Technological Forecasting & Social Change 80 (2013) 329–350

Contents lists available at SciVerse ScienceDirect

Technological Forecasting & Social Change

Impact of environmental dynamics on economic evolution: A stylized agent-based policy analysis

Volker Nannen [a,h,*], Jeroen C.J.M. van den Bergh [b,c,d,e,f], A.E. Eiben [g]

[a] IFISC (CSIC-UIB), Institute for Cross-Disciplinary Physics and Complex Systems, Universitat de les Illes Balears, 07122 Palma de Mallorca, Spain
[b] ICREA, Barcelona, Spain
[c] Institute of Environmental Science and Technology, Universitat Autònoma de Barcelona, Edifici Cn, 08193, Bellaterra, Spain
[d] Dept. of Economics and Economic History, Universitat Autònoma de Barcelona, Edifici Cn, 08193, Bellaterra, Spain
[e] Faculty of Economics and Business Administration, VU University Amsterdam, De Boelelaan 1105, 1081 HV Amsterdam, The Netherlands
[f] Institute for Environmental Studies, VU University Amsterdam, De Boelelaan 1105, 1081 HV Amsterdam, The Netherlands
[g] Department of Computer Science, Faculty of Sciences, VU University Amsterdam, De Boelelaan 1081a, 1081 HV Amsterdam, The Netherlands
[h] Departament d'Arquitectura i Tecnologia de Computadors, Universitat de Girona, Edifici P-IV, Campus de Montilivi, 17071 Girona, Spain

ARTICLE INFO

Article history:
Received 31 January 2012
Received in revised form 19 July 2012
Accepted 19 August 2012
Available online 8 September 2012

Keywords:
Agent-based economics
Dynamic environments
Evolutionary economics
Optimal diversity
Public policies
Risk aversion

ABSTRACT

The general problem of how environmental dynamics affect the behavioral interaction in an evolutionary economy is considered. To this end, a basic model of a dynamic multi-sector economy is developed where the evolution of investment strategies depends on the diversity of these strategies, social connectivity, and relative contribution of sector specific investments to production. Four types of environmental dynamics are examined that differ in how gradual and how frequently the environment changes. Numerical analysis shows how the socially optimal level of diversity increases with the frequency and speed of environmental change. When there is uncertainty about the specific type of environmental dynamics—whether for lack of data or because it is not constant—the socially optimal level of diversity increases with the degree of risk aversion of the policy maker or the society.

1. Introduction

1.1. Economic evolution in dynamic environments

Evolutionary reasoning and agent-based modeling have become standard practice in various disciplines, including social sciences (e.g., [1,2]). An evolutionary model uses a population of entities that undergo selection and variation. Although specific domains ask for the development of particular types of model, several common, general issues arise. Here we aim to address one such issue, namely, how environmental dynamics bears upon the behavioral interaction of an evolutionary economy consisting of multiple agents with heterogeneous economic strategies. Specifically, we will study whether different types of environmental dynamics call for distinct behavioral interaction, and how a policy maker can make use of this insight even when the current type of environmental dynamics is unknown. The relevance of these questions is evident: few economic environments are static, and their dynamics are often irregular and unpredictable.

Generally, one cannot expect evolution in a changing environment to approach a steady state. Often, what matters is not how well the agents adapt if given enough time, but how fast they adapt to a new challenge. In a socio-economic context a wide range of environmental variables can be identified: macroeconomic conditions, technological opportunities, policies and institutions, and

* Corresponding author at: Departament d'Arquitectura i Tecnologia de Computadors, Universitat de Girona, Edifici P-IV, Campus de Montilivi, 17071 Girona, Spain. Tel.: +34 971172813.
E-mail addresses: vnannen@gmail.com (V. Nannen), jeroen.bergh@uab.es (J.C.J.M. van den Bergh), gusz@few.vu.nl (A.E. Eiben).

0040-1625/$ – see front matter
http://dx.doi.org/10.1016/j.techfore.2012.08.013

natural resources. When heterogeneous groups of users, polluters, or harvesting strategies are involved, a reduction to a representative agent model is often not possible. Instead, the heterogeneity and interaction of agents and strategies is better treated by an evolutionary agent-based model [3,4].

With regard to the evolutionary system, there is a range of theoretical starting points and modeling approaches [5,6]. First of all, one can choose to use very theoretical, abstract models of the evolutionary game type. In evolutionary game theory, studies of social behavior have been mostly limited to constant environments, letting selection pressure depend on the population distribution. This simplification allows for analytical treatment. However, addition of a dynamic environment typically leads to a system that is no longer amenable to analytic solutions. Numeric simulations of multi-agent systems form an alternative to the analytic approach that offers much more flexibility in examining system behavior. They allow a distinction between local and global environments, and between stationary and mobile agents. They further allow to study the influence of population size, and the effects of dynamic environments on group and network formation [7,8]. In addition, different assumptions can be made regarding selection factors and innovation mechanisms (random mutations, deterministic trends, recombination) and bounded rationality of agents (habits, imitation).

For our purpose a relevant distinction is between external and internal environmental dynamics. Whereas systems with only exogenous variables are relatively simple, endogenous variables generate complex feedback systems. Unfortunately, most real-world systems studied by biologists and social scientists are of the latter type. Yaari et al. [9] use local positive feedback loops to model growth in post-liberalized Eastern Europe. Implications of such a model to policy control are discussed by Challet et al. [10]. Lamieri and Ietri [11] and Windrum and Birchenhall [12] model coevolution of consumers and firms to study product innovation, technological successions, and the emergence of business cycles. Resource dynamics (e.g., [13,14]) and dynamic control of a pest population that evolves resistance to pesticides [15] are policy-relevant examples. Another, general example is a coevolutionary system in which two heterogeneous populations cause selection pressure on one another [16]. This leads to very complex coevolutionary interactions because the environment of each evolutionary (sub)system is evolving as well. Coevolution thus implies a particular type of internal environmental dynamics [17]. However, coevolution of multiple, interacting evolving populations easily leads to intractable models, and therefore is not a logical starting point for the present analysis (it may be addressed in a subsequent paper). We want to first know how a single population evolves under various types of environmental dynamics.

In this article we investigate the impact of different types of general external environmental dynamics on the socially optimal type of behavioral interactions among the agents in the population. For this purpose we develop a stylized, abstract evolutionary agent-based model that would best describe a community of small and medium-sized enterprises which serve similar markets with similar products, and which are characterized more by cooperation and an open exchange of information than by competition and secrecy. We identify the key control variable and establish its optimal level under different environmental dynamics and for different degrees of risk aversion of the policy maker or the society. While our results are solid insofar as they are robust over a wide range of implementation choices and parameter values, specific application would require adaptation of the model, for example, by including competition, niches, savings behavior, or coevolution of multiple populations.

Our use of evolutionary agent-based simulations for policy analysis in a dynamic environment departs somewhat from the main body of literature in evolutionary economics. This literature, from Schumpeter [18] and Nelson and Winter [19] to Dosi [20] and Silverberg et al. [21], develops an evolutionary theory that explains the emergence of complex empirical phenomena like technological progress and innovation diffusion from the interaction of simple agents. By contrast, the present approach was inspired by a quantitative approach to evolutionary theory that focuses on system control, as developed for example in the vast literature on the evolution of drug resistance in pathological agents and how to prevent it, or the mathematical models on cancer and HIV of Nowak [22].

Within economics, a quantitative approach with focus on control is more typical of the management literature. Here, the problem of how firms have to diversify and reinvent themselves in the face of various types of environmental dynamics is ubiquitous. While normally not phrased in evolutionary terms, the reader will agree that the essential elements of an evolutionary process—a population that undergoes variation and selection—are usually well defined. For example, Ansoff [23] and Ansoff and Sullivan [24] conclude that a firm needs to diversify its portfolio of methods and products in order to stay profitable in a changing environment, and that the level of diversification—ranging in qualitative terms from "incremental" to "creative"—needs to match the degree of changeability and predictability of the environmental dynamics. Thore et al. [25,26] use data envelope analysis (DEA) to track the time path of the empirical production frontier for the U.S. computer industry. They observe that individual firms left the efficiency frontier and returned to it in accordance with the life cycles of their products and technologies. Building on this, Phillips and Tuladhar [27] show that the number of years a computer manufacturer stayed at the efficiency frontier corresponds to the amount by which it could adjust output levels to environmental stimuli. The authors proceed to link the optimal level of output flexibility to the variety of environmental stimuli, in accordance with the law of requisite variety [28].

1.2. A model of environmental change

Economic change in general and business cycles in particular are often characterized by sustained co-movement of several variables and sectors. For example, Hornstein and Praschnik [29] study co-movement between production sectors, Croux et al. [30] study co-movement in the output of economic regions, and Forbes and Rigobon [31] study co-movement in stocks. We take account of this empirical stylized fact by defining economic dynamics as co-movement of two or more production coefficients of a non-aggregate Cobb–Douglas type multi-sector economy. The production coefficients can depend on an array of economic dynamics, like technological development and resource dynamics. When the technology or the environment changes, the production coefficients can change as well.

Water management provides a specific example of a production input that is highly dependent on environmental conditions, available technology and the specific requirements of currently profitable crops. An example of global scale is the progressive