalues any patent that may exist on the ideal technology, so that the patent on the ideal technology ends immediately. Please note that you have to pay one ECU for trying a new sub-technology.

After each period t you are informed about your own earnings (D_t) and your choice in period t. Further, you learn about the earnings and choices of the other participant in period t. Finally, all current patents and your accumulated earnings from all the periods so far are indicated to you.

Your total profit in the experiment is determined by the sum of the received ECU from all periods of the experiment ($D = D_1 + D_2 + ... + D_{15}$) minus the sum of all incurred costs for trying new technologies and sub-technologies (denoted as K). You start with an endowment of 30 ECU, so that your earnings at the end of the experiment will amount to $30 + D - K$ ECU. All ECU that you earned in the experiment will be exchanged at the rate of 1 ECU = €0.1 and will be paid to you in cash. Note that there is the possibility to go bankrupt in this experiment if you unsuccessfully spend your entire endowment on exploration without finding any ideal (sub-)technology. In this case, you will not receive any profit for the 15 periods.

Before the experiment starts, we will ask you to correctly answer a number of questions that aim at improving your understanding of the experiment. Please fill in that questionnaire thoroughly. Once you have finished, an experimenter will come to your place and verify your answers.