Commerce, Complexity, and Evolution

Commerce, Complexity, and Evolution is a significant contribution to the new paradigm straddling economics, finance, marketing, and management, which acknowledges that commercial systems are evolutionary systems and must therefore be analysed with evolutionary tools. Evolutionary systems display complicated behaviours that are to a significant degree generated endogenously, rather than being solely the product of exogenous shocks; hence the conjunction of complexity with evolution. The papers in this volume consider a wide range of systems, from the entire economy at one extreme to the behaviour of single markets at the other. The papers are united by methodologies that, at their core, are evolutionary, although the techniques cover a wide range, from philosophical discourse to differential equations, genetic algorithms, multiagent simulations, and cellular automata. Issues considered include the dynamics of debt deflation, stock management in a complex environment, interactions among consumers and their effect on market behavior, and nonlinear methods to profit from financial market volatility.

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Commerce, Complexity, and Evolution

Topics in Economics, Finance, Marketing, and Management: Proceedings of the Twelfth International Symposium in Economic Theory and Econometrics

Edited by

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Series editor's preface

This volume is the twelfth in a series, called *International Symposia in Economic Theory and Econometrics*. The proceedings series is under the general editorship of William Barnett. Individual volumes in the series generally have coeditors, who differ for each volume, as the topics of the conferences change each year. The co-organizers of the twelfth symposium, which produced the current proceedings volume, were Carl Chiarella, Steve Keen, Bob Marks, and Hermann Schnabl. The coeditors of this proceedings volume are William Barnett, Carl Chiarella, Steve Keen, Bob Marks, and Hermann Schnabl.

The topic of the conference and focus of this book is "Commerce, Complexity, and Evolution: Complexity and Evolutionary Analysis in Economics, Finance, Marketing, and Management." The volume showcases the many facets of the new evolutionary approach to analyzing and modeling commercial systems. The collection is distinguished by the wide range of methodologies presented, ranging from philosophical discourse at one extreme to multiagent modeling at the other. The volume is a significant contribution to the new paradigm acknowledging that commercial systems are evolutionary systems and must therefore be analyzed by use of evolutionary tools. This new paradigm straddles economics, finance, marketing, and management.

The conference that produced this volume was held at the University of New South Wales in Sydney, Australia, in 1996, and attracted participants from Australia, Japan, Europe, and the United States. The conference was sponsored by the Faculty of Commerce at the University of New South Wales. Many of the prior volumes in this series were sponsored by the IC2 Institute at the University of Texas at Austin, and some have been cosponsored by the RGK Foundation.

The first conference in this Cambridge series was co-organized by William Barnett and Ronald Gallant, who also coedited the proceedings volume. That volume has appeared as the Vol. 30, October/November 1985, edition of the *Journal of Econometrics* and has been reprinted as a volume in this Cambridge

University Press monograph series. The topic was "New Approaches to Modeling, Specification Selection, and Econometric Inference."

Beginning with the second symposium in the series, the proceedings of the symposia appear exclusively as volumes in this Cambridge University Press monograph series. The co-organizers of the second symposium and coeditors of its proceedings volume were William Barnett and Kenneth Singleton. The topic was "New Approaches to Monetary Economics." The co-organizers of the third symposium, which was on "Dynamic Econometric Modeling," were William Barnett and Ernst Berndt; and the coeditors of that proceedings volume were William Barnett, Ernst Berndt, and Halbert White. The co-organizers of the fourth symposium and coeditors of its proceedings volume, which was on "Economic Complexity: Chaos, Sunspots, Bubbles, and Nonlinearity," were William Barnett, John Geweke, and Karl Shell. The co-organizers of the fifth symposium and coeditors of its proceedings volume, which was on "Nonparametric and Semiparametric Methods in Econometrics and Statistics," were William Barnett, James Powell, and George Tauchen. The co-organizers and proceedings coeditors of the sixth symposium, which was on "Equilibrium Theory and Applications," were William Barnett, Bernard Cornet, Claude d'Aspremont, Jean Gabszewicz, and Andreu Mas-Colell. The co-organizers of the seventh symposium, which was on "Political Economy," were William Barnett, Melvin Hinich, Douglass North, Howard Rosenthal, and Norman Schofield. The coeditors of that proceedings volume were William Barnett, Melvin Hinich, and Norman Schofield.

The eighth symposium was part of a large-scale conference on "Social Choice, Welfare, and Ethics." That conference was held in Caen, France, on June 9–12, 1993. The organizers of the conference were Maurice Salles and Herve Moulin. The coeditors of that proceedings volume were William Barnett, Herve Moulin, Maurice Salles, and Norman Schofield. The ninth volume in the series was on "Dynamic Disequilibrium Modeling: Theory and Applications," and was organized by Claude Hillinger at the University of Munich, Giancarlo Gandolfo at the University of Rome "La Sapienza," A. R. Bergstrom at the University of Essex, and P. C. B. Phillips at Yale University. The coeditors of the proceedings volume were William Barnett, Claude Hillinger, and Giancarlo Gandolfo.

Much of the contents of the tenth volume in the series comprises the proceedings of the conference "Nonlinear Dynamics and Economics," held at the European University Institute in Florence, Italy, on July 6–17, 1992. But the volume also includes the related, invited papers presented at the annual meetings of the American Statistical Association held in San Francisco on August 8–12, 1993. The organizers of the Florence conference, which produced part of the tenth volume, were Mark Salmon and Alan Kirman at the European University Institute in Florence, and David Rand and Robert MacKay from the Mathematics Department at Warwick University in England, and the organizer of the invited American Statistical Association sessions, which produced the other papers in the volume, was William Barnett, who was Program Chair in Economic and Business Statistics of the American Statistical Association during that year.

The eleventh volume was the proceedings of a conference held at the University of Aarhus, Denmark, on December 14–16, 1995. In addition to being the eleventh in this series, that volume was the proceedings of the Sixth Meeting of the European Conference Series in Quantitative Economics and Econometrics (EC)2. The organizer of the Aarhus conference was Svend Hylleberg at the University of Aarhus. The editors of the proceedings volume were William A. Barnett, David F. Hendry, Svend Hylleberg, Timo Teräsvirta, Dag Tjøstheim, and Allan Würtz. The topic of the conference and focus of that book was "Nonlinear Econometric Modeling," with an emphasis on nonlinear time series.

The intention of the volumes in this proceedings series is to provide refereed journal-quality collections of research papers of unusual importance in areas of currently highly visible activity within the economics profession. Because of the refereeing requirements associated with the editing of the proceedings, the volumes in the series do not necessarily contain all of the papers presented at the corresponding symposia.

William A. Barnett
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Volume editors' preface

Commerce, Complexity, and Evolution is a significant contribution to the new paradigm straddling economics, finance, marketing, and management, which acknowledges that commercial systems are evolutionary systems and must therefore be analyzed with evolutionary tools. Evolutionary systems also display complicated behaviors that are, to a significant degree, generated endogenously, rather than being solely the product of exogenous shocks, hence the conjunction of complexity with evolution. The papers in this volume consider a wide range of systems, from the entire economy at one extreme to the behavior of single markets at the other. The authors consider commerce from a variety of perspectives, ranging from marketing to macroeconomics. The papers are united by methodologies that, at their core, are evolutionary, although the techniques cover a wide range, from philosophical discourse to differential equations, genetic algorithms, multiagent simulations, and cellular automata. Some of the many issues considered include the dynamics of debt deflation, stock management in a complex environment, interactions among consumers and their effect on market behavior, and nonlinear methods to profit from financial market volatility. Because intellectual analysis is itself an evolutionary process, several of the papers critically analyze this newly emerging approach to understanding humankind's most complex invention, its social system.

The papers are a refereed, revised, and updated subset of those first presented to the twelfth conference in the series *International Symposia in Economic Theory and Econometrics*. The conference was held at the University of New South Wales in Sydney, Australia, in 1996, and attracted participants from Australia, Japan, Europe, and the United States.

This volume, edited by William A. Barnett, Carl Chiarella, Steve Keen, Robert Marks and Hermann Schnabl, consists of four parts: Part I considers the philosophical and methodological implications of the evolutionary approach to economic and social analysis; Part II presents several nonlinear models of macroeconomic dynamics and presents nonlinear techniques for analyzing financial data; Part III presents a range of applied evolutionary techniques to single markets, including nonlinear cobweb models, genetic algorithms, neural networks, complex systems simulations and cellular automata; and Part IV present complex system approaches to analyzing marketing and interdependent behaviors.

The Papers: An Introduction

Martens ("Toward a generalized Coase theorem: a theory of the emergence of social and institutional structures under imperfect information") applies concepts from systems theory, evolution, and psychology to consider the treatment of innovation in economic theory. He argues that, in contrast to neoclassical new growth theory and nonneoclassical Schumpeterian analysis, innovation cannot be properly treated without considering uncertainty, information-processing constraints, and the endogenous development of consumer preferences. This line of analysis leads to a vision of the market economy as a third tier of evolution above Darwinian survival and Lamarckian learned adaptation, in which the trading system enables the inexpensive exchange of critical information, thus enhancing overall survival. As Coase (1960) argued, however, trading introduces transaction costs, which can themselves prevent exchange if they are too high. Martens argues that this hypothesis can be extended to cover public goods, and this leads to a perspective on innovation and the evolution of institutions as uncertainty-reducing adaptations.

Nightingale ("Universal Darwinism and social research: the case of economics") casts a critical eye over the potentially faddist use of the term evolutionary to describe "any notion of alternative states of an economic system." He proposes a definition for a genuinely evolutionary approach to economics and asks whether it is possible for the evolutionary paradigm to be any more than a poor analogy, with economists "digging around the mullock heaps of the more developed sciences, searching for scraps of sustenance." Although his answer is a tentative "yes" in terms of present-day contributions to evolutionary economics, he argues that the concepts of evolution has as much inherent validity in the economic sphere as it does in biology.

Juniper ("Uncertainty, risk, and chaos") considers Keynes' discussions of investment behavior under uncertainty, expectations formation, and the concept of the "state of confidence" as a weight that is placed on forecasts in a world with an uncertain future. His survey of recent literature criticizes the attempt to use so-called evolutionary notions to argue for the reduction of uncertainty to risk and situates the modern concept of chaos theory within Keynes' rubric.

Standish ("The role of innovation in economics") concludes these philosophical papers and provides a bridge to the analytic, modeling, and simulation papers that follow. Arguing that there are strong parallels between ecology and economics, Standish notes that the two disciplines have followed a similar path of development, from statics through dynamics, to now arrive at evolutionary computation. He introduces an evolutionary program, *Ecolab*, which analyzes the development of an open-dimensional generalized Lotka–Volterra system of species interaction. The interaction matrix expands as new species are produced by means of mutation and crossover, and the interactions drive some species to extinction. The system displays self-organizing criticality as the dominant eigenvalue of the system tends toward zero. This ecological model is extended to include the economy by considering products as species and innovation as the analogy of mutation. Equilibrating price dynamics are introduced, not in the belief that prices achieve equilibrium in a dynamic setting but in the spirit of an ansatz whose dynamics can then be explored.

Keen ("The nonlinear economics of debt deflation") gives an excellent account of Fisher's appreciation of the dynamics underlying great depressions and Minsky's financial instability hypothesis. He constructs a nonlinear model, which incorporates insights of Fisher and Minsky and can generate the debt-induced depressions they foresaw. His model is locally stable but globally unstable. Keen goes on to model Minsky's insight that a government sector can stabilize the market. The model then becomes locally unstable but globally stable. His concluding comments on the current debt crises in Asia (which has subsequently spread to other parts of the world economy) underlines the significance and relevance of his modeling framework for economists wishing to develop prescriptions for the unfolding world economic order.

Chiarella and Flaschel ("The emergence of complex dynamics in a 'naturally' nonlinear integrated Keynesian model of monetary growth") develop a general six-dimensional Keynesian model of economic growth and cycles, because to date the literature has relied on partial models of Keynesian dynamics. Their results therefore provide a more considered yardstick by which to judge the alleged achievements of later non-Keynesian models. In contrast to the model in Keen, which has relatively simple production and distribution relations but uses nonlinear behavioral functions, the model in this chapter has quite a detailed model incorporating stocks, savings behavior, capacity utilization, and price dynamics in the context of simple linear behavioral relations. The nonlinearities that emerge in this model and determine its behavior are thus a natural product of the sectoral interactions in an economic system, without the additional consideration of nonlinear behavioral relations. The model demonstrates that a fully specified Keynesian model with no extrinsic nonlinearities is able to demonstrate complex dynamic behavior, which has not hitherto been appreciated in the macroeconomic literature. Results that wage flexibility destabilizes the system whereas price flexibility stabilizes it are also novel with respect to mainstream economic analysis (although consistent with results from Keen).

Barnett and Xu ("Stochastic volatility in interest rates and complex dynamics in velocity") demonstrate that money velocity is nonlinear even within a general-equilibrium model, to support the contention that money velocity may be unstable within the actual economic system. This theoretical result is offered as an explanation of the otherwise inexplicable behavior of money velocity since the late 1970s, as money velocity is traditionally regarded as a stable function of relatively few determinants. Barnett and Xu show that an infinite-horizon representative-agent model can generate a money velocity equation that follows a nonlinear dynamic process whose stability depends on model parameters and that can, under plausible conditions, demonstrate logistic map chaos. The introduction of exogenous uncertainty results in money velocity's being stochastically nonlinear. Data from 1960 till 1992 confirm the prediction of the chapter that high-risk aversion will reduce the stability of money velocity.

Colin's chapter ("A genetic-programming-based approach to the generation of foreign-exchange trading models") brings to mind the experience of one of the editors' Master's students, who recently went looking for successful applications of genetic algorithms (GAs) in finance. He found few examples, probably not because there are no applications of GAs in finance (see Debroeck's 1994 anthology for some early examples), but because there were some very successful examples – so successful, in fact, that their programmers were in no rush to make them publicly available (see Drake and Marks, 1998, for the survey). Given this dearth of published papers, we are pleased to have Colin's chapter on using GAs to assist in foreign-exchange trading. Colin argues that genetic programming (not specifically GAs) is appropriate for the generation of trading systems, which can aid in enhancing portfolio returns. The genetic-programming approach allows for greater complexity than GAs because it can incorporate data structures that can grow or shrink according to the requirements of the fitness function. Thus trading models can be developed without any prior assumptions being made about the complexity of the market. His results suggest that, when used in conjunction with disciplined money management techniques, these models may be useful in enhancing portfolio returns.

Lajbcygier et al. ("Hybrid option pricing with an optimal weighted implied standard deviation") show that a hybrid model – consisting of the Black–Scholes model augmented by an artificial neural network – is significantly more accurate at pricing options than the modified Black–Scholes model. The model was applied to the All Ordinaries Share Price Index (AO SPI) on the Sydney Futures Exchange. The research indicates that the deviations of actual data from the modified Black–Scholes model are of the order of 2% and are not noise but systematic deviations.

Schnabl ("Evolutionary patterns of multisectoral growth dynamics") outlines a technique that can identify the main interlinkages in an economy from input–output data. He also discusses evolutionary patterns displayed by an application of this analysis across time, which enables the death of certain industries and the birth of others to be detected. Policy makers could use this analysis to determine whether an economy's investment in product-innovation strategies is too low.

Foster and Wild ("The detection of evolutionary change in nonlinear economic processes: a new statistical methodology") extend spectral analysis, a technique that has been available in econometrics packages since at least the early 1970s, when the National Bureau of Economic Research used TROLL (for Time-Shared Reactive Library, developed at MIT and running on IBM 370 mainframes and compatibles) by means of the Tymshare remote network for research. Foster and Wild note that, nonetheless, the interest in evolutionary economics has not yet been matched by the development of econometric tests designed to investigate processes of change in an evolutionary economic system. Evolutionary economic processes, they argue, can be characterized in terms of time irreversibility, structural change, and true uncertainty. They propose a new methodology that can detect the time irreversibility, nonequilibrium, and unstable characteristics of evolutionary change in an economic system, the method of time-varying spectral analysis by using sliding windows over the data. They present an econometric approach to evolutionary processes that uses spectral methods to decompose the residual variances of econometric models of diffusion processes with logistic trajectories in order to establish, first, whether or not time irreversibility exists, second, whether the process can be viewed as a nonequilibrium process in nature (which provides evidence of structural change), and, third, whether the process is unstable in the saturation phase of logistic diffusion (which provides evidence of true uncertainty in the structural change). Fourier decompositions of the data generated by a logistic diffusion process will display dominant low-frequency components in the early growth stage, middle-frequency components in the inflexion stage, and a dominance by high-frequency components during the saturation stage. Together with other quoted work of the authors, this study can be seen as starting to lay the foundations of an econometrics of evolutionary economic processes.

Matsumoto ("Ergodic chaos in a piecewise linear cobweb model") extends the literature on nonlinear cobweb models with a model in which a linear supply function has upper and lower bounds. This model has the advantage of restricting system outputs to meaningful values (nonnegative prices and quantities), in contrast to earlier models with only upper bounds. Using an effective combination of analysis and numerical simulations, he shows that the range of dynamic behavior can range from stable periodic cycles to ergodic chaos.

Gaffney et al. ("The cobweb model and a modified genetic algorithm") extend the work of Arifovic, which itself was motivated by the contrast between the instability of cobweb models and the comparative stability of experimental markets. They translate the underlying genetic ideas into more meaningful equivalent economic concepts and model the mutation and crossover rules in a more economically meaningful way. Inspired by Carlson's demonstration that the model converges if agents base their price forecasts on the average of previous prices, Gaffney et al. use a real-number representation of the GA and averaging, instead of the standard binary GA representation and the crossover operator. They also add an "election" operator to simulate suppliers choosing between old and new forecasts on the basis of predicted profitability. Their modified GA always converges to the equilibrium and does so more smoothly than Arifovic's binary GA.

Pearce ("The convergence of genetic learning algorithms, with particular reference to recent cobweb models") discusses convergence and nonconvergence of GAs. In particular he shows that some of the basic results concerning nonconvergence of GAs hold in a much more general setting than previous mathematical analyses would suggest. His results also give greater insight into the convergence obtained by Gaffney et al. in their simulation study of the cobweb model.

Johnston and Betts ("A complex-systems simulation approach to evaluating plan-based and reactive trading strategies") evaluate the relative effectiveness of just-in-time reactive pull inventory management techniques and material requirements planning push methods by using a multiagent simulation. The environment of the simulation is affected by the actions of the agents, thus allowing the possibility of a wildly varying environment over time, with complex consequences for the nature and the stability of evolved strategies. For reasons of parsimony and focus, the model consists of a number of agents trading and maintaining their stock of a generic nonproduced good, in which some agents plan ahead whereas others commit to orders only one period in advance and trade to immediate demand. Simulations indicate that the prevalence of planners over reactions is a positive function of individual stocks and that the niche for reactor agents increases as the future becomes less predictable and peaks close to the complete breakdown of order.

Yao and Darwen ("Genetic algorithms and evolutionary games") generalize the iterated prisoners' dilemma beyond its standard 2-person bounds to consider populations as high as 16. The issues of interest are whether cooperation can emerge from an initial population of random strategies, how group size affects the evolution of cooperation, and how stable evolved strategies are. Yao and Darwen use a GA representation in which information on the number of cooperators in each previous round is stored, rather than the actual actions of each agent; this method is both more compact and more realistic. They find that cooperation can still evolve in larger groups, but it is harder to achieve as group size rises and is a positive function of the memory length. Cooperative strategies are in general not evolutionarily stable, but in a result that has interesting applications to predator–prey modeling, coevolution with the addition of extra noncooperative strategies gives more general strategies that do cooperate well with each other, but are still not exploited by noncooperative strategies.

Marks ("Evolved perception and the validation of simulation models") has undertaken a research program that evaluates the performance of market simulation experiments against real historical data for a specific oligopolistic market, that for instant coffee. The real and the simulated agents in this strategic game deal with the "curse of dimensionality" by partitioning the external reaction space, mapping from this external state to a more compact internal perceived state, and reacting to a rival's action only if it changes this perceived state. This raises the issue of the manner in which partitioning and mapping occur, and Marks discusses three possible measures for determining the optimal partition in this context of bounded rationality.

Oda et al. ("The application of cellular-automata and agent models to network externalities in consumers' theory: a generalization-of-life game") criticize the conventional treatment of demand in the presence of interactions among consumers, as it removes feedback between purchasing decisions and decision formation by presuming that no purchases occur until all buyers have made their purchasing decisions. They develop a simple but richer model of interactive demand functions in which there is no dichotomy between decision formation and economic activity. This model indicates that equilibrium values cannot be determined a priori and that there is no tendency for a convergence to equilibrium, with limit cycles and other dynamic phenomena being equally likely outcomes from a given set of initial conditions. They conclude with observations on the veracity of equilibrium analysis of consumer behavior and observe that the diffusion of a network-influenced product may follow a stable logistic process with heterogeneous consumers but may not if consumers are homogeneous.

Gans ("Engendering change") considers the possibility of coordination failure in circumstances in which multiple equilibria can occur, in which case the economy can be trapped in a low-efficiency equilibrium when such an equilibrium is locally stable but globally unstable. The example considered is racial discrimination in the labor market, and the policy issue investigated is whether the best strategy to escape from the low-efficiency equilibrium (of discrimination against individuals on the grounds of a perceived difference between groups) involves individually targeted or broad-effect policies. The situation of racial discrimination is characterized as one in which imperfect information on individuals results in the wage received by a worker, reflecting in part his or her marginal product and also information concerning the productivity of other members of the same group. The author finds that inflexible employer beliefs are best tackled with broad-effect policies, whereas flexible employer beliefs are best altered by policies targeted at the behavior of individual workers.

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