Competition in Innovation
- An experimental study

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Innovation is the main driver of modern economic growth.

Innovation:
is the conversion of knowledge and ideas into a benefit, which may be for commercial use or for the public good; the benefit may be new or improved products, processes or services.

Innovations (and technological change) have significant implications on

- modern economic development and growth (Cameron, 1998)
  . . . as they expand the knowledge base of an economy and enhance process and organizational efficiency (total factor productivity)
- competitiveness at the corporate, sectoral, regional, or national level
  . . . as they contribute to value creation and decrease costs (consider innovation systems literature)
- employment and economic policy
  . . . as innovative, prospering sectors provide new job opportunities and tax yields and compensate for less efficient, declining industries (Schumpeter, 1942)

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Abundant literature exists on particular aspects of innovation

Frequently debated issues:

- inefficiencies through over-/ underinvestment in R&D (private vs. social return to R&D, Nelson 1959, Arrow, 1962)
- surplus appropriability (enforceability of property rights, imitation rate, prominence of substitutes, Nordhaus, 2004)
- knowledge spillovers (Griliches, 1992, Grossman & Helpman, 1992) related: knowledge as a public or private good (Winter, 1987),
- negative congestion externalities (duplication of research efforts, Jones & Williams, 1999)
- creative destruction (redistribution of rents from past to current innovators, Schumpeter, 1942)
- diffusion/transferability of knowledge (industrial districts - Mansfield, 1923, tacit vs. codified knowledge, Ducatel, 1998)
- learning effects/ competence building (Lundvall, 1997)

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Yet, open research questions remain

So far, experimental methods have only sporadically been used to examine hypotheses about R&D behavior of firms (Suetens, 2003).

Previous experimental evidence . . . . . .

- patent/ innovation race models (e.g. "tug of war" models)
- stochastic invention models
  . . . magnitude of R&D investments determine probability of achieving innovation
- two-stage games
  . . . first stage: decision on R&D allocation (decreases cost function), second stage: decision on production
- models providing choice between innovation and imitation
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Experimental evidence

- Seminal paper; Cooperative and noncooperative R&D in duopoly with spillovers (d'Aspremont & Jacquemin, 1988)
- Subjects are given the choice between imitation and innovation (under uncertainty). Market generally are efficient but need time to converge. Uncertainty causes heterogeneity in behavior. (Jullien & Ruffieux, 2001)
- Spillovers have no significant effect on the investment rate in R&D. If agreed upon, binding contracts between competitors facilitate cooperative R&D levels. (Suetens, 2003)
- There are no R&D investment differences between large and small firms in patent races. (Zisso, 2003)
- Competition promotes investments in risky research that aims to further innovation. (Isaac & Reynolds, 1992)
- Behavior and competence portfolio of innovating agents are coherent and not randomly distributed which implies path dependency and learning effects. (Di Mauro & Santangelo, 2004)

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Conceptualizing a new model

Nevertheless, theory in the field of innovation economics still lacks a suitable model which ...

- adequately characterizes innovative agents
  ... behavioral regularities in R&D activities
- and the incentives guiding their behavior
  ... market characteristics (concentration, appropriability conditions, spillovers, return on investment/ expected success rate, information states)
- in a highly dynamic and interactive system.
  ... strategic interaction in a sequential game

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Conceptualizing a new model (cont.)

A new model should . . .

- incorporate individual innovation strategies
  . . . provide subjects with multiple, distinct decision options ("innovate", "imitate")
- interpret innovation in the genuine sense (Arrow, 1991)
  . . . investments take place in state of uncertainty (an "optimal" search algorithm is intentionally ruled out)
- reflect the competitive and interactive nature of innovation.
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Why to conduct an economic experiment?

Advantages:

- useful to verify/falsify hypotheses about behavior of agents in situations of economic interaction
- facilitate data acquisition, if empirical data are not available or cannot feasibly be obtained (with respect to costs, biases, general unavailability)
- maintenance of controlled environment (baseline/ control treatments, parameters variations, flow of information, interaction patterns)

Critical issues:

- adequacy of experimental model (Does model produce data which allows to answer posed research questions?)
- provision of proper economic incentives (sufficient stakes)
- assurance of external validity (replications, variation of sample composition, consideration of cultural peculiarities)

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General setting

- Firms (agents) repeatedly interact in a duopolistic market
- with the aim of generating a superior product portfolio (comprising n independent products),
- while resorting to quality, rather than price competition.

- Subjects interact for duration of T rounds in partner design. In a subsequent second sequence of the experiment, subjects are randomly rematched.
- They may achieve product innovations by either actively pursuing (costly) research or by imitating the successful competitor.
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Research

- A subject's portfolio consists of n aspects A_i with $n = 8$.
- Initially, subjects face m_i alternative research projects for each aspect, of which only one will bring about a product innovation in aspect A_i $\quad A_i \in \{a_i^1, \ldots, a_i^m\}$ with $m_i \geq 2$.
- For each aspect A_i, the successful research project a_i^* is exogenously defined.
- Subjects do not - yet - possess any knowledge of the identity of these successful research projects.
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Revenues & costs

- Whenever the subject's specification $\hat{a}_i$ equals the ideal specification, the subject is able to sell one unit of the product.

$$\delta_i(\hat{a}_i, \tilde{a}_i, a_i^*) = \begin{cases} 2 & \text{if } \hat{a}_i = a_i^* \text{ and } \tilde{a}_i \neq a_i^* \\ 1 & \text{if } \hat{a}_i = a_i^* \text{ and } \tilde{a}_i = a_i^* \\ 0 & \text{otherwise} \end{cases}$$

- Subject is charged constant search costs γ for every effected research project (if research is novel).

$$\gamma_{i,j}(\hat{a}_{i,t}) = \begin{cases} 2 & \text{if } \hat{a}_i = a_i^j \text{ for any } t = 1, \ldots, T \\ 0 & \text{otherwise} \end{cases}$$

- Successful research - which leads to innovation in aspect A_i - is rewarded by temporary patent protection of aspect A_i for duration of k rounds (with $k = 4$).

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Endowment & profit function

- Subjects receive positive initial endowment ϵ at beginning of each sequence (corresponds to firm's capitalization).
- Profit function for round t

  $\pi_t = \sum_{i=1}^{n} \delta_i^t(\hat{a}_i, a_i^*) - \sum_{i=1}^{n} \sum_{j=1}^{m_i} \gamma_{i,j}^t(\hat{a}_{i,j})$

  with $t \in \{1, 15\}, n \in \{1, 8\}, m_i \in \{1, 4/8\}$.
- Final payoff aggregation

  $\Pi = \sum_{i=1}^{T} revenues_t - \sum_{i=1}^{T} search\ costs_t + \epsilon$

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Experiment overview

- 15 rounds of duopolistic non-price competition in partner design, followed by one repetition (2 sequences altogether)
- After each round, subjects were informed about own and competitor's research activities and economic success.
- Product portfolio consisting of 8 aspects which comprise 8, respectively 4 research projects.
- Patent protection of $k = 4$ rounds.
- 78 students from the University of Jena, Germany, in 2003/2004.
- Experiment duration approximately 65 minutes, average earnings of €18.78 [€7.54 - €25.70]

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Strategy considerations vs. theoretical solution

- Complexity of experiment renders computation of game-theoretical optimal solution by means of backward induction difficult (magnitude of search space, stochastic elements, repeated interaction).
- It is unlikely that subjects are able to derive optimal strategy, which emulates decision making under (quasi) uncertainty.
- Instead, subjects may pursue:
  - trial-and-error strategy
  - employ successful heuristics (net present value analysis)
  - benefit from learning effects.
- Subjects may condition investments on:
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  - existence of patents
  - remaining time until experiment completion
  - arguably - relative economic performance.

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Expectations

Hypothesis 1:

We observe a more pronounced pioneer behavior, if economic wealth increases due to former pioneering[1].

Hypothesis 2:

More pioneering behavior is observed in the case of bitter competition, whereas attenuated competition promotes follower behavior.

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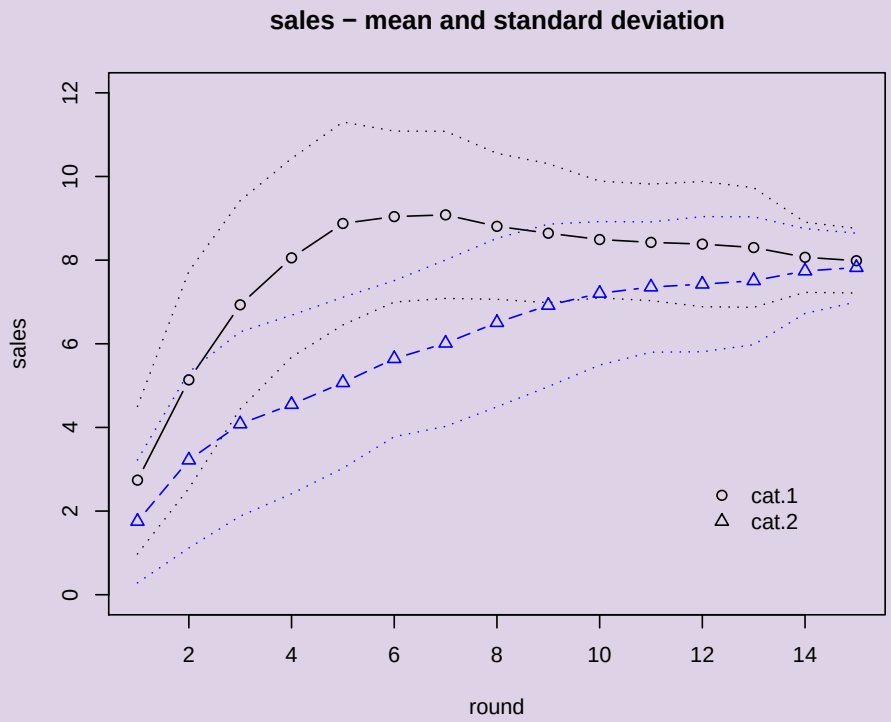
Average sales



cat.1 - (leading players) earnings ($t = 15$): mean 118.4, sd 14.9

cat.2 - (lagging players) earnings ($t = 15$): 85.7, sd 21.8

t-test (two-sided) shows significant difference for all $t \in \{1, 13\}$

Observation

A subject who is able to acquire an early advantage in form of patents will generally be able to defend his leading market position.

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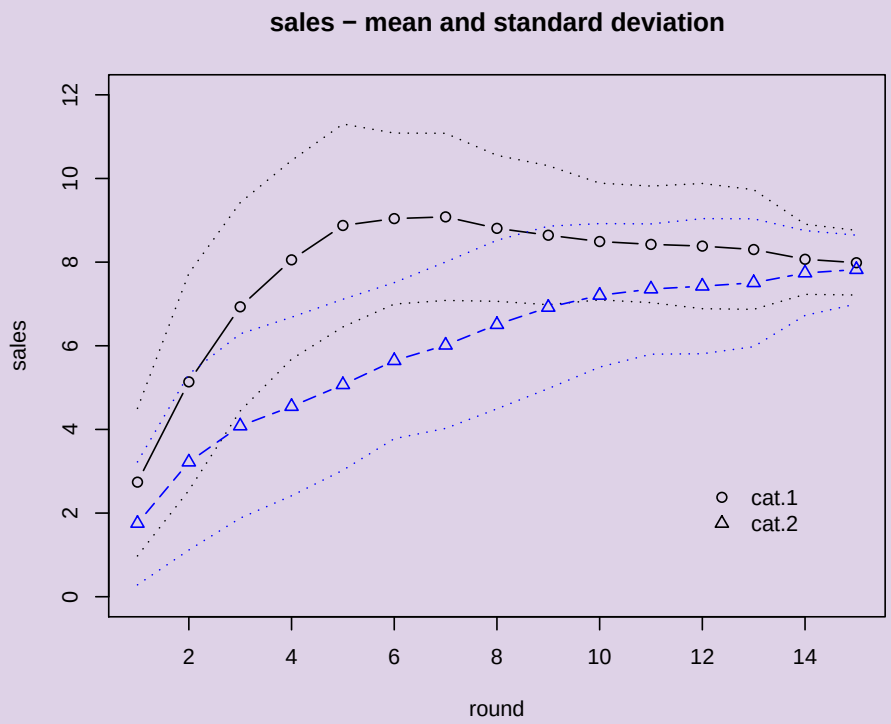

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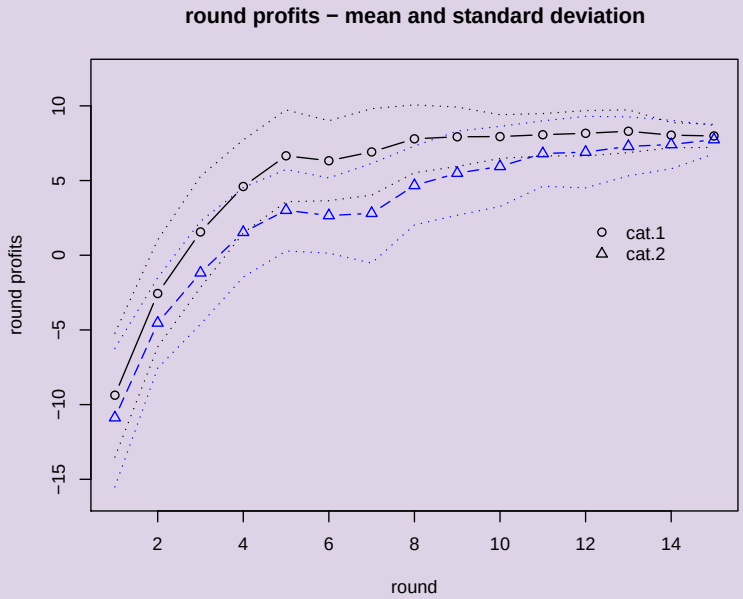

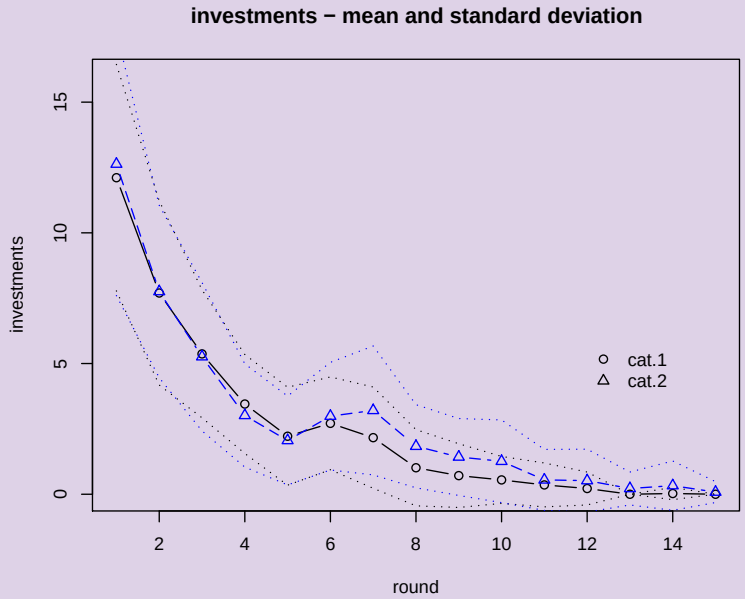

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Similarly to sales levels, cat.1 players continously realize higher round profits than cat.2 players during the entire sequence.

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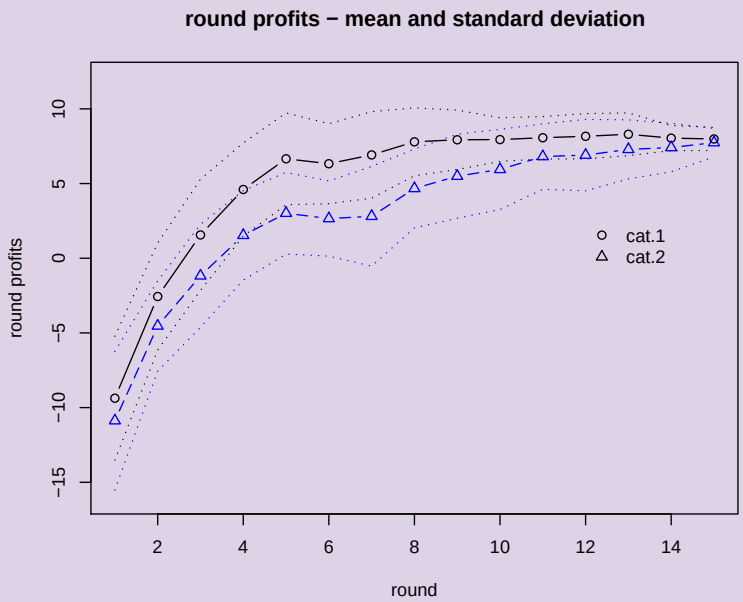

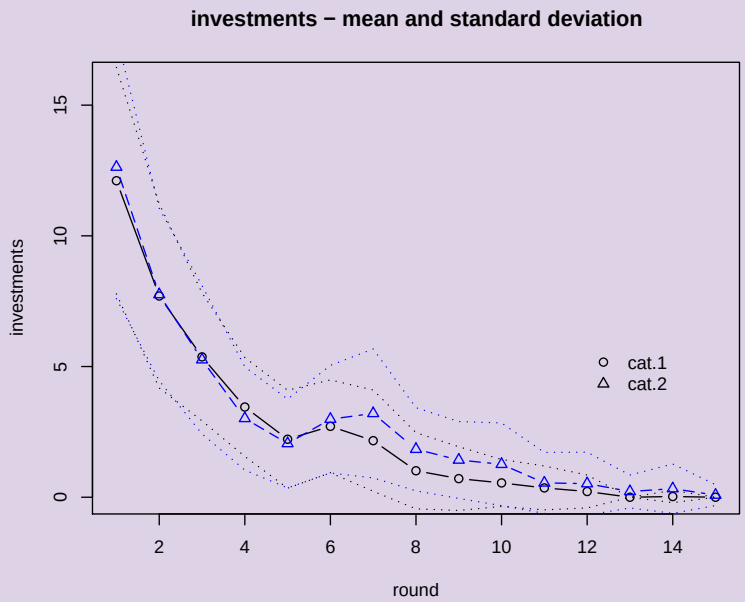

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Search efficiency

Do both categories of players systematically differ in their search efficiency?

- investment inefficiencies such as redundant search and unrealized sales do not differ significantly between cat.1 and cat.2
- learning effects decrease error frequency: mean loss in worst-performing round equals 0.95 (0.79) sales units in sequence 1 (2) $\Rightarrow$ redundant search

Do differences in initial investments already predetermine the eventual economic outcome of the sequence?

- mean of investments in round one does not differ significantly between cat.1 and cat.2: mean investment 12.1 (12.6) units for cat.1 (cat.2) ($p = 0.504$, t-test (two-sided))

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Focusing on individual decisions

Descriptive statistics reveal...

No significant difference in the behavior of both categories of players can be found, if aggregated parameters are considered. Strong similarities are found with respect to

- magnitude of initial and total search investments
- frequency of investment inefficiencies
- rate of coordinative attempts to avoid duplicative search
- success rate (repeated tournament winner/loser) in subsequent sequence of experiment (52% of 1st sequence winners also win in 2nd sequence (conditional probability))

Effectively, the investment behavior of innovating agents can not satisfactorily be described on the basis of aggregated data.

Thus, a model which fares better in describing innovative investment behavior must focus on atomistic decisions of individual subjects.

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Effectively, the investment behavior of innovating agents can not satisfactorily be described on the basis of aggregated data.

Thus, a model which fares better in describing innovative investment behavior must focus on atomistic decisions of individual subjects.

Individual investment pattern

model	OBJ	ABS	REL
constant	4.245***	4.702***	4.687***
	(0.266)	(0.284)	(0.24)
eight	−1.96***	−1.835***	−1.879***
	(0.133)	(0.144)	(0.139)
eigth × *two*	−0.175	−0.413**	−0.351**
	(0.145)	(0.189)	(0.174)
NoOp	−0.435***	−0.413***	−0.522***
	(0.033)	(0.036)	(0.037)
NoOp × *two*	0.055	−0.003	−0.052
	(0.036)	(0.046)	(0.036)
PrOne	2.01***	2.193***	1.82***
	(0.183)	(0.195)	(0.188)
PrOne × *two*	−1.043***	−1.081***	−0.881***
	(0.257)	(0.255)	(0.276)
ownAcc		−0.021***	
		(0.006)	
ownAcc × *two*		0.016**	
		(0.007)	
relAcc			−2.357***
			(0.619)
relAcc × *two*			−0.136
			(0.897)
relAcc × *neg*			7.076***
			(1.046)
relAcc × *neg* × *two*			−2.713*
			(1.494)
AIC	3686	3677	3640

Three logit estimation models to characterize individual investment behavior:

- OBJ = objective criteria
- ABS = absolute (self-centered) focus
- REL = relative (competitor-centered) focus

sample size:
3464 (2796) decisions of 78 (72) subjects in sequence 1 (2)

$$relAcc = \frac{own\ account - competitor\ account}{sum(accounts)}$$

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Conclusion

This study tried to show that ...

- competition in a market is crucial for inspiring innovations.
- agents involved in innovation races consider the economic success of their competitor as their own reference point.
- major motivation to carry out risky search investments is the objective to win the innovation race (tournament concept).

Relative economic performance of subjects (or firms) represents an parameter that well describes investment behavior.

Propensity to invest in costly research is predominantly determined by the intensity of competition, yet that relation is ambiguous:

- *"Intense competition"* (firms resemble each other in terms of capitalization) provokes *substantial pioneering* while
- *"Attenuated competition"* (firms' capitalization differs clearly) encourages *imitation* (more pronounced for lagging firms).

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