Handbook of Research on Nature Inspired Computing for Economics and Management

Edited by:

Jean-Philippe Rennard,
Grenoble Graduate School of Business, France

The **Handbook of Research on Nature Inspired Computing for Economics and Management** is the original, comprehensive reference work on research and applications of nature inspired computing to economics and management. It is an authoritative source, providing global coverage of this new and exciting field. Gathering the work of over 100 internationally known contributors, this two-volume set explores how complexities found in nature can be modeled to simulate and optimize business situations. It also provides practitioners a global view of the current and future applications of this ground-breaking technology.

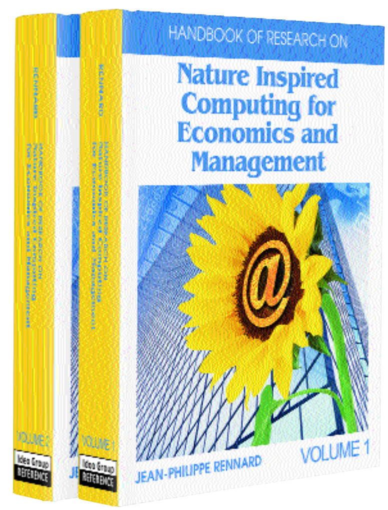
Key Features

- Authoritative contributions by over 100 internationally renowned experts
- A single source for comprehensive information on an expansive field
- In-depth definitions of more than 400 key terms
- 114 tables and more than 380 figures with detailed illustrations
- Organized by topic and indexed, making it a convenient method of reference for all IT/IS scholars and professionals
- More than 1,850 references to existing literature and research on computer modeling for business
- Cross-referencing of key terms, figures, and information

Topics Covered

Applications of nature inspired computing for:

- Algorithms
- Economy: theory and practice
- Evolutionary systems
- Finance and stock-market
- Forecasting
- Manufacturing systems
- Marketing, e-commerce, and e-auctions
- Modeling
- Multi-agent systems and bottom-up simulations for social sciences
- Neural networks
- Operations management
- Software agents



ISBN: 1-59140-984-5; US $350.00 h/c
*Pre-Pub Price: US $295.00
**Online Access Only: US $280.00
2-volume set; 1,100+ pp
Available September 2006

*Pre-publication price is good through one month after publication.
** Online access is for institutions and is good for the life of the edition.

> *"Students in computer sciences, social sciences, and management will find all the necessary material to master the field, and to help them in their training."*
> — **Prof. Jean-Philippe Rennard**

Free institution-wide online access when your library pur chases a print cop y, a value of $280.

CONTRIBUTORS

J.R. Abraham
Univ. of the West of England

Vito Albino
Politecnico di Bari

David Al-Dabass
Nottingham Trent University

Nikolaos Ampazis
University of the Aegean

Carl Anderson
Qbit, LLC.

Robert Axelrod
University of Michigan

Claude Baron
LESIA, INSA

Jason Barr
Rutgers University

Yaneer Bar-Yam
New England Complex Systems Institute

Nicola Baxter
BT PLC

Alain Berro
Toulouse University

Riccardo Boero
University of Surrey

Anthony Brabazon
University College Dublin

Alessandro Brun
Politecnico di Milano

Charlotte Bruun
Aalborg University

Nunzia Carbonara
Politecnico di Bari

Rajesh Chakrabarti
Georgia Institute of Technology

Nirupam Chakraborti
Indian Institute of Technology

Mattia Ciprian
University of Trieste

Carlos A. Coello-Coello
CINVESTAV-IPN

Pierre Collet
Univ. du Littoral Côte d'Opale

David Collings
BT PLC

Lee Cooper
UCLA

Ernesto Costa
Universidade de Coimbra

Prithviraj Dasgupta
University of Nebraska

John Debenham
University of Sydney

Giovanna Di Marzo Serugendo
University of Geneva

Danilo Di Stefano
AREA Science Park

Christos Dimopoulos
Cypurs College

Jon Dron
University of Brighton

Eva Ebenhöh
University of Osnabrück

Tom Erez
Inst. for Scientific Interchange

Peyman Faratin
M.I.T.

Tiago Ferra de Sousa
Polytechnic School of Castelo Branco

Stefka Fidanova
Bulgarian Academy of Science

Ilaria Giannoccaro
Politecnico di Bari

David Goldberg
University of Illinois

Timothy Gosling
University of Essex

Juan Guillermo Villegas
Universidad de Antioquia

Eliécer Gutiérrez
Universidad de los Andes

Dawid Herbert
Bielefeld University

Pedro Isasi
University Carlos III of Madrid

Nanlin Jin
University of Essex

Mária José Pérez Fructuoso
Universidad Carlos III de Madrid

Mak Kaboudan
University of Redlands

Massimiliano Kaucic
University of Trieste

Wolfgang Kerber
Philipps-Universität Marburg

Wershing Klaus
Bielefeld University

Mark Klein
M.I.T.

Halina Kwasnicka
Wroclaw Univ. of Technology

Witold Kwasnicki
University of Wroclaw

Stéphanie Lavigne
Université Toulouse I

Isabelle Leroux
Le Mans University

Henrique Lopes Cardoso
University of Porto

Azahar Machwe
University of the West of England

José Manuel Molina López
Universidad Carlos III de Madrid

Robert Marks
Australian Grad. School of Mgmt.

Luis Martí Orosa
Universidad Carlos III de Madrid

Robin Matthews
Kingston University

Andrés Medaglia
Universidad de los Andes

Ugo Merlone
University of Torino

David Midgley
INSEAD

Ioannis Minis
University of the Aegean

Asunción Mochón
UNED

Sarit Moldovan
The Hebrew Univ. of Jerusalem

Isaac Naveh
Renssalaer Polytechnic Institute

Giulia Nogherotto
University of Trieste

Bart Nooteboom
Tilburg University

Eugénio Oliveira
University of Porto

Michael O'Neil
University of Limerick

Claudia Pahl-Wostl
University of Osnabrück

Ian Parmee
Univ. of the West of England

Valentino Pediroda
University of Trieste

Andreas Pyka
University of Augsburg

David Quintana
University Carlos III of Madrid

Jean-Phillippe Rennard
Grenoble Grad. School of Bus.

Ana Paula Rocha
University of Porto

Samuel Rochet
LESIA, INSA

Juliette Rouchier
GREQAM, CNRS

Nicole Saam
Ludwig-Maximilians-Universität

Yago Sáez
University Carlos III of Madrid

Jesús Sáez
Univ. Carlos III de Madrid

Stéphane Sanchez
Université Toulouse I

Francesco Saraceno
Observatoire Français des Conjonctures Économiques

Hiroki Sayama
Tokyo University of Technology

Lijun Shan
National Univ. of Defence Tech.

Rui Shen
Natl. Lab for Parallel and Distributed Processing

Peer-Olaf Siebers
University of Nottingham

Arlindo Silva
Polytechnic School of Castelo Branco

Sorin Solomon
Racah Institute of Physics

Ron Sun
Renssalaer Polytechnic Instit.

Kuldar Taveter
University of Melbourne

Pietro Terna
University of Torino

Edward Tsang
University of Essex

Neil Urquhart
Napier University

Thomas Vallée
Nantes University

Harko Verhagen
Stockholm University & Royal Institute of Technology

Gerd Wagner
Brandenberg University of Technology at Cottbus

Ji Wang
National Laboratory for Parallel and Distributed Processing

Ali Yassine
University of Illinois

Tian-Li Yu
University of Illinois

Hong Zhu
Oxford Brookes University

Marta Zorzini
Politecnico di Milano

ENTRIES

Handbook of Research on Nature-Inspired Computing for Economics and Management

Volume I
Chapters I–XXVI

Jean-Philippe Rennard
Grenoble Graduate School of Business, France

Idea Group
REFERENCE

IDEA GROUP REFERENCE
Hershey · London · Melbourne · Singapore

Acquisitions Editor:	Michelle Potter
Development Editor:	Kristin Roth
Senior Managing Editor:	Jennifer Neidig
Managing Editor:	Sara Reed
Copy Editor:	Maria Boyer
Typesetter:	Diane Huskinson
Cover Design:	Lisa Tosheff
Printed at:	Yurchak Printing Inc.

Published in the United States of America by
Idea Group Reference (an imprint of Idea Group Inc.)
701 E. Chocolate Avenue, Suite 200
Hershey PA 17033
Tel: 717-533-8845
Fax: 717-533-8661
E-mail: cust@idea-group.com
Web site: http://www.idea-group-ref.com

and in the United Kingdom by
Idea Group Reference (an imprint of Idea Group Inc.)
3 Henrietta Street
Covent Garden
London WC2E 8LU
Tel: 44 20 7240 0856
Fax: 44 20 7379 0609
Web site: http://www.eurospanonline.com

Library of Congress Cataloging-in-Publication Data

Handbook of research on nature inspired computing for economics and management / Jean-Philippe Rennard, editor.
p. cm.
Summary: "This book provides applications of nature inspired computing for economic theory and practice, finance and stock-market, manufacturing systems, marketing, e-commerce, e-auctions, multi-agent systems and bottom-up simulations for social sciences and operations management"--Provided by publisher.
ISBN 1-59140-984-5 (hardcover) -- ISBN 1-59140-985-3 (ebook)
1. Economics--Data processing. 2. Economics, Mathematical. 3. Management--Data processing. 4. Evolutionary computation. 5. Evolutionary programming (Computer science) I. Rennard Jean-Philippe.
HB143.5.H36 2007
330.0285'632--dc22

2006019134

British Cataloguing in Publication Data
A Cataloguing in Publication record for this book is available from the British Library.

Chapter XX
Evolutionary Modeling and Industrial Structure Emergence

Halina Kwasnicka
Wroclaw University of Technology, Poland

Witold Kwasnicki
University of Wroclaw, Poland

ABSTRACT

In the first part of the chapter, an outline of the evolutionary model of industrial dynamics is presented. The second part deals with a simulation study of the model focused on identification of necessary conditions for emergence of different industrial strictures. Textbooks of traditional economics distinguish four typical industry structures and study them under the names of pure competition, pure monopoly, oligopoly, and monopolistic competition. Variations in behavior modes of differently concentrated industries ought to be an outcome of the cooperation of well-understood evolutionary mechanisms, and not the result of juggling differently placed curves representing supply, demand, marginal revenue, marginal cost, average costs, and so forth. Textbook analysis of industrial structures usually omits influence of innovation on market behavior. Evolutionary approach and simulation allow for such analysis and through that allow enriching the industrial development study. One of the important conclusions from this chapter is that evolutionary analysis may be considered as a very useful and complementary tool to teach economics.

INTRODUCTION

Almost all evolutionary economics (on EE foundations, see Dopfer, 2005) models worked out in past decades are dynamical ones and are focused on far-from-equilibrium analysis. There is no place to review and to characterize evolutionary models in economics in detail.[1] In a nutshell the other main features of evolutionary models may be summarized as follows:

- development seen in historical perspective; macro-characteristics flow from aggregation of micro-behaviors of economic agents;
- population perspective;
- diversity and heterogeneity of behavior;
- search for novelties (innovation), hereditary information;
- selection which leads to differential growth; and
- spontaneity of development.

Some of those features seem to be crucial to call a model an evolutionary one, in our opinion to those crucial features belong: diversity and heterogeneity of economic agents (firms) and their behavior, search for innovation based on a concept of hereditary information (knowledge), and selection process which leads to diversified rate of growth and spontaneity of development. Heterogeneity and variety can therefore be considered as an important characteristic of evolutionary approaches to technological change (Nelson, 1995; Saviotti, 1996). An interesting question in relation to economic evolutionary models is presence of decision-making procedures. In many models that procedure is not present; in many others it has a more or less complicated form.

In the remaining part of this chapter, we outline an evolutionary model[2] and present a selection of current simulation results of that model. The main aim of this chapter is to show that evolutionary modeling can be used not only as an efficient research tool in economic analysis, but also as supporting tool in the economic education.

THE EVOLUTIONARY MODEL OF INDUSTRIAL DYNAMICS

The model describes the behavior of a number of competing firms producing functionally equivalent products. The decisions of a firm relating to investment, price, profit, and so forth are based on the firm's evaluation of behavior of other, competing firms, and the expected response of the market. The firm's knowledge of the market and knowledge of the future behavior of competitors is limited and uncertain. Firms' decisions can thus only be suboptimal. All firms make the decisions simultaneously and independently at the beginning of each period (e.g., once a year or quarter). After the decisions are made, the firms undertake production and put the products on the market. The quantities of different firms' products sold in the market depend on the relative prices, the relative value of products' characteristics, and the level of saturation of the market. In the long run, a preference for better products, namely those with a lower price and better characteristics, prevails.

Each firm tries to improve its position in the industry and in the market by introducing innovations in order to minimize the unit costs of production, maximize the productivity of capital, and maximize the competitiveness of its products on the market.

Simulation of industry development is done in discrete time in four steps:

1. search for innovation (i.e., search for new sets of routines which potentially may replace the old set currently employed by a firm);
2. firms' decision-making process (calculation and comparison of investment, production, net income, profit, and some other

characteristics of development which may be attained by employing the old and the new sets of routines; decisions of each firm on: (a) continuation of production by employing old routines or modernizing production, and (b) opening (or not) of new units);

3. entry of new firms; and
4. selling process (market evaluation of the offered pool of products; calculation of firms' characteristics: production sold, shares in global production and global sales, total profits, profit rates, research funds, etc).

The Search for Innovation

The creative process is evolutionary by nature, and as such its description should be based on a proper understanding of the hereditary information (see Kwasnicki, 1996, Chapter 2). According to the tradition established by Nelson and Winter (1982), we use the term *routine* to name the basic unit of the hereditary information of a firm. The set of routines applied by the firm is one of the basic characteristics describing it. In order to improve its position in the industry and in the market, each firm searches for new routines and new combinations of routines to reduce the unit costs of production, increase the productivity of capital, and improve the competitiveness of its products in the market. Nelson and Winter (1982, p. 14) define routines as "regular and predictable behavioral patterns of firms" and include in this term such characteristics as "technical routines for producing things ... procedures of hiring and firing, ordering new inventory, stepping up production of items in high demand, policies regarding investment, research and development, advertising, business strategies about product diversification and overseas investment." A large part of research activity is also governed by routines. "Routines govern choices as well as describe methods, and reflect the facts of management practice and organizational sociology as well as those of technology" (Winter, 1984).

Productivity of capital, unit costs of production, and characteristics of products manufactured by a firm depend on the routines employed by the firm (examples of the product characteristics are reliability, convenience, lifetime, safety of use, cost of use, quality and aesthetic value).

We assume that at time *t*, a firm is characterized by a set of routines actually employed by the firm. There are two types of routines: *active* routines are employed by this firm in its everyday practice, and *latent* routines are stored by a firm but are not actually applied. Latent routines may be included in the active set of routines at a future time. The set of routines employed by a firm may evolve. There are four basic mechanisms for generating new sets of routines, namely: *mutation*, *recombination*, *transition*, and *transposition*.

The probability of discovering a new routine (mutation) depends on the research funds allocated by the firm for autonomous research, that is, in-house development. It is assumed that routines mutate independently of each other. The scope of mutation also depends on funds allocated for in-house development. The firm

Figure 1. Routines transition

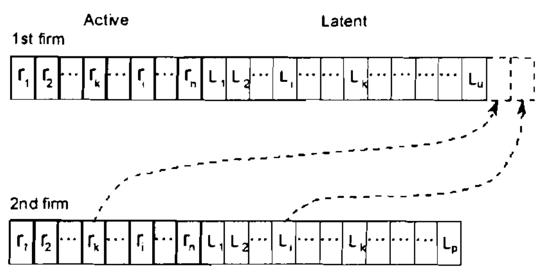
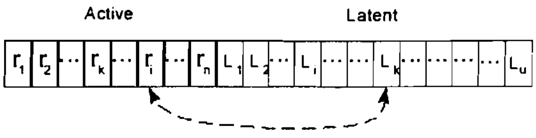


Figure 2. Routines transposition



may also allocate some funds for gaining knowledge from other competing firms and try to imitate some routines employed by competitors (recombination). A single routine may be transmitted (*transition*; see Figure 1) with some probability from firm to firm. It is assumed that after transition, a routine belongs to the subset of latent routines. At any time a random *transposition* of a latent routine to the subset of active routines may occur (see Figure 2). It is assumed that the probabilities of transition of a routine from one firm to another and the probabilities of transposition of a routine (from a latent to an active routine) are independent of R&D funds, and have the same constant value for all routines.

In general, the probability of transposition of a routine for any firm is rather small. But randomly, from time to time, the value of this probability may abruptly increase, and very active processes of search for a new combination of routines are observed. This phenomenon is called recrudescence. *Recrudescence* is viewed as an intrinsic ability of a firm's research staff to search for original, radical innovations by employing daring, sometimes apparently insane ideas. This ability is connected mainly with the personalities of the researchers, and random factors play an essential role in the search for innovations by recrudescence, so the probability of recrudescence is not related to R&D funds allocated by a firm to 'normal' research.

As a rule, mutation, recombination, and transposition on a normal level (that is, with low probabilities in long periods) are responsible for small improvements and, during the short periods of recrudescence, for the emergence of radical innovations.

Firm's Decisions

It seems that one of the crucial problems of contemporary economics is to understand the process of decision making. Herbert Simon states that "the dynamics of the economic system depends critically on just how economic agents go about making their decisions, and no way has been found for discovering how they do this that avoids direct inquiry and observations of the process" (Simon, 1986, p. 38).

The background of the decision-making procedure adopted in the model is presented in detail in Kwasnicki (1996). It is assumed that each firm predicts future development of the market (in terms of future average price and future average product competitiveness); and on the basis of its expectations on future market development and expected decisions of its competitors, each firm decides on price of its products, investment, and quantity of production that it expects to sell on the market. Each firm also considers current investment capability and the possibility of borrowing.

Price, production, and investment are set by a firm in such a way that some objective function is maximized. Contrary to the neoclassical assumption, it is not a maximization in the strict sense. The estimation of values of the objective function is not perfect and is made for the next year only. In other words, it is not a global, once and for all, optimization, but rather an iterative process with different adjustments taking place from year to year.

We assume that firms apply the following objective function:

$$O_i(t+1) = (1-F_i)\frac{\Gamma_i(t+1)}{\Gamma(t)} + F_i\frac{Q_i^s(t+1)}{QS(t)},$$

$$F_i = a_1 \exp(-a_2 \frac{Q_i^s(t+1)}{QS(t)}) \qquad (1)$$

where F_i is the magnitude coefficient (with values between 0 and 1), Q_i the supply of firm i, Γ_i the expected income of firm i at $t+1$ (defined by equation 2), QS is the global production of the industry in year t, and Γ the global net income of all firms in year t. $\Gamma(t)$ and $QS(t)$ play the role of constants in equation and ensure that the values of both terms in this equation are of the same order; a_1 and a_2 are parameters.

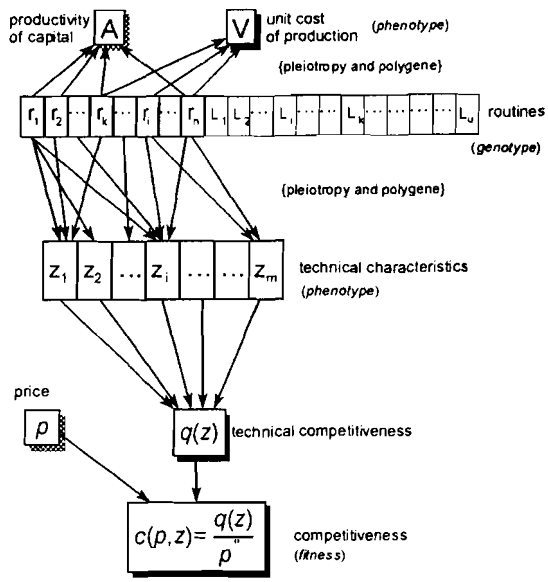
The expected income of firm i ($\ni_i$) is defined as:

$$\Gamma_i = Q_i^s(t)(p_i(t) - V_i v(Q_i^s(t)) - \eta), \qquad (2)$$

where V is unit production costs, $v(Q)$ is the factor of unit production cost as a function of the scale of production (economies of scale), η is the econstant production cost.

The function O_i expresses short- and long-term thinking of firms during the decision-making process (the first and second terms in equation 1, respectively). Plausible values for the parameters are $a_1 = 1$ and $a_2 = 5$, implying that the long run is much more important for survival and that firms apply a flexible strategy, namely the relative importance of short- and long-term components change in the course of a firm's development (the long-term one is much more important for small firms than for the large ones).

Figure 3. From routines to competitiveness, productivity of capital and unit cost of production—from genotype to phenotype



Products Competitiveness on the Market

The productivity of capital, variable costs of production, and product characteristics are the functions of routines employed by a firm (see Figure 3). Each routine has multiple, pleiotropic effects—that is, may affect many characteristics of products, as well as productivity, and the variable costs of production. Similarly, the productivity of capital, unit costs of production, and each characteristic of the product can be a function of a number of routines (polygeneity). We assume that the transformation of the set of routines into the set of product characteristics is described by m functions F_d,

$$z_d = F_d(r), \qquad d = 1,2,3,\ldots,m, \tag{3}$$

where z_d is the value of characteristic d, m the number of product characteristics, and r the set of routines. It is assumed that the productivity of capital $A(r)$ and the unit cost of production $V(r)$ are also functions of the firm's routines, where these functions are not firm specific and have the same form for all firms.

An attractiveness (competitiveness) of the product on the market depends on the values of the product characteristics and its price. The competitiveness of products with characteristics z and price p is equal to:

$$c(p,z) = \frac{q(z)}{p^{\alpha}}, \qquad z = (z_1, z_2, \ldots, z_m), \tag{4}$$

where $q(z)$ is the technical competitiveness, z a vector of product characteristics, and α price elasticity.

In the presence of innovation, technical competitiveness varies according to the modification of routines made by each firm, or because of introducing essentially new routines. Technical competitiveness is an explicit function of product characteristics. As explained above, each routine does not influence the product's performance directly, but only indirectly through the influence on its characteristics. We assume the existence of a function q enabling calculation of technical competitiveness of products manufactured by different firms. We say that q describes the adaptive landscape in the space of product characteristics. In general, this function depends also on some external factors, varies in time, and is the result of co-evolution of many related industries.

All products manufactured by the entrants and incumbents are put on the market, and all other decisions are left to buyers; these decisions primarily depend on the relative values of competitiveness of all products offered, but quantities of products of each firm offered for sale are also taken into account.

The dynamics of industry development depend also on so called replicator (selection) equation, imposing that the share of firm i in global output increases if the competitiveness of its products is higher than the average of all products present on the market, and decreases if the competitiveness is lower than the average. The rate of change is proportional to the difference between the competitiveness of products of firm i and the average competitiveness.

SIMULATION OF INDUSTRY DEVELOPMENT

Textbooks of traditional economics distinguish four typical industry structures and study them under the name of pure (perfect) competition, monopoly, oligopoly, and monopolistic competition.[3] To explain how prices and profits are formed in the typical industries, traditional economics uses such notions as: demand and supply functions, marginal cost, average total cost, average variable cost, average fixed cost, marginal revenue, total revenue, and so on. Usually, each typical situation is considered separately in different chapters. Reading these chapters and looking at diagrams supporting the reasoning, one may get the impression that different mechanisms are responsible for the development of industries with different concentrations. It seems that the study of industry behavior at different concentrations ought to be based on an understanding of the development mechanisms that are essentially invariable and do not depend on current industry conditions, particularly on the actual number of competitors. Variations in behavior modes of differently concentrated industries ought to be an outcome of the cooperation of well-understood mechanisms of development, and not the result of juggling differently placed curves representing supply, demand, marginal revenue, marginal cost, average total cost, average variable cost, average fixed cost, and many other variables. We do not claim that the findings of traditional economics flowing from the analysis of *curves placement* are wrong; quite the contrary, they are in accord with real phenomena, but does such analysis explain anything?

To prove that the long-run profit is equal to zero for a perfect competition market, the traditional economic theories assume an infinite number of competitors in the market. In reality, as in our simulation, the number of competitors may be only finite, but we may expect that for a reasonably large number of competitors, the results will be very close to the theoretical predictions. How many firms may be treated, from a practical point of view, as *the infinite number of competitors*? Some characteristics of the industry at the equilibrium state obtained in a series of experiments with a different number of competitors, under additional assumptions that the initial size of all firms is the same (that is, equi-partition of the market is assumed) and that the size of the market is constant (that is, $\gamma = 0$), are presented in Table 1.

The controlling variable in the series of experiments is the number of competitors. The results presented in Table 1 are the outcome of the co-working of the same mechanisms of development embedded in the model described in the previous section. The results are grouped into two parts: for the normal rate of return, ρ equal to zero, and for the rate ρ equal to 5%. Our normal rate of return corresponds, in some way, to the normal profit embedded in the neoclassical supply function. The value of the normal rate of return may be considered as an effect of the development of the whole economy, and for any single industry may be treated as exogenous. In any real processes the normal rate of return is greater than zero, but the results of a simulation for equal to zero are presented as an example of some extreme, theoretical case, just to compare the role played by the normal rate of return for industry development. The values of profit under $\rho = 0$ may be considered as a *natural* normal rate of return. In both series of experiments, close similarity of the model's behavior to real industrial processes is observed, and in this sense the results correspond to the findings of traditional economics. As in real processes of industry development, the greater the concentration of the industry, the larger the profit of the existing firms, but with the difference that, in contrast to the assumption of profit maximization of traditional economics, the objective of the firms in our model (the O_i—equation 1) is a combination of the short term (firm's income) and long term (firm's production, or expected firm's share).[4] The one extreme is monopoly (with profit in excess of 150% in our simulations); the other is perfect competition between an infinite number of firms with profit equal to zero. The profit drops very quickly with an increasing number of competitors. In our simulations, industries with the Herfindahl firms' number equivalent[5] n_H greater then 12 competitors may be considered as very close to the ideal situation of perfect competition (profit-to-capital ratio for these industries is smaller than 10^{-7}). The dynamics of change strongly depend on industry concentration. Starting from the same initial conditions, the more concentrated industries reach an equilibrium state much quicker. For fewer than eight competitors, the equilibrium state is reached within 20-40 years, but for a greater number of competitors the dynamics is significantly slower, and for industry very close to perfect competition (over 15 competitors), equilibrium is reached within 80-120 years. Many other simulation experiments suggest that for plausible values of parameters, the competition process may be considered as per-

Table 1. Industry concentration; global characteristics at the equilibrium state

n $n_H(0)$	Π/K [%]	Π/S [%]	p/V
normal rate of return ρ = 0			
1	151.907	71.685	4.2382
2	52.692	46.757	2.2539
4	22.096	26.915	1.6419
6	11.450	16.026	1.4290
8	6.050	9.160	1.3210
10	2.804	4.464	1.2561
12	0.643	1.060	1.2128
13	0.000	0.000	1.2000
16	0.000	0.000	1.2000
32	0.000	0.000	1.2000
normal rate of return ρ = 0,05			
1	146.908	69.326	4.2382
2	47.692	42.321	2.2539
4	17.096	20.824	1.6419
6	6.450	9.028	1.4290
8	1.050	1.590	1.3210
10	0.000	0.000	1.3000
12	0.000	0.000	1.3000
16	0.000	0.000	1.3000
32	0.000	0.000	1.3000

Where: Π - profit; K – capital; S – sales; p – price; V – unit cost of production

fect for the industries with the Herfindahl firms' number equivalent greater than 12. We observe a trade-off between the profit rate and the normal rate of return, for example, for highly concentrated industry if the normal rate of return increases from 0 to 5%, as in Table 1, the profit rate decreases also by 5%, and the price is kept on the same level. But the trade-off acts up to the moment when a positive profit for the same price of products is maintained. If the profit for the same price becomes a loss, then firms decide to increase the price to keep a zero profit and are satisfied with the normal rate of return. In our simulation, for ρ = 5%, the trade-off is observed for industry with fewer than nine competitors; for a greater number of firms, the *natural* normal rate of return is lower than 5%, and the firms increase the price to keep profit equal to zero (compare relevant values in Table 1). The positive normal rate of return also causes the profit-to-sales ratio to diminish, but there is no full trade-off as between the normal rate of return and the profit/capital ratio. Reduction of the profit/sales ratio is always smaller than the increase in the normal rate of return.

Changes of the values of the capital physical depreciation have a similar effect on the characteristics of industry development as changes in the normal rate of return; for example, we observe a similar trade-off between the capital physical depreciation and the profit as we observe in experiments with a positive normal rate of return; reduction of the capital physical depreciation (amortization) in highly concentrated industry by 5% leads to an increase of the profit/capital ratio, also by 5%. So it may be expected that for highly concentrated industries, the rising of amortization or rising of the normal rate of return will not significantly affect the products' price, but for less concentrated industries we may expect higher prices to cover the higher opportunity costs.

Table 2. Concentration of the market; non-uniform firms' size distribution

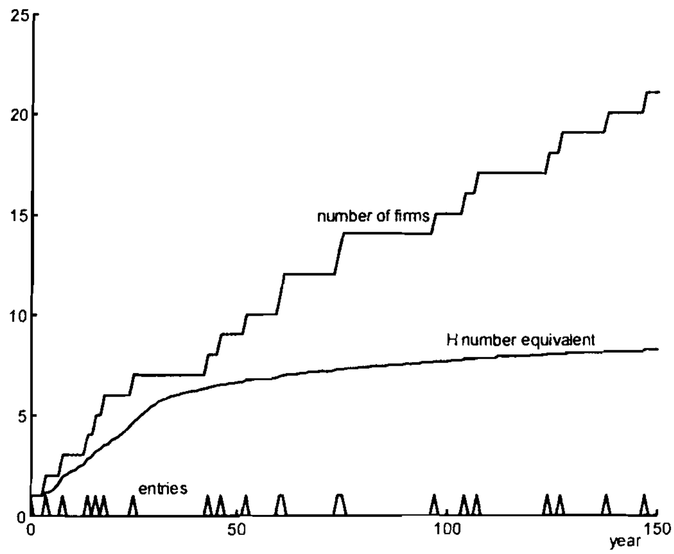
n	$n_H(0)$	$n_H(100)$	$n_H(200)$	T_e [year]	Π/K(100) [%]	Π/K(100) [%]	p/V(200)
2	1.02	2.00	2.00	14	47.692	47.692	2.2539
4	2.61	4.00	4.00	22	17.096	17.096	1.6419
6	4.18	6.00	6.00	47	6.450	6.450	1.4290
8	5.75	7.30	7.68	–	2.932	2.282	1.3456
12	8.93	9.76	9.81	–	0.216	0.033	1.3007
16	12.12	12.15	12.16	–	0.026	0.001	1.3000
32	25.52	25.59	25.59	–	0. 022	0.001	1.3000

Note: T_e is a year in which the H index is equal to the number of firms, i.e. $n_H = n$. The years of measurement of relevant characteristics are given in parentheses.

The dynamics of change also depend on the initial structure of industry. To investigate to what extent the initial firms' size distribution influences the dynamics of the process, the following series of experiments were made. Starting from highly diversified firms' size, we measure the values of basic characteristics of industry over the course of time and observe the tendency towards uniform distribution for different concentrations of the industry. The initial Herfindahl firms' number equivalent and some general characteristics of development of the model for a different number of competitors for t = 100 and 200 are presented in Table 2. For relatively high concentration of the market (that is, for the number of firms smaller than eight), there are no significant differences in the dynamics of change between industries with uniform and non-uniform firms' size distribution. This is due to a very strong tendency towards uniform distribution (caused by intensive price competition) for the highly concentrated industries. The more concentrated the industry is, the quicker the uniform firms' size distribution is reached—compare values of T_e in Table 2 for highly concentrated industries. For a small concentration of the industry, the dynamics of reaching the equilibrium state are significantly lower and also there is no such strong tendency towards the uniform firm's size distribution; quite the contrary, some conservative tendency to stabilize the size distribution is observed. For industries very near to perfect competition, the distribution of the firms' size is almost the same as at the beginning of simulation (seen in relevant values of n_H for years 100 and 200, when the number of firms is greater than 12). As we will see in the next section, the only way for small firms to pursue the big firms and to gain higher market shares is to introduce innovation.

In the following series of experiments, an investigation of the ability of free entrants to penetrate the industries of different concentrations has been made (no economies of scale present). It was assumed that for a given number of equal-sized firms, at some moment, a small firm with an assumed small capital enters the market. From the moment of entrance, we observe the evolution of the structure of industry, and particularly we observe the market share of the entrant. What interests us is "Does the entrant's market share grow to reach the same size as that of the initial firms?" Or in other words, "Is the firms' size distribution at equilibrium uniform?" As a measure of convergence, we use time T_e which spans from the moment of entrance to the moment of the uniform firms' size distribution (let us call this time the penetration time). As it turns out, the invasion is quite easy for a highly concentrated industry; for example, for the monopoly industry the newcomer is able to increase its initial market share of 0.5% to the equilibrium 50% market fraction in nine years: for two, three, and four firms, the relevant values of the penetration time T_e are 16, 22, and 35 years, respectively. The penetration time grows hyperbolically with diminishing concentration of industry; for example, if the industry is dominated by six competitors, the newcomer needs 98 years to get the same fraction of the market as the initial firms, and for seven firms the relevant time becomes very long, namely 195 years. There is no possibility of penetrating the market if the number of firms is greater than seven. Because of much higher competitive conditions, the average profit within the industry is very small, and the newcomer is not able to collect enough capital to invest and to raise its market share.[6] The penetration time for n_H greater than seven is infinite; at the equilibrium state the newcomer's market share stabilizes at a very low level, which is lower than the smaller the industry concentration is; for example, for eight, nine, ten, and fifteen competi-

Figure 4. Number of firms, entries, and Hefindahl-Hirshman firms' number equivalent



tors, the newcomer's share at equilibrium is equal to 0.35%, 0.11%, 0.1%, and 0.09%, respectively.

In the basic model only the price competition is considered, and as we see, it is very difficult to enter the market under perfect competition. The prerequisite for successful invasion of the highly competitive market is concurrent introduction of the product's innovation, but this problem will be discussed in the next section, where the model which incorporates a search for innovation process will be presented. The orthodox economics states that in oligopolist industries, market shares are usually determined on the basis of non-price competition, such as advertising and product variations, so the real firms' size distribution deviates from the uniform one, and that oligopolists frequently have adequate financial resources to finance non-price competition. Basically it is true and we observe such type of industry behavior in the presence of incremental innovations (to some extent responsible for the *product variations*).

From Monopoly to Perfect Competition

Typical history of any industry starts from a single founder firm. For some time that firm is a monopolist on a small market. In a course of time, the market is growing and new competitors enter the market. Orthodox (textbook) economics assumes that with no entry barriers and no innovation, the industry will evolve toward perfect competition with a large number of equal, small firms. Let us create that situation in our simulation. We start from a single, small firm, the industry growth rate is equal to 3%, firms do not innovate, and there is the possibility of firms' entering into a market. Even in such simple economy, the process of industry development is far from that proposed in economics textbook. The results are pre-

Figure 5. Evolution of industry structure with entry and no innovation

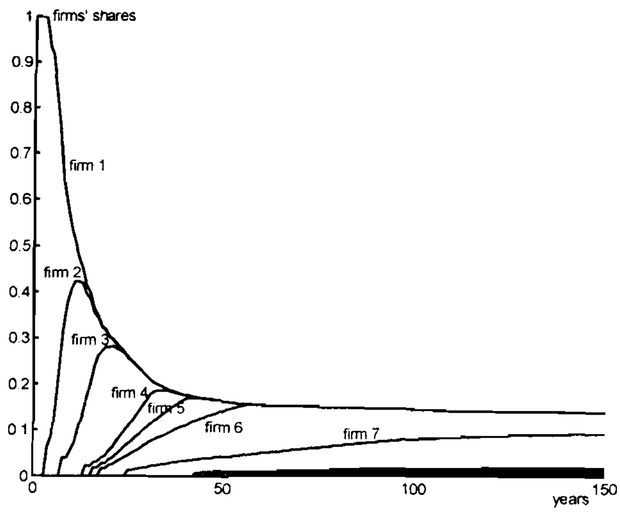
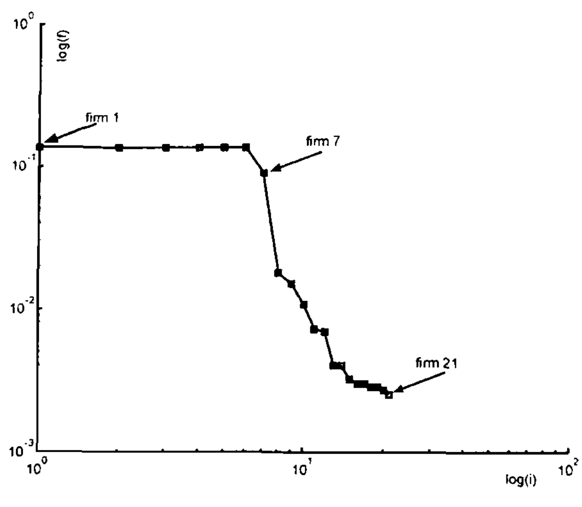
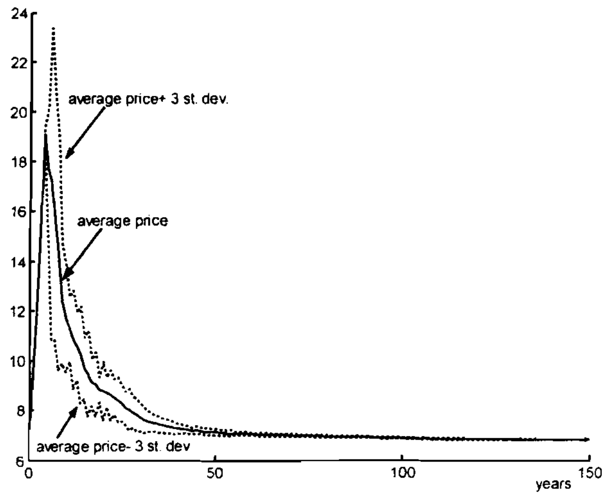


Figure 6. Firms' size distribution (log-log scale)



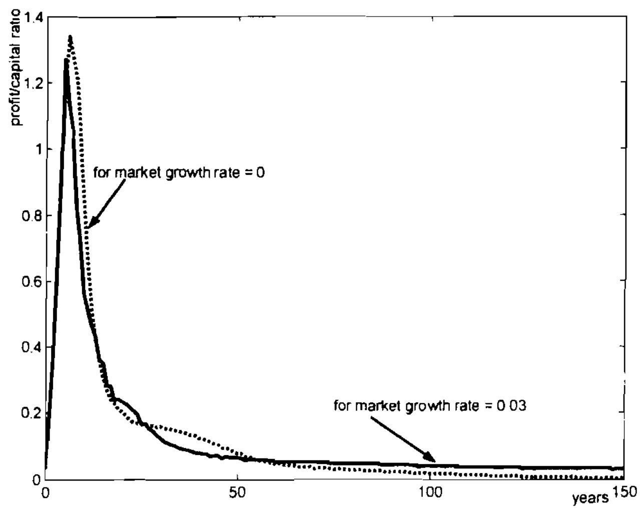
sented in Figures 4 to 7. Steady growth of a number of firms operating on the market are summarized in Figure 4. Due to relevant incumbents' price policy, we do not observe exits from the market. After 150 years of development, there are 21 firms, but contrary to the orthodox postulate, firms are not equal sized. In fact only the early entrants (in our experiment, the first five entrants) are able to compete efficiently with the founder firm and relatively

Figure 7. From monopoly to competitive price



quickly, all six firms have the same market shares equal to 16% (see Figure 5). This efficient competition was able due to *natural* price policy of the monopolist. The founder firm increased the price in the first years of industry development up to 19 units (Figure 7) and next was forced do reduce the price in a course of new competitors' emergence. Entering firms impose lower price, therefore their products are more competitive and their market shares increase. Notice that this process of price competition leads to diversity of prices on the market (in Figure 7, this high diversity of price is seen by comparison of two dotted lines related to the range 'average price ± three standard deviations'). Later entrants are not able to compete efficiently because the average price is significantly reduced and the price margin is very low. The good example of such late entrant is *firm* 7 which entered the market it the twenty-seventh year. Although the price and its diversity at this time were relatively high, but during the expansion of that firm the price was significantly reduced to its equilibrium value therefore after over 100 years, in the end of simulation its market share was equal to 9%—much lower then the share of the first six firms with their market shares equal to 14%. To the end of simulation, another 14 firms entered the market and their equilibrium shares were lower the later the entering year. We can say that contrary to the orthodox postulate that under perfect competition we have a large number of equal-sized firms, our simulation results suggest that natural mechanisms of competition force emergence of different-sized firms. The equilibrium firms' size distribution is far from the orthodox uniform one; in fact it consists of two segments—the first segment relates to the relatively few early entrants and has uniform distribution, and the second one relates to later entrants and its distribution is highly skewed. Typical equilibrium distribution is presented in Figure 6: the first six firms reach equal shares and all other 15 entrants have much lower shares (the shares of last nine entrants is smaller then 0.5%).[7]

Figure 8. Profit-to-capital ratio for stable and expanding market



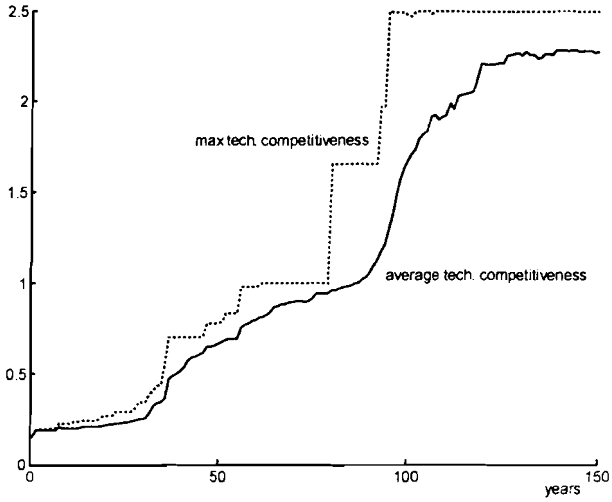
The path from monopoly to perfect competition structure is also seen in time changes of profit-to-capital ratio (Figure 8). In the first years of industry evolution, the concentration was very high (Herfindahl firms' number equivalent was smaller than two firms—see Figure 4, n_H, 'H number equivalent') and the profit ratio skyrocket to almost 130%, but it was quickly reduced in the next decades to less then 20%. In the equilibrium the profit ratio is very close to the growth rate of the market (i.e., to 3%). This is another flaw of the orthodox economics, which teaches that under perfect competition, the profit ratio is equal to zero. It is true only for the stable market. Just for comparison, changes of the profit ratio in the case of stable market (i.e., for growth rate equal to zero) is presented in Figure 8 (dotted line). It is seen that there are no significant differences between stable and growing markets in the early decades of evolution, but the differences are significant at the near equilibrium states. The profit is equal to zero for stable market, but is close to the market growth ratio for expanding market.

Innovation and Industry Evolution

The most important weakness of the orthodox economics seems to be lack of innovation in their models and concentration on equilibrium analysis. Innovation can be considered as the heart of modern economic evolution. Here we present only a small sample of the simulation results just to show how similarities of the proposed model's behavior relate to real industrial innovative processes.

The only difference with the conditions of simulation presented in the former section is possibility of searching for innovation—that is, firms are able to modify their routines just to find innovations leading to improving technical competitiveness of their products, diminishing unit cost of production and to increasing the productivity of capital. Just to show how diversified behavior of the firms is, the changes of technical competitiveness, variable cost of production, and productivity of capital are presented in Figures 9, 10, and 11. Besides the average values of relevant characteristics, the

Figure 9. Average technical competitiveness and maximum technical competitiveness



so-called frontiers of development are presented (namely maximum values of technical competitiveness, minimum values of unit cost of production, and maximum productivity of capital). The discrepancies between the average values and the frontiers give a hint about the existing diversity of firms' characteristics. It is important to underline that the mode of development perceived through the average values is a rather gradual one, but the mode of frontiers development is far from being gradual. It is clearly seen that the frontiers evolution is a punctuated one (i.e., the stasis periods are separated by jumps of the frontier values). The jumps in the frontiers are related to radical innovations' emergence. In the stasis phases innovations are also introduced but they are incremental ones. The most visible effect of introducing radical innovation relates to increase of market shares of successful firms; firm 8 introduced the first radical innovation (around the year 40) and firm 9 the second radical innovation around the year 70, and their shares increased significantly during next two or three decades after introducing the radical innovation (see Figure 12). Success terms of gaining significant market share can also be reached by introducing a series of relatively important incremental innovations. This is a case of firm 6 (Figure 12) which introduced such series in the third decade of industry development. Notice that besides the relatively small number of firms having significant shares of the market, there always exists a large number of small and very small firms (Figure 12).

This process of radical innovation emergence strongly influences the mode of changes of other characteristics of industry development. As an example we present changes of firms' number, price and, profit ratio (Figures 13, 14, and 15, respectively). We see that the emergence and dissemination of radical innovation causes an increased number of exits and a significant reduction in the number of firms, as well as an increase in market concentration (Figure 13—number of firms, exits, and *H number equivalent*). Emergence of radical innovation also causes an increase in price

Figure 10. Average unit cost of production and minimum unit cost of production

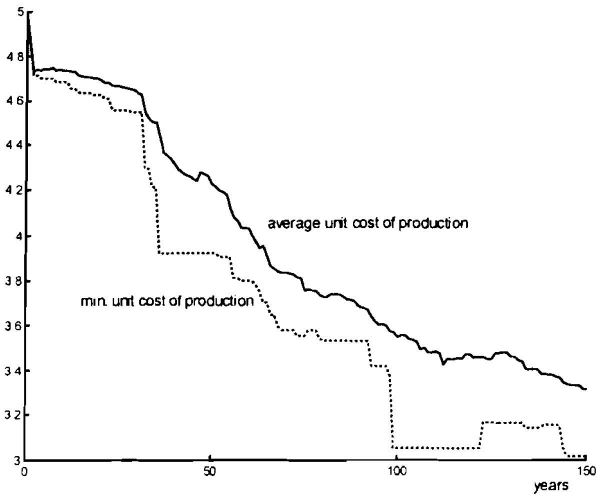
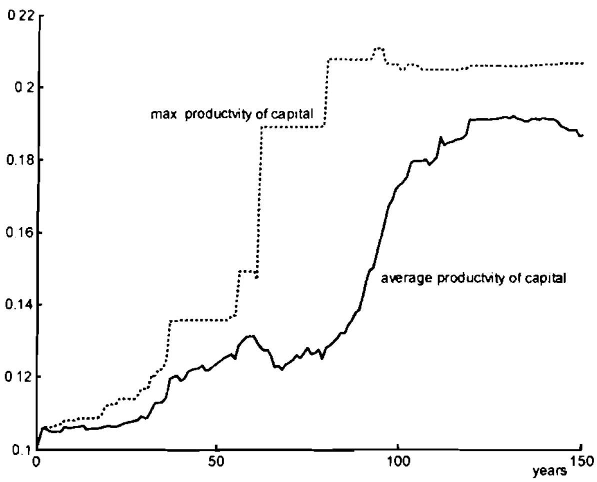


Figure 11. Average productivity of capital and maximum productivity of capital



diversity (Figure 14). This occurs because innovative firms tend to increase the price (to gain temporal monopoly rent and to cover the costs of R&D process), and the unsuccessful firms, having no possibility to imitate the innovation of successful firms, decrease the price just to made their technologically obsolete products more competitive.

The last few decades of industry development in our simulation run seem to be interesting. The orthodox economics suggests that high industry concentration is usually related to high

Figure 12. Evolution of industry structure with entry, exit, and innovation

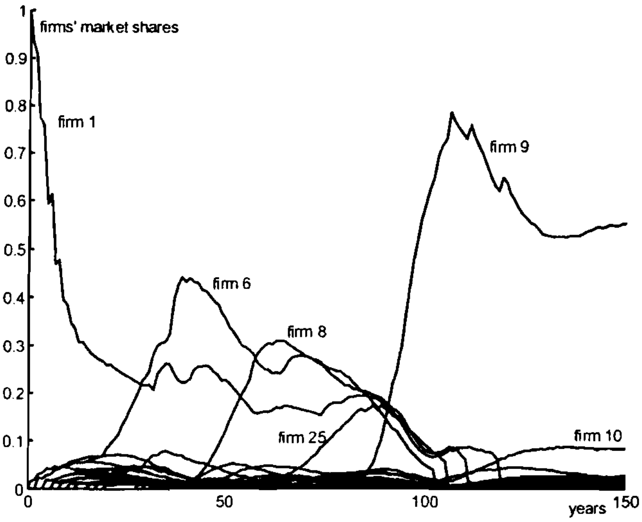


Figure 13. Number of firms, units, entries, and exits

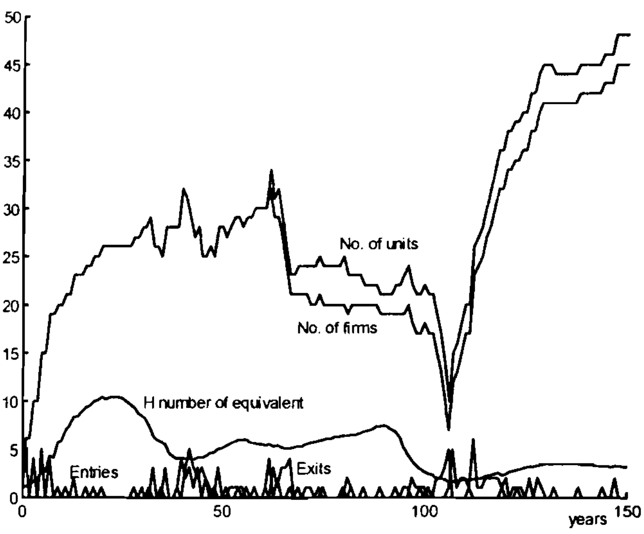
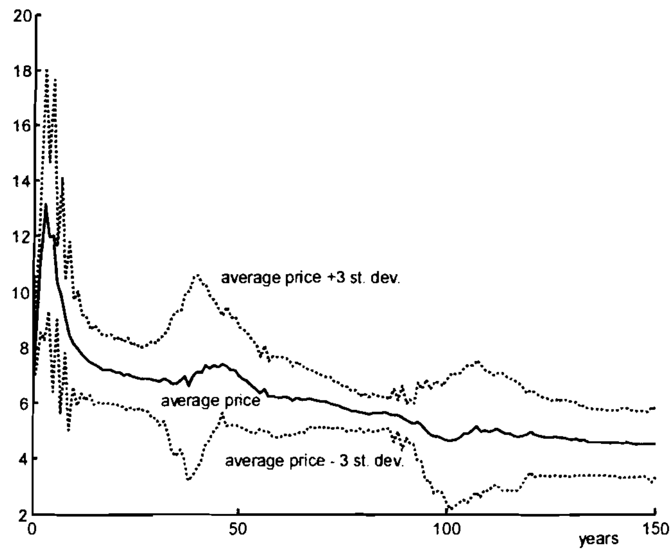


Figure 14. Average price and its diversity

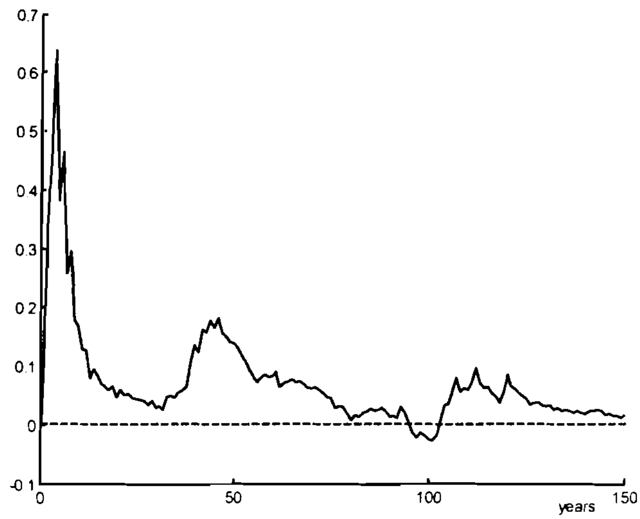


prices and large profits. Figures 13, 14, and 15 show that in that period we have a relatively large number of firms operating in the market (around 40 firms), but concentration of the market was rather high (H number of equivalent was equal to 3.2 firms). This high concentration is accompanied by low, although diversified, price (Figure 14) and very small profit ratio (1.5%). We can identify the development of the industry in the last decades of simulation to well-known, orthodox market structure of monopolistic competition.

CONCLUSION

Results of simulation experiments show that evolutionary modeling allows support of textbook conclusions related to industry development, but also reveals the weakness of the orthodox, textbook analysis. Repertoire of behavior of evolutionary models is much richer that those presented in the economics textbook. We can say that all phenomena related to textbook industrial analysis can be explained within the evolutionary paradigm, but the evolutionary analysis allows the explanation of a much wider spectrum of phenomena. Among them are questions related to the necessary number of firms operating in a market to call the market the perfect competitive one, problems of trade-off between profit rate and the normal rate of return, non-uniform firms size distribution for the perfect competition market, and the importance of innovation for industry behavior. It is shown that the closeness of evolutionary modeling to real processes is far reaching. One of the important conclusions from that paper and from the experience of teaching microeconomics is that evolutionary analysis may be considered as a very useful and complementary tool to teach economics.

Figure 15. Profit-to-capital ratio



REFERENCES

Dopfer, K. (Ed.). (2005). *The evolutionary foundations of economics*. Cambridge, UK: Cambridge University Press.

Frenken, K. (2005). *History, state and prospects of evolutionary models of technical change: A review with special emphasis on complexity theory*. Utrecht University, The Netherlands. Retrieved from http://www.complexityscience.org/NoE/Frenkencomplexityreview.pdf/

Kwasnicki, W., & Kwasnicka, H. (1992). Market, innovation, competition. An evolutionary model of industrial dynamics. *Journal of Economic Behavior and Organization, 19*, 343-368.

Kwasnicki, W. (1996). *Knowledge, innovation, and economy. An evolutionary exploration* (2nd ed.). Cheltenham; Brookfield: Edward Elgar.

Nelson, R. R. (1995). Recent evolutionary theorizing about economic change. *Journal of Economic Literature, 33*, 48-90.

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

Saviotti, P. P. (1996). *Technological evolution, variety and the economy*. Cheltenham; Brookfield: Edward Elgar.

Silverberg, G. (1997). *Evolutionary modeling in economics: Recent history and immediate prospects*. Research Memoranda 008, Maastricht Economic Research Institute on Innovation and Technology, The Netherlands. Retrieved from http://ideas.repec.org/p/dgr/umamer/1997008.html

Silverberg, G., & Verspagen, B. (2003). Evolutionary theorizing on economic growth. In K. Dopfer (Ed.), *The evolutionary principles of* *economics* (revised ed.). Cambridge: Cambridge University Press. Retrieved from http://ideas.repec.org/p/wop/iasawp/wp95078.html

Simon, H. A. (1986). On behavioral and rational foundations of economic dynamics. In R. H. Day & G. Eliasson (Eds.), *The dynamics of market economies.* Amsterdam: North-Holland.

Wallace, A. R. (1898). *The wonderful century. Its successes and failures.* New York.

Winter, S. (1984). Schumpeterian competition in alternative technological regimes. *Journal of Economic Behavior and Organization, 5,* 287-320.

KEY TERMS

Competitiveness: Ability of economic agents (firms) to compete in the market by offering technologically advanced or cheaper products.

Evolutionary Economics: In the broadest sense, a study of economic phenomena using analogies and metaphors of biological evolution. It represents an alternative approach to so-called "mainstream economics," where analyses is based on mechanical analogies and metaphors borrowed form classical physics.

Replicator Equation: A differential or difference equation that defines the selection dynamics of a population of competing agents (firms), considered within a frame evolutionary economics (also of evolutionary games).

Routine: *Regular and predictable behavioral patterns of firms*; in evolutionary economics, the concept of routine plays a similar role as concept of gene in evolutionary biology.

ENDNOTES

1. Good reviews of recent literature on evolutionary modeling can be found in Silverberg (1997), Silverberg and Verspagen (2003), and Frenken (2005). See also http://prawo.uni.wroc.pl/~kwasnicki/todownload/Schumpeterian modelling.pdf and http://prawo.uni wroc.pl/~kwasnicki/todownload/NW conference.pdf
2. Further reading on that model can be found at http://prawo.uni.wroc.pl/~kwasnicki/e-model.htm
3. What follows is only a short description of the essential features of these basic structures as understood by traditional (textbook) economics: *Pure (or perfect) competition* is a feature of industry which consists of a large number of independent firms producing a standardized product; no single firm can influence market price; the firm's demand curve is perfectly elastic, therefore price equals marginal revenue. *Monopoly* is where there is a sole producer of a commodity, and there are no straight substitutes for that commodity. *Oligopoly* is characterized by the presence within the industry of a few firms, each of which has a significant fraction of the market. Firms are interdependent; the behavior of any one firm directly affects, and is affected by, the actions of competitors. In *monopolistic competition,* there is a large enough number of firms; each firm has little control over price, interdependence is very weak or practically absent, so collusion is basically impossible; products are characterized by real and imaginary differences; a firm's entry is relatively easy.

4 More detailed discussion on efficiency of different firm objectives are presented in Kwasnicki (1992, 1996).

5 The Herfindahl–Hirschman index of concentration of the industry is equal to $H = \sum_i (f_i)^2$, where f_i is the market share of fim *i*. The Herfindahl firms' number equivalent is defined as $n_H = 1/H$ and is the number of equal-sized firms that would have the same H index as the actual size distribution of firms.

6 The raising of the price above that imposed by the *old* firms to get higher profit is not possible because of diminishing competitiveness of the newcomer's products.

7 In the end of simulation, when the industry was very close to the equilibrium state, there were 21 firms of different size, but the Herfindahl firms' number equivalent was equal to 8.2 (i.e., the market situation was similar to the perfect competition of roughly eight equal-sized firms of 12.5% market share each)—see Figure 4.