

Introduction to the special issue ‘Nonlinear Economic Dynamics’

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This special issue on “Nonlinear Economic Dynamics” contains a selection of papers presented at the 9th International Conference on Nonlinear Economic Dynamics (NED2015), that took place on June 25–27, 2015, at Chuo University, Tokyo, Japan.

NED is a biennial international meeting of scholars interested in economic dynamics, with the intention to bring together different streams of the growing literature in this field and to stimulate a fruitful exchange between theoretical research and applications in economics. The theory of dynamical systems is among the areas of mathematics that have witnessed the largest advancements in the last 60 years, with a wide spectrum of applications ranging from physics to biology to economics and social science. Moreover, during the last decades economic theory has started to experience an important shift in methodology. The classical approach that views economic outcomes as equilibrium phenomena, resulting from the choices of fully rational and identical economic agents, has failed to explain many important features of economic complexity in the real world, and has been criticized for its inability to predict sudden changes, such as economic crises and financial turmoils. As a consequence, a growing interest in alternative approaches has emerged, emphasizing the role of bounded rationality, agents’ heterogeneity, social interaction, learning and adaptive adjustment processes. Following this new paradigm, firms, organizations, markets and economies are viewed as complex evolving systems characterized

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by nonlinear interactions, possibly leading to the emergence of non-equilibrium outcomes in the short and the long run. The corresponding mathematical modeling approaches require a wide range (and a combination) of analytical and numerical techniques, some of which are very innovative. Such techniques are based on a mix of theories and methods, among which the qualitative theory of nonlinear dynamical systems, optimal control, game theory, and stochastic processes. Of course, the use of nonlinear dynamics in economics is well-established since the early contributions in the 40 s – 50 s of XX century, and even in more recent neoclassical models, the theory of nonlinear systems has yielded important results on the ‘indeterminacy’ and bifurcations of stationary competitive equilibria. However, its use was often restricted to the analysis of the *local* behavior around steady states of the system, whereas the study of the *global* effects of nonlinearity requires a broader approach and the tight interplay of analytical techniques and numerical investigation.

The goal of this special issue is to provide the reader with an overview of new directions in the *global analysis* of economic dynamics and to show applications of concepts from the qualitative theory of nonlinear dynamical systems in the fields of economics, finance, environment, and strategic interaction in social decisions. The wide spectrum of applications and the mathematical methods employed in the dynamic analysis are intended to offer a broad view on the different research streams that contribute to the blossoming literature on Nonlinear Economic Dynamics.

The papers appearing in this issue have undergone the standard refereeing process of the *Journal of Evolutionary Economics*. The contributions address a variety of recent research topics in such different areas as Oligopoly Theory and Game Dynamics, Financial Market Dynamics, Macroeconomics, Demography and Economic Geography. It is thereby our hope that this special issue will stimulate further collaborations amongst researchers from different fields, through a fruitful trade-off between theory and applications.

For the convenience of the reader, we briefly review below the contributions included in this issue, by emphasizing some common themes and features of the models proposed and mathematical methods employed.

The first group of papers on Oligopoly and Game Dynamics opens with “Dynamics of a minimal consumer network with uni-directional influence”, in which Ekaterinchuk, Jungeilges, Ryazanova and Sushko reconsider a model of interdependent consumer behavior where two individuals adjust their preferences in response to their own past consumption decisions and the observable past consumption of the other individual. The authors analyse the quite rich dynamics emerging in two special cases, described by noninvertible triangular maps, and emphasize the economic interpretations of the observed phenomena. In particular, the global dynamic analysis of the model focuses on the coexistence of attractors and the mechanisms leading to their qualitative transformations.

The paper by Bischi and Merlone, “Evolutionary minority games with memory”, models the time evolution of a population of players facing a binary choice in a class of minority games with memory effects, by means of a dynamic adjustment mechanism based on the exponential replicator dynamics in discrete time. The stability of the unique Nash equilibrium is investigated under two different assumptions about the players’ memory, one where players rely on the current and the previous payoffs,

and the other where memory comprises the whole time series of payoffs observed in the past, through a discounted sum with exponentially fading weights. Both cases are reduced to analytically tractable two-dimensional dynamical systems. However, a global analysis reveals some complex dynamic behaviours, such as chaotic patterns and path dependence due to the presence of coexisting attractors.

The paper by De Giovanni and Lamantia, titled "Evolutionary dynamics of a duopoly game with strategic delegation and isoelastic demand", deals with strategic delegation in Cournot competition, in both a two-stage game and an evolutionary setting. The paper shows that - depending on the price elasticity of demand - strategic delegation under quantity competition may result in output reduction (as compared with the standard Cournot-Nash equilibrium), a phenomenon which usually comes in association with price competition. The welfare implications of the model are also investigated, and the robustness of the results is addressed by means of an evolutionary model with heterogeneous players.

The paper "Market share delegation in a nonlinear duopoly with quantity competition: the role of dynamic entry barriers" by Gori, Pecora and Sodini examines local and global dynamics of a nonlinear duopoly model with quantity setting (managerial) firms and horizontal product differentiation, resulting in a two-dimensional nonlinear map. The analysis focuses on the impact of the degree of product differentiation or the managerial power in the market share bonus. By combining analytical methods and numerical experiments, the paper shows that the Nash equilibrium of the game may not describe the long-term outcome of the market, as the equilibrium may be unstable and other attractors (simple or chaotic) may capture the long-term dynamics. Model extensions are also proposed, allowing for a potential new entrant subject to entry barriers, in order to discuss how the non-invertibility of the map can affect the entry process.

The paper of Davide Radi, "Walrasian versus Cournot behavior in an oligopoly of bounded rational firms", proposes an evolutionary oligopoly game where firms can select between a best-reply rule and a Walrasian rule in an industry characterized by a finite number of ex-ante homogeneous firms with naïve expectations. With the distribution of behavioral rules evolving over time according to a replicator dynamics, based upon realized profits, two long-run equilibria may emerge, a Walrasian equilibrium and a Cournot-Nash equilibrium. The paper investigates the parameter configurations under which a globally stable Walrasian equilibrium may become unstable through a bifurcation, and may give rise to a new attractor, representing complicated dynamics with evolutionary stable heterogeneity. However, in the presence of a large firms' propensity to select the more profitable behavioral rule, the Cournot-Nash equilibrium can become a global 'Milnor attractor'.

The paper by Gori, Guerrini and Sodini, titled "A characterisation of duopoly dynamics with frictions in production adjustments", revisits the classical dynamic duopoly model in discrete time of Puu (1991), by adopting a continuous-time framework with delays to allow for production and gestation lags along with continuous trading. The model is governed by a two-dimensional system of delay differential equations. Unlike in Puu (1991), the model can generate complex dynamics far enough from the origin when marginal costs vary, due to the role played by time delays and inertia in the output adjustment mechanism. From a mathematical

viewpoint, the existence of Hopf bifurcations is detected by means of the recent technique of ‘stability crossing curves’.

In the paper “Extended Oligopolies with Contingent Workforce”, by Matsumoto, Merlone and Szidarovszky, a new version of a single-product Cournot oligopoly without product differentiation is introduced, in which firms face additional costs once they change their output levels, and where such adjustment costs may be different depending on the adjustment direction (e.g. due to searching and selection costs of new workers in case of output expansion). The paper focuses on the impact of the gap between the adjustment costs. The resulting dynamics is complex and the consequences of this complexity are examined in terms of their policy implications.

The second group of papers on Financial Market Dynamics starts with the paper “An evolutive financial market model with animal spirits: imitation and endogenous beliefs”, by Cavalli, Naimzada and Pireddu. The paper investigates a financial market model with optimistic and pessimistic fundamentalists, who respectively overestimate and underestimate the asset’s fundamental value. Two evolutionary mechanisms are simultaneously at work: while investors’ estimates of the fundamental value evolve through an imitative process, agents have a tendency to switch to the other group of speculators - via a discrete-choice mechanism - if they performed better in terms of relative profits. The stability and bifurcations of the unique steady state are analyzed and the emergence of complex behaviors, including possible multistability phenomena, is demonstrated. A stochastically perturbed version of the model is also investigated.

In the paper titled “Heterogeneity, spontaneous coordination and extreme events within large-scale and small-scale agent-based financial market models”, Schmitt and Westerhoff start from a large-scale agent-based financial market framework in which speculators usually follow their own individual technical and fundamental trading rules to determine their orders, yet sunspot events may lead to temporary coordination of their trading behavior. By reducing the large-scale model to a small-scale model - represented by a three-dimensional first-order nonlinear stochastic dynamical system - the authors show that this framework has a remarkable ability to match a large number of stylized facts of financial markets, including the occurrence of lasting volatility outbursts. Moreover, severe market reactions may occur if heterogeneity among speculators temporarily breaks down during sunspot-initiated periods.

The paper “The adaptiveness in stock markets: testing the stylized facts in the DAX 30” by He and Li tests a simple asset pricing model of heterogeneous agents to characterize the power-law behavior of the DAX 30 from 1975 to 2007. The authors provide supporting evidence on the empirical findings that investors and fund managers tend to make investment decisions using combinations of fixed and switching strategies based on fundamental and technical analysis. A mechanism analysis based on the calibrated model offers a behavioural insight into the role of investors’ rational switching behavior in generating volatility clustering and long range dependence in return volatility.

The third group of papers on Macroeconomic Dynamics and Demography opens with “The role of centrality and market size in a 4-region asymmetric new economic geography model” by Commendatore, Kubin, Mossay and Sushko, where a new economic geography footloose-entrepreneur model is proposed having a more general

structure than in previous studies. The four regions are differentiated on the basis of their size and geographical position along a line and there are two distinct trade blocs, each consisting of a pair of regions. While direct and indirect trade between all regions is allowed, factor mobility can occur only between regions of the same bloc. The general structure of the model allows to investigate the interplay between *centrality* effect and *local market size* effect, giving rise to a plethora of long-term outcomes, including four equilibria with full agglomeration in each trade bloc that can be ranked by factor owners.

In order to address the question of how “green” growth differs from other patterns of growth, the paper “Optimal waste control with abatement capital” by Saltari and Travaglini investigates the control problem of a social optimum with waste (generated by consumption), abatement and productive capital stocks. Two main results are obtained: (i) An environmental Keynes-Ramsey rule showing how along the transitional path consumption dynamics is affected by capital and waste, implying that faster waste emissions not always call for faster abatement investment, which may unexpectedly lead to overshooting in waste and productive capital stock; (ii) In the steady state, both productive capital stock and output are unchanged relative to the standard Ramsey model, yet the output composition changes, since steady state consumption must be reduced to make room to abatement investment.

In order to understand the impact of learning on heterogeneous behaviour amongst agents, the paper “Genetic Algorithm Learning in a New Keynesian Macroeconomic Setup” by Hommes, Makarewicz, Massaro and Smits uses a Genetic Algorithm (GA) framework to replicate recent results from Learning-to-Forecast (LtF) experiments. Individuals optimise an adaptive, a trend following and an anchor coefficient in a population of general prediction heuristics. Experimental treatments are replicated in a New-Keynesian environment with increasing complexity and Monte Carlo simulations are used to investigate how well the model explains the experimental data. The authors show that the evolutionary learning framework is able to replicate three different types of behaviour, i.e. convergence to steady state, stable oscillations and damped oscillations. Therefore, heterogeneous behaviour in LtF experiments with different types of complexity can be explained by an adaptive, anchor and trend extrapolating component, using one GA model.

In the paper “Nonlinear monetary policy rules in a pure exchange overlapping generations model”, Agliari, Naimzada and Pecora investigate the dynamics of a pure exchange overlapping generations model where, in each period, the monetary authority determines money supply based on the deviation of the inflation rate from its target in a nonlinear fashion, in such a way that the money growth rate remains within a predetermined range. It is shown that, depending on the timing of the monetary policy and the degree of reaction of the Central Bank, the target equilibrium may be destabilized via different types of bifurcations and coexistence of attractors may also arise. This study demonstrates that active monetary policy rules may be relevant for their stabilizing properties, but may also open the door to equilibrium cycles of any periodicity and even chaos.

The paper “Global Convergence in an Overlapping Generations Model with Two-Sided Altruism”, by Aoki and Nishimura, deals with the evolutionary dynamics of an overlapping generations economy with two-sided altruism, where each generation

cares about the utilities of its parental generation, its offspring, and its own. The authors assume that the young and old generations in each period act jointly, like a central planner. After introducing the concepts of a two-sided altruistic path and a two-sided altruistic stationary path, they prove that the former always converges to the latter, in the two-sided altruistic model. This stationary capital level is higher than the steady-state level in the model with a constant discount factor.

In their paper “A Bifurcation Analysis of Gender Equality and Fertility”, Feichtinger, Prskawetz, Seidl, Simon and Wrzaczek use a two-dimensional system of nonlinear ordinary differential equations to study the diffusion from traditional to egalitarian gender-behavior and its impact on fertility. The authors investigate the impact of key parameters - such as the pace of diffusion of egalitarianism and the extent to which social interactions affect the egalitarians’ birth rates - on the long-run development of the total fertility within a population, by conducting an extensive bifurcation analysis under different parameter constellations. They also show that the initial fraction of traditionalists in the population may crucially influence the long run outcome. The paper thus illustrates how bifurcation theory can be used to study the process of increasing gender equality.

We end this introduction to the special issue with our special thanks to the Editors-in-Chief of the *Journal of Evolutionary Economics* as well as to the journal’s editorial staff, for the opportunity to publish this Special Issue and for their careful support throughout the whole editorial process. We also wish to express our gratitude to the referees for their help in reviewing the contributions. We are grateful for financial support from the Japan Society for the Promotion of Science (Grant-in-Aid for Scientific Research (A) 26242018, (C) 24530202, 25380238, 26380316) and MEXT-supported Program for the Strategic Research Foundation at Private Universities 2013-2017. Finally, we are grateful to Chuo University, Tokyo and the Local Organizing Committee for supporting, hosting and organizing the 9th International Conference on Nonlinear Economic Dynamics (NED2015).