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Competition in Innovation and Imitation - A Theoretical and Experimental Study -

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Abstract

For given product specifications by two competing firms the demand levels are determined by a randomly generated ideal composition of aspects. Firms can vary some or all aspects of these products, based on information about own (and other's) previous demand. Although the product space is much too large to be explored systematically, we expect (and test for) rather reasonable innovative success and welfare levels due to own innovative attempts and imitation of a successful other. Parameter variations concern the pioneer advantage and search costs.

Key Words: Innovation, Imitation, Patent Tournament, Trial and Error Process
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1. INTRODUCTION

Innovations are the driving forces of modern economic growth. However, since innovations are per se new, it is scientifically impossible to describe how innovations are made. If this were possible, there would be no more innovations (Arrow, 1991). Hence economic models of innovation lack endogenous novelties and do not explain the actual innovative step.

In some situations one may be able to derive analytically or numerically the best (or at least a better than the presently used) alternative. What renders this topic an exciting area of scientific research, however, is when the space of possible mutants is too large for our cognitive capacity. Our study is an attempt to observe in an experimental setting behavioral structures of agents who adjust their product in (Schumpeterian) non-price competition. We initiated a trial and error process by providing a product space which is too large for systematic search. Except for imposing quite arbitrarily some Bayesian setting subjects will not develop optimal strategies, but use search or innovation heuristics. But even such an analysis will not be concerned with the detection of the genuinely new. All that is offered is an experimental approach to describe and understand how agents engage in innovative activities.

More specifically, we are concerned with behavioral structures of subjects when agents are trying to introduce something new or at least better. In particular, we are interested in how sellers search for better (in the sense of higher consumer acceptance) product designs, and how this depends on their own past choices and success as well as on the choice and success of their competitor. Thus, we combine two research traditions of the economic literature, the economics of innovation and experimental economics, which both propagate a more realistic model of "economic man." To the best of our knowledge, this is one of the first attempts to explore innovative activities experimentally.[6]

In section 2 we will introduce the fundamental idea of competition in innovation and discuss its theoretical background. The product space and the demand model are introduced and some general search strategies in such a setting are discussed in section 3. Details of experimental design and protocol as well as the experimentally observed behavior are reported in section 4. The concluding remarks in section 5 summarize our basic findings.

[6] Isaac & Reynolds (1988, 1992) investigate experimentally patent tournaments in terms of price competition. Zizzo (2002) set up a patent race for a single patent. However, there is no competition in the product space. Less related are experimental studies of stopping heuristics in search problems where one tries to select the most suitable candidate when candidates are presented sequentially (see, e.g., Zwick, Rapoport, King Chung Lo & Muthukrishnan (2003) for the so-called secretary problem).

2. MOTIVATION

Innovative activities are undertaken under uncertainty of their ultimate outcome and under competition for innovation rents. We are interested in how agents search for technological solutions with higher consumer acceptance, how this depends on the past, e.g., via their own and others' technological and economic success.

A brief review of the literature may help to locate our approach and differentiate it from related work. The literature on optimal innovation in general and on patent races in particular investigates the optimal designs of innovation strategies when innovators can assess the profit of alternative innovation strategies.[7] Our approach differs by not assuming rational behavior. Let us nevertheless look at the results on so-called patent races, especially sequential patent races as a kind of benchmark for the outcomes and innovation dynamics which we could expect.

In patent races, innovation attempts depend on the profit incentive as well as on the competitive threat. The profit motive – or stand-alone-motive – is concerned with the profits an innovator can gain in isolation, whereas by the competitive threat the rivalry of competitors is taken into account. The outcome of patent races and the characteristic development of sequential patent races depend on how competitors are affected by these two determinants. In the patent races analyzed by Beath, Katsoulacos, and Ulph (1995), the outcome is stochastic and undetermined when two (symmetric) competitors are affected by both, the profit motive and the competitive threat. Contrary to that, Reinganum (1985) discusses only differences in profit motives and Harris & Vickers (1985, 1987) only differences in the competitive threat. Here firms with a higher profit motive or a higher competitive threat invest more in R&D and are thus more likely to win the patent race.

In models of deterministic sequential patent races, e.g., Vickers (1986), one investigates the conditions under which the strategic interaction between different innovators leads to specific innovation sequences. Sequential structures range from dominance sequences, where always the same competitor takes the lead, to so-called action-reaction sequences of leapfrogging where the technological lead of one innovator in period t can imply a change in technological leadership in period $t+1$. Introducing uncertainty leads to (analytically non-solvable) stochastic innovations sequences for which Beath, Katsoulacos, and Ulph (1988) in a number of simulation experiments distinguish gradual catching-up sequences and continuous leapfrogging.

[7] Seminal contributions such as Arrow (1962), Dasgupta & Stiglitz (1980) or Reinganum (1985) are just based on this idea: the optimizing agent, endowed with full information and unbounded problem-solving capabilities, pursues an optimal R&D program maximizing the difference between the additional gross profits accruing from an innovation and the costs to achieve that innovation.

This literature, although rooted in the rational choice approach, gives us some ideas about the likely outcomes when strategic considerations play a role.

Here we do not employ the assumptions of full information as well as of unbounded individual cognitive capabilities. Innovative endeavors are made under considerable uncertainty (Knight 1921, Shackle 1968) so that behavior relies to a considerable degree on trial and error (Dosi & Egidi 1993). For such a setting, a behavioral approach which considers agents as bounded in their information processing capability and in their cognitive capabilities seems more adequate. Hopefully, our experimental data can suggest what determines innovation behavior and "learning" in the sense of gathering new information and solving technological and economic problems. As those activities do not necessarily lead to optimal decisions, this kind of behavior is often characterized by satisfycing (Simon, 1956).

With this perspective the evolutionary approach allows in principle for various forms of innovative activities or strategies. In fact there are only few studies which focus on such types of innovative behavior, e.g., the "go-it-alone strategy" (Fusfield & Haklish 1985), the imitative or "defense and dependent" strategy (Freeman 1982), or the absorptive strategies (Cohen & Levinthal 1989). In such studies the determinants of innovative decisions, highlighted by the neoclassical analysis, do not lose significance or explanatory content. But it is questioned how and to which degree they can explain innovation behavior of boundedly rational agents.

With these theoretical considerations in mind, we were interested in how innovators behave in rather unstructured situations. Of course, in order to derive clear-cut results we have to reduce those situations to tractable dimensions. We do so by allowing, first, only for new or qualitatively improved products and, second, by restricting the competitive situation to the case of two competitors whose profit prospects and competitive threats are designed in a symmetric way.

3. INNOVATIVE COMPETITION

3.1. Product space and demand model

We consider a duopolistic market in which one product is sold by each firm. The heterogeneity of their products varies depending on the firms' specification of products. Assume that the product has n (≥ 2) aspects $i = 1, \ldots, n$ which all can vary in multiple ways. For $i = 1, \ldots, n$ the alternative specifications of aspect a_i are completely unordered, i.e., all that can be stated is whether the two products agree in aspect a_i or differ. Thus, for $i = 1, \ldots, n$ one has an unordered set

$$A_i \in \left\{a_i^1, ..., a_i^{m_i}\right\} \quad \text{with } m_i \geq 2$$

of m_i alternative specifications. We denote by

$$a = (a_1, ..., a_n) \in \times_{i=1}^n A_i =: \mathbb{A}$$

an arbitrary product specification and by a^* the ideal one by which the demand level of the competing firms will be determined.

The two firms X and Y must select a product $x = (x_1, ..., x_n) \in \mathbb{A}$, or resp. $y = (y_1, ..., y_n) \in \mathbb{A}$. The maximal total demand of $2n$ units would result in individual demands of $\phi_x(x, y) = n = \phi_y(y, x)$ only in case of $x = a^* = y$. Otherwise, at least one competitor misses the ideal product specification which results in a loss of demand. Since the sets A_i are unordered, one can define for any $x = a$, or resp. $y = a$ the distance of a and a^* in the i-th aspect by

$$\delta_i (a_i, a^*) = \{ \begin{array}{l} 0 \text{ if } a_i = a_i^* \\ 1 \text{ otherwise} \end{array}$$

Only in case of $n - \sum_i \delta_i (a_i, a^*) > 0$, the firm with product a encounters a positive demand, whereas in case of $\sum_i \delta_i (a_i, a^*) = n$, it does not sell at all. More specifically, we define $\phi_x^t(x^t, y^t)$and $\phi_y^t(y^t, x^t)$ in period t as follows:

$$\phi_x^t(x^t, y^t) = \sum_{i=1}^n \left[1 - \delta_i \left(x_i^t, a_i^*\right)\right] \left[1 + \delta_i \left(y_i^t, a_i^*\right)\right]$$

and

$$\phi_y^t(y^t, x^t) = \sum_{i=1}^n \left[1 - \delta_i \left(y_i^t, a_i^*\right)\right] \left[1 + \delta_i \left(x_i^t, a_i^*\right)\right]$$

Clearly, $\phi_x^t(x^t, y^t) = n = \phi_y^t(y^t, x^t)$ for $x^t = y^t = a^*$ and $\phi_x^t(x^t, y^t) + \phi_y^t(y^t, x^t) \leq 2n$ otherwise. Supposing constant and positive sales prices allows identifying demand levels with revenues. Assume further that there are constant costs of technological change whenever a new specification for one aspect a_i is chosen, and that both firms interact on the market for T periods $t = 1, ..., T$ $(T \geq 1)$. Abstracting from production costs, we can identify the overall (undiscounted) profits π_x and π_y of firm X and Y as follows:

$$\pi_x = \sum_{t=1}^{T} \phi_x^t(x^t, y^t) - \lambda_x \sum_{i=1}^{n} \sum_{j=1}^{m_i} \gamma_{i,j}\left(x_i^t\right)$$

and

$$\pi_y = \sum_{t=1}^{T} \phi_y^t(y^t, x^t) - \lambda_y \sum_{i=1}^{n} \sum_{j=1}^{m_i} \gamma_{i,j}\left(y_i^t\right)$$

with

$$\gamma_{i,j}\left(z_i^t\right) = \{ \begin{array}{l} 1 \text{ if } z_i^t = a_i^j \text{ for some } t = 1, ..., T \\ 0 \text{ otherwise.} \end{array}$$

for $z = x, y$. The positive parameterλ_x and λ_y define the switching costs when changing one of the n different product aspects. We will assume $\lambda_x = \lambda_y$ to preserve the symmetry of the market.

Note that the optimal choice is always given as $x = a^*$, or resp. $y = a^*$, regardless whether the other firm is located optimally or not. Any deviation from the optimal product specification results in a loss (of 1 (2) units, depending on whether the other firm has chosen the corresponding aspect (non-)optimally). This should promote imitation when the product specification and demand level of the other firm can be observed. Imitating a more successful other firm should speed up progress.

Since each firm could immediately imitate the competitor's innovation, we protect a successful innovator who has been first in finding some optimal aspect. More specifically, we introduce some kind of transitory monopoly rights, i.e., a patent phase: for firm X and its competitor Y

$$\begin{aligned} \text{if } (x_i^h &= a_i^* | x_i^g \neq a_i^* \text{ and } y_i^g \neq a_i^*)_{\forall g<h} \\ \text{then } y_i^\tau &\neq a_i^* \text{ for periods } \tau = h+1 \text{ to } \tau = h+k \text{ for some } k > 0. \end{aligned}$$

So if firm X is first in finding in round h the optimal i-th aspect a_i^* by $x_i^h = a_i^*$, the other cannot choose $y_i^\tau = a_i^*$ in rounds $\tau = h+1$ to $\tau = h+k$ with $k\,(\geq 1)$. Similarly, if the other is first in finding $a_i^*$by $y_i^t = a_i^*$, then X cannot choose a_i^* for k rounds thereafter. If both find a_i^* at the same time, both can choose a_i^* afterwards.

3.2. Innovate or imitate: Two basic attitudes

Motivation of participants is controlled by monetary payoffs as usual. But since the product space is too large to render a rational choice approach reasonable, one has to discuss what motivates trial and error search processes. We claim that trial and error is controlled by the competitive aspect of the experiment: subjects do not determine their strategies by calculating their monetary payoff for the entire experiment (How much do I earn in the experiment?), but rather compare their payoff performance with that of their competitor (How do I fare relative to the competitor?). This means we distinguish relative gains and losses in mental accounts (Kahneman & Tversky, 1984). Due to the enormous product space and the practical impossibility to develop optimal strategies, the active goal is to succeed in competition, but not the overall payoff. The profit is not valued absolutely since there are no obvious payoff aspirations, but is relatively judged by comparing it to that of the competitor. As a consequence, we expect trial and error processes to be more competitive rather than driven by own monetary success as, for instance, postulated in reinforcement learning (e.g., Roth & Erev, 1995).

In principle we expect two basic attitudes, a more active attitude of those subjects who innovate by exploring the product space (hereafter pioneers) and a more passive attitude of those who imitate successful innovations, but do not explore the product space (hereafter followers). The two dispositions may result from different relative positions in the game. Pioneers and followers could be differently motivated by gains and losses. The closer the two competitors' payoffs are, the more active is the goal to earn more than one's competitor. Thus, we should observe more pioneer behavior in case of close R&D competition, but decreasing willingness to invest into R&D, and hence more follower behavior when subjects are either far ahead or far behind (the next section will specify in more detail what we mean by far ahead and far behind, respectively).

To test the alternative hypothesis that innovative investments are only controlled by their expected profits, we specified the numbers m_i of possible specifications of aspects $i = 1, ..., n$ asymmetrically. In total we had $n = 8$ aspects. 4 of those 8 aspects i had $m_i = 8$ specifications each while the other 4 aspects had $m_i = 4$ specifications each. Hence the maximal total demand is 16 units per period. Even without calculating the expected profit of an "innovative step," one can say at least that an aspect with only 4 unexplored specifications yields a higher expected profit than an aspect with 8 unexplored specifications. Thus, we should observe an initial concentration of innovative activities on those aspects with 4 alternative specifications only.

4. EXPERIMENTAL RESULTS

In total 30 subjects participated in the experiment. Subjects (undergraduate students of the University of Jena) were mostly in their second or third year of studying business administration or economics and participated in 2 sequences of 15 periods of the game described above.[8] We used the partner design for each sequence, but a stranger design across the two sequences. Participants were asked to answer a short five-item multiple choice questionnaire to check their full understanding of the instructions. Incorrect answers were explained before the experiment started. Experiments took place in the computer laboratory of the Max Planck Institute Jena in spring 2003. For twice playing 15 periods subjects needed approximately 65 minutes and earned on average 16.36 euros (with a range from 5.04 to 23.20 euros). As to the time for the patent phase, we set $k = 4$ periods.

After each period subjects were informed about their success in finding the ideal specification (e.g., whether they gained a patent), the actual choice of the opponent, the opponent's success (in terms of patents and monetary profit), and their own payoff. Subjects were provided pen and paper so that they could take notes (which was done by the overwhelming majority). In each round a participant could refrain from specifying an aspect which, of course, led to no demand regarding this aspect. The parameters λ_x and λ_y were set as $\lambda_x = \lambda_y = 2$, and the initial endowment for each participant was 40 units (at the end of the experiment, units were converted at an exchange rate of 1 unit = 0.08 euros) so that players could go bankrupt in the course of the experiment (which, however, never happened).

In order to analyze the individual overall performance, all subjects were assigned to one of two categories. The first category comprised all subjects who achieved the higher final payment in their market. The second category consequently comprised all the losing subjects in terms of their overall payoff. The case that both subjects had identical closing accounts at the end of a sequence never happened. The subjects with the higher closing account were labeled as the 'first half' category (Cat.1) while the subjects with the inferior closing account were assigned to the 'second half' category (Cat.2). Note that for some pairs, second half subjects earned more than first half subjects in other pairs. Due to their more extensive patent ownership, the members of Cat.1 experience higher sales levels already in the first few rounds (see Fig.1). In round 7, the average sales maximum for Cat.1 is reached with 9.67 units. From there onwards, sales levels of Cat.1 and Cat.2 gradually return to the balanced market share of 8.00 units each.

[8] Due to a software crash in the second sequence, we lost the data for 6 subjects so that the analysis for sequence two includes only 24 instead of 30 subjects.

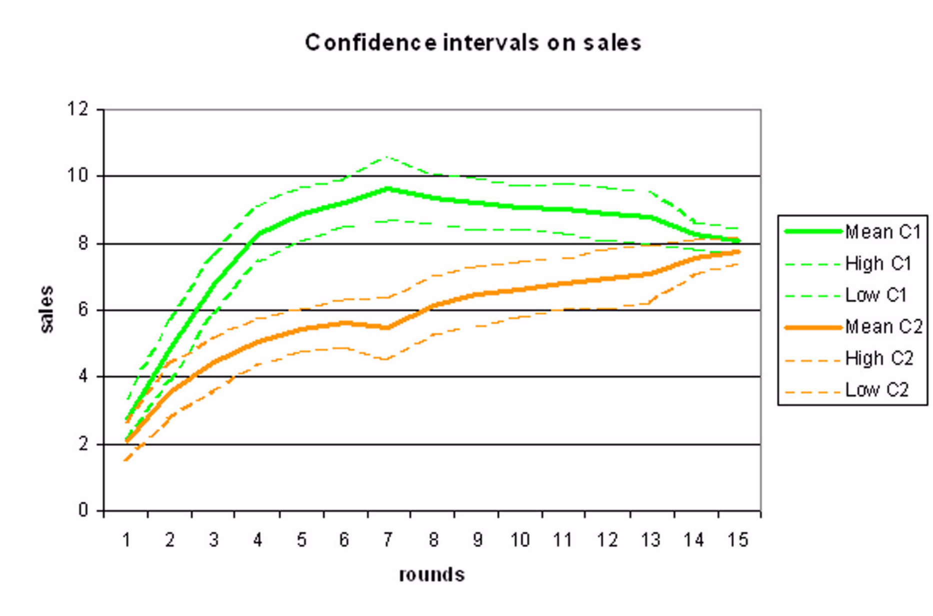

FIG. 1 Average Sales

Members of Cat.2 then benefit from expiring patents of Cat.1 sellers and gradually increase their sales levels from round 7 on. Not surprisingly the periodic profits of both categories converge to equality at the end of the sequence after the maximal dispersion is reached in period 7 (see Fig.2).

Round profits are strictly negative at the beginning of the sequence for both categories, Cat.1 and Cat.2. We could not find any significant difference in investment behavior for the first period.[9] Cat.1 (Cat.2) subjects invested on average 11.8 units (13.4 units) with a standard deviation of 4.65 units (4.47 units). Due to their superior patent ownership, members of Cat.1 early on realized higher sales levels than their competitors. Examination of the categories' closing accounts suggests a path-dependent trajectory. Cat.1 subjects earned on average 122.9 units (standard deviation 14.2) while Cat.2 subjects earned 81.8 units (27.4) If a subject is able to acquire an early advantage in form of patents, he will be able to defend his leading market position. An effect of 'leapfrogging' - e.g., the change of roles between the market leader and the follower (see Vickers, 1986) - could not be observed in the experiment. It is interesting to mention that variance of payoffs among Cat.2 players is significantly higher than for Cat.1 players. This results from different investment behaviors which will be analyzed later on.

Individual errors like duplication of R&D investments or unrealized sales (subjects do not choose a non-patent protected albeit publicly known ideal configuration)

[9] $p = 0.174$ for the hypothesis of equal means in 2-tailed t-test.

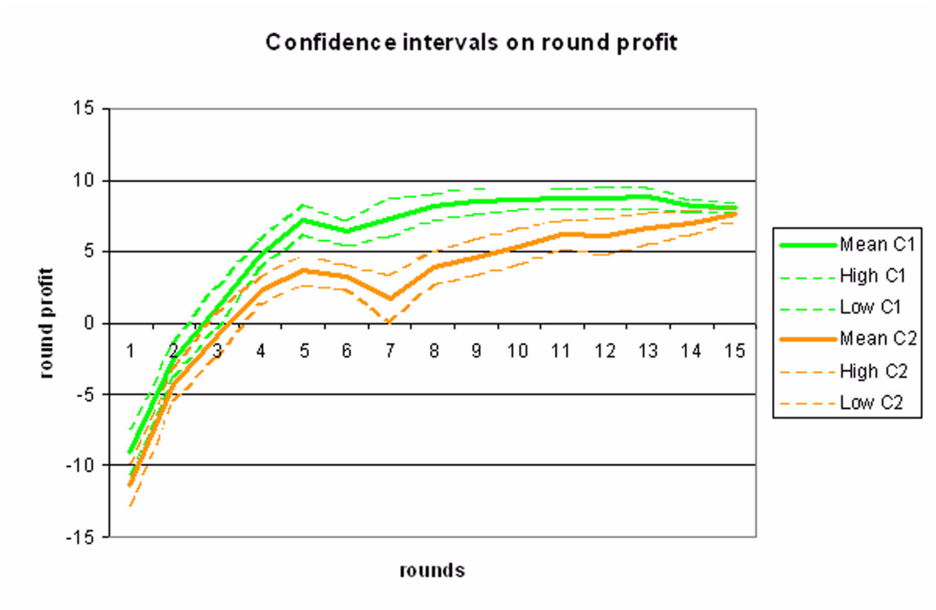

FIG. 2 Average Round Profit

were rare.[10] The frequency of unrealized sales decreased from sequence one to sequence two (0.36 units on average per round as compared to 0.14). Similarly, duplicate R&D also occurred less often in the second sequence (0.11 as compared to 0.03). The share of subjects who rank first in the first sequence and again in the second sequence is 0.50. Consequently, the probability of subjects who were second in the first sequence to win the second sequence is also 0.50. This suggests that subjects do not possess any kind of a specific innovation ability providing them with a competitive advantage. Research success in our experiment rather seems to be pure chance at least when being judged by relative performance on a market.

Let us now analyze the two basic motives for R&D investments in our experiment. Investments are shaped by own expected profits, and investments are motivated by competition. To test the competitive motivation of players, we use a probit model analyzing each individual investment decision. The analysis included all those decisions where investment was a reasonable but risky opportunity. We excluded all those cases where the ideal specification was already known (and so there was no reason for further exploration of the product space in this dimension) or only one alternative was left (so that investment was no longer risky). In total we had for the first sequence 1744 decisions of 30 subjects (seq 1) and 1392 decisions of 24 subjects for the second sequence (seq 2). We partitioned subjects (pos or neg, respectively neg) into those who in the round under consideration had more, or resp. less, credit on their account than their opponent since we assume that both groups

[10] This is not surprising since participants could use pen and paper to record and recall their (and their competitors') specifications.

were differently motivated by pioneering and imitation. The dependent variable is 1, if subjects invested in a new specification and 0 otherwise. The explanatory variables are the number of other investment options (*# other options*), the own current account (*own account*), the difference between the subject's own and her competitor's credit relative to the subject's own credit (*rel account*), and, finally, the dummy variable d_1 which is one for investment opportunities in period 1 and 0 otherwise. Table 1 shows the results for the different combinations:

	pos seq 1	*neg* seq 1	*pos* seq 2	*neg* seq 2
constant	-0.3837	-0.4232	-0.2412	0.1487
$(p - value)$	(0.3205)	(0.1340)	(0.3776)	(0.7337)
# other options	0.2088	0.2436	0.1182	0.1308
$(p - value)$	(0.000)	(0.000)	(0.002)	(0.001)
own account	-0.0245	-0.024	-0.0211	-0.0324
$(p - value)$	(0.002)	(0.007)	(0.017)	(0.079)
rel account	0.3324	0.2671	0.2794	0.7376
$(p - value)$	(0.3925)	(0.0499)	(0.7449)	(0.000)
d_1	[11]	7.4641		8.015
$(p - value)$		(1.00)		(1.00)
# correct predictions	0.755	0.81	0.765	0.822
$R^2_{McFadden}$	0.0825	0.4322	0.0756	0.4772

Table 1: Probit model for the competitive motivation of R&D investments

The results reveal a significant positive influence of the variable "other options" (*# other options*). Thus, the fewer remaining options, the smaller the probability that subjects invest in that aspect. The more undecided the competition is the greater is, the willingness to invest. In contrast, we see an effect of saturation since a higher current account (*own account*) significantly lowers the probability to invest (except for "*neg* seq 2"). The relative account (*rel account*) has a significant influence on the investment decision only for subjects with less credit than the competitor ("*neg* seq 1" and "*neg* seq 2"). Note that this influence is negative since the variable itself is negative for subjects in the "*neg*" partition. Hence the closer one comes within reach of the competitor, the more willingly one invests. Comparing the results for the first and the second sequence shows that the importance of one's relative standing increases for subjects in the "*neg*" partition. Finally, the dummy variable d_1 indicates all those investment opportunities in period 1. This, however, had no significant influence on subjects' behavior. Our probit model predicts between 75 and 82 percent of all individual decisions correctly and a goodness-of-fit was assessed.[12]

[11] All observations of the first periods belong to the *neg*-cases since the distances of payoffs are zero. Hence there are no dummy variables in the *pos*-cases.

[12] Hosmer-Lemeshow goodness-of-fit chi-square tests reject a lack-of-fit on a p=0.05 level for all models.

We also tested the hypothesis of own payoff orientation. An investment in an aspect with four specifications is initially more favorable than searching for the ideal specification in an aspect with eight specifications. Therefore, we tested a probit model for the individual investments partitioning investments of the first sequence (seq 1) and of the second sequence (seq 2). Again, the dependent variable is 1, if subjects invested in a new specification and 0 otherwise. The explanatory variable is a dummy variable for all aspects with eight specifications (d_8). Additionally, we estimated the same model with a dummy variable which is one for periods 1 to 3 when the aspect has eight specifications, and 0 otherwise (d_8^*). However, as shown in Table 2, the coefficients of both dummy variables are (significantly) positive so that in contrast to our hypothesis a smaller number of possible specifications does not increase the probability for investment. Hence we can hardly support the hypothesis that fewer unexplored specifictions inspire more innovation.

	seq 1	seq 1	seq 2	seq 2
$constant$	-0.49	-0.491	-0.536	-0.563
$(p-value)$	(0.000)	(0.000)	(0.000)	(0.000)
d_8	0.458		0.39	
$(p-value)$	(0.000)		(0.000)	
d_8^*		0.901		0.845
$(p-value)$		(0.000)		(0.000)
$\#$ *correct predictions*	0.60	0.68	0.63	0.69
$R^2_{McFadden}$	0.024	0.069	0.017	0.063

Table 2: Probit model for the profit maximizing motivation of R&D investments

5. CONCLUSION

In summary, our findings show that the willingness to invest into R&D is motivated to a large extent by competition. Closer competition, measured by a smaller monetary distance between competitors, promotes investment. With a larger monetary distance, the probability of the follower to invest decreases. Closer competition motivates a pioneer strategy of trial and error attempts, while large differences between competitors inspires imitation (which we could observe for both possible positions, the "far-ahead-leader" and the "far-behind-follower"). Monetary saturation also slows down innovative activity.

Innovations are the driving forces of modern economic growth. According to our experimental findings, competition is the driving force for innovations. Here we did not induce or at least control for personal characteristics like risk attitudes, which could promote or influence innovative activities. Quite surprisingly, we could not find any support for tackling easier search problems first, i.e., those with only four instead of eight possible specifications. In contrast, our main conclusion is that in innovation agents are trying to win the race. Innovations in the form of trial and error attempts are governed by competition. In our experiment only competitors in pairs with relatively close monetary positions revealed a pioneering attitude of exploring the product space. With clear-cut competitive (dis)advantages imitation becomes more prominent.

REFERENCES

[1] Arrow K.J. (1962), Economic Welfare and the Allocation of Resources for Invention, in: Nelson R.R. (ed.), The Rate and Direction of Innovative Activity: Economic and Social Factors, Princeton: Princeton University Press, 1962, 609-25

[2] Arrow K.J. (1991), The dynamics of technological change. In: OECD, Technology and Productivity: The Challenge for Economic Policy, Paris, 473-476

[3] Beath J., Y. Katsoulacos, D. Ulph (1988), Strategic innovation, in: Dempster M.A.H. (ed.), Mathematical models in economics, Oxford: Oxford University Press, 1988

[4] Beath J., Y. Katsoulacos, D. Ulph (1995), Game Theoretic Approaches in the Modelling of Technological Change, in: Stoneman P. (ed.), Handbook of the Economics of Innovation and Technological Change, Oxford UK, Cambridge, Mass.: Blackwell, 1995, 132-81

[5] Cohen W.M., D.A. Levinthal (1989), Innovation and Learning: The Two Faces of R&D, Economic Journal 99, 1989, 569-96

[6] Dasgupta P., J.E. Stiglitz (1980), Industrial Structure and the Nature of Innovative Activity, Economic Journal 90, 1980, 266-93

[7] Dosi G., M. Egidi (1993), Substantive and Procedural Uncertainty: An Exploration of Economic Behaviour in Changing Environments, Journal of Evolutionary Economics 1, 1991, 145-68

[8] Freeman C. (1982), The Economics of Industrial Innovation, 2nd edition, Pinter Publishers, London, 1982

[9] Fusfield H.L., Haklish C.S. (1985), Cooperative R&D for Competitors, Harvard Business Review 6, 1985

[10] Harris C.J., J. Vickers (1985), Perfect Equilibrium in a Model of Patent Race, Review of Economic Studies 52, 1985, 193-209

[11] Harris C.J., J. Vickers (1987), Racing with Uncertainty, Review of Economic Studies 49, 1987, 372-87

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

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

[14] Kahneman, D. & Tversky, A. (1984), Choices, values, and frames, American Psychologist 39, 341-350

[15] Knight F.H. (1921), Risk, Uncertainty and Profit, New York: Kelly, 1921

[16] Reinganum J. (1985), Innovation and industry evolution, Quarterly Journal of Economics, 100, 1985, 81-99

[17] Roth, A. & Erev, I. (1995), Learning in extensive form games, Games and Economic Behaviour, 8, 164-212

[18] Shackle G.L. (1968), Decision, Order and Time in Human Affairs, Cambridge: Cambridge University Press, 1968

[19] Simon, H.A. (1956), Models of man, New York: John Wiley and Sons, Inc.

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

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

[22] Zwick, R., Rapoport, A., King Chung Lo, A. & Muthukrishnan, A.V. (2003), Consumer Search: Not Enough Or Too Much? Marketing Science, in press

Appendix: Instructions

Thank you for participating in our experiment. We kindly ask you to refrain from any public announcements and attempts to communicate directly with other participants. In case you violate this rule, we have to exclude you from the experiment. If you do have any questions, please rise your hand, and one of the persons who run the experiment will come to your place and answer your questions. In the experiment you will repeatedly, namely in rounds $t = 1$ to $t = 15$, interact with one other participant who has received the same instructions as you. In each round t of interaction, both of you are asked to specify for a product, namely a car, 8 different components (color, motor craft,...), which we call components a_1 to a_8. For components a_1 to a_4, there are eight different alternatives (e.g., for colors green, blue, red,...), and for component a_5 to a_8, there are four alternatives from which you and the other participant can select.

We will now describe how your choice of vector a and the other's choice determine what you will earn in a given round. To do so let us refer to

$$\begin{array}{ll} \hat{a} = (\hat{a}_1, ..., \hat{a}_8) & \text{as your own choice,} \\ \widetilde{a} = (\widetilde{a}_1, ..., \widetilde{a}_8) & \text{as the other's choice,} \\ a^* = (a_1^*, ..., a_8^*) & \text{as the ideal choice.} \end{array}$$

For your choice $a = \hat{a}$ in round t, you will receive

$$\delta_i\left(\widehat{a}_i^t, a_i^*\right) = \{ \begin{array}{l} 1 \text{ ECU if } \widehat{a}_i^t = a_i^* \\ 2 \text{ ECU if } \widehat{a}_i^t = a_i^* \text{ and } \widetilde{a}_i^t \neq a_i^* \\ 0 \text{ ECU if } \widehat{a}_i^t \neq a_i^*, \end{array}$$

Thus, if you miss all eight ideal components a_i^* by your eight choices $\hat{a}_i^t$, your success is 0. If you have chosen the right component ($\widehat{a}_i^t = a_i^*$), then you will receive from that choice 1 ECU if the other has done so, too ($\widetilde{a}_i^t = a_i^*$) and 2 if not ($\widetilde{a}_i^t \neq a_i^*$). Altogether you will therefore receive $D_t = \sum_{i=1}^{8} \delta_i\left(\widehat{a}_i^t, a_i^*\right)$. So in one round you can earn at most $8 * 2 = 16$ ECU, which requires $\widehat{a}^t = a^*$ and $\widetilde{a}_i^t \neq a_i^*$ for $i = 1, ..., 8$ and at least nothing in case of $\widehat{a}_i^t \neq a_i^*$ for $i = 1, ..., 8$.

Important to note is that if for any component $i = 1, ..., 8$ you are first, say in round t, in finding $a_i^*$by your choice $\widehat{a}_i^t = a_i^*$ then the other cannot choose a_i^* in the next 5 rounds. Similarly, if the other is first in finding $a_i^*$by $\widetilde{a}_i^t = a_i^*$ in a round t, then you cannot choose a_i^* in the next 5 rounds. If both of you find a_i^* at the same time, you can both choose a_i^* afterwards.

Also important to note is that you have to pay 2 ECU for each trying out a new alternative a_i^j of any of the 8 components This rule holds only for new alternatives.

You are also free to leave one component unspecified. This is also free, but you will definitely earn no profit for this component. Your total success score $D = \sum_{t=1}^{15} D_t\left(\widehat{a}^t, \widetilde{a}^t\right)$ in all rounds $t = 1, 2, ..., 15$ determines your earnings minus your switching costs K. At the start of the experiment, you will get an endowment of 40 ECU, so that after 15 periods your profit is $40 + D - K$ ECU. At the end of the experiment, we will exchange all ECUs earned in the 15 rounds at a rate of

$$1 \text{ ECU} = 0{,}01 \text{ euros}$$

and pay off the participants. There is also the possibility to go bankrupt in this experiment if you spend the entire endowment for exploration without finding any ideal specification. In this case you will receive no profit for the 15 rounds.

After each round t you will be informed about

- your own success $(D_t\left(\hat{a}^t, \widetilde{a}^t\right))$ in that round t,
- the other's success $(D_t\left(\widetilde{a}^t, \hat{a}^t\right))$ in that round t,
- your own choice $\hat{a}^t = (\hat{a}_1^t, ..., \hat{a}_8^t)$ in that round t,
- the other's choice $\widetilde{a}^t = (\widetilde{a}_1^t, ..., \widetilde{a}_8^t)$ in that round t,
- the optimal alternatives found in the last five rounds (which are forbidden if only the other was first in finding it, and which are ruled out for the other if only you were first), and
- your accumulated profit from all the rounds so far.

After receiving this information feedback, we will start the new round $t+1$ with the same partner and the same ideal choice $a^* = (a_1^*, ..., a_8^*)$. After 15 periods, a first sequence is finished and a new one of 15 periods starts with another participant and new, randomly determined ideal specifications.

Before the first round starts, we will ask you some questions concerning the rules of this experiment in a questionnaire. Please answer them correctly. One of the persons who run the experiment will come to your place and clarify wrong answers.

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