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Models in evolutionary economics and environmental policy: Towards an evolutionary environmental economics

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ABSTRACT

In this paper we review evolutionary economic modelling in relation to environmental policy. We discuss three areas in which evolutionary economic models have a particularly high added value for environmental policy-making: the double externality problem, technological transitions and consumer demand. We explore the possibilities to apply evolutionary economic models in environmental policy assessment, including the opportunities for making policy-making endogenous to environmental innovation. We end with a critical discussion of the challenges that remain.

1. Introduction

It is commonly argued that technological innovation will be an important key to decrease the impact of industrial society on the environment. The understanding of environmental innovation – that is, innovation that contributes to the sustainability of the natural environment – from an economic perspective is, however, still limited. Environmental economists working in the neoclassical tradition find it difficult to incorporate technological innovation, since the outcomes of inventive activity cannot be foreseen – not even in a probabilistic sense. Therefore, the treatment of environmental innovation as a maximization problem is of limited practical relevance [1]. Ecological economists may be better able to analyse environmental innovation because they work outside the maximization framework. Yet, hitherto they have been relatively silent on environmental innovation.

With neoclassical and ecological economics having failed to develop a systematic research programme on environmental innovation, evolutionary economics emerged as an alternative and promising framework [2]. In the last 15 years or so, we witness an increasing number of contributions in environmental economics adopting an evolutionary perspective, including conceptual frameworks [3–7], empirical studies [8–12] and policy-oriented discussions [13–16]. More recently, scholars have started to develop formal evolutionary models in environmental studies, both explanatory and prospective [17–30]. These efforts reflect a further deepening of the evolutionary programme in the area of environmental studies, which opens up possibilities for application in policy-making. The goal of this paper is to provide a systematic review of the recent efforts in evolutionary modelling in environmental studies, and to assess their implications for environmental policy-making.

We apply the following structure. We first briefly discuss evolutionary theory and its application to the study of the economy (Section 2). We go on to discuss three areas in which an evolutionary approach in environmental economics has a particularly high value-added for environmental policy-making: the double externality problem, technological transitions and consumer demand (Section 3). We then take up a 'reflexive' approach to the role of government in environmental innovation from an innovation

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systems approach, exploring opportunities for making policy-making endogenous to environmental innovation (Section 4). We end with a discussion of the methodological challenges that remain (Section 5).

2. Defining properties of evolutionary dynamics

Evolution is an extremely strong concept for understanding the dynamics in the world surrounding us. After the publication of the seminal works by Charles Darwin, evolutionary theory was mainly elaborated and applied in the sphere of biology, which still leads many present-day observers to consider evolutionary theory as a biological theory. Following this view, applications of evolutionary theory outside biology are often considered ‘metaphorical’. However, various authors have pointed out that evolution is a general principle based on variation, selection and replication [31–33]. With the advent of computer simulation, the general evolutionary principle has been formalized in a number of canonical models, for example genetic algorithms [34], evolutionary games [35], random fitness landscapes [36] and multi-agent models [37,38], which are applied both in biology and other disciplines like economics, sociology, psychology, language studies, science studies, technology studies and management.

In biological evolution, mutation and crossover of chromosomes are the principle generators, and natural selection is the test. Natural selection operates by differential offspring as the fitter variants have their chromosomes replicated in more offspring than less fit variants. In technology evolution, the unit of analysis analogue to genes is harder to identify. Most often, scholars identify organisational routines as the unit of analysis [39]. Routines enable organizations, in particular firms, to produce particular technological artefacts at a certain level of economic efficiency. Routines are replicated vertically (through the creation of new firms as spin-offs or subsidiaries of existing firms) as well as horizontally (through imitation among existing firms). Investments in Research & Development (R&D) generate new routines leading to new artefacts. Innovative activity can thus be considered as a search process in which firms try, through trial-and-error, to improve the quality of their outputs or reduce the costs of output of a given quality. The fitness of artefacts is thus best thought of as value-for-money [40]. The selection process operates by differential profits among firms, as fitter artefacts are sold at higher profit margins than less fit artefacts. Consequently, firms producing the fitter artefacts have higher changes of survival than firms producing less fit artefacts. Note, however, that selection in modern societies does not only depend on sales but also on the extent technologies are socially legitimate as reflected in governmental regulations and social norms.

A second property of evolutionary theory lies in the population framework, which basically defines the level on which evolution works. Fisher [41] identified that the frequencies of various genes within a population changes over time according to their fitness. Units or individuals with above average fitness increase in frequency in a population, while units with below average fitness decrease in frequency and eventually become extinct. The population perspective can also be distinguished in markets where firms compete through innovation. Firms employing different technologies will be characterized by different fitness as expressed in profits. An evolutionary perspective thus rejects the assumption that firms all use, under the same conditions, the same technology. Yet, in the absence of further innovation and under specific conditions, market selection will lead firms that use the best performing technology to be the only survivors, akin to the process of natural selection [39,42].

It is sometimes argued that technological innovation is not an evolutionary process because technological innovations do not occur at random, while biological mutations do so. Unlike biological evolution, the direction of innovative search is not determined at random, but is rooted in technological paradigms that guide the search behaviour of firms [43]. This also means that technological development is, to some extent, a self-fulfilling prophecy: technological paradigms create widespread expectations about the future potential of a particular technology thereby mobilising resources and supporting institutions, which in turn accelerate the development of a technology thus confirming the expectations underlying the resources and institutions [44,45]. Still, the process of technological development can be considered as an evolutionary process, because agents will always remain fundamentally uncertain about the outcomes of their investments in R&D. As a result, the success of their search activities will only become apparent ex post depending on the sales figures and profit margins.

A specific phenomenon in evolutionary processes, with special relevance to technological development, is frequency-dependent selection. Frequency dependency means that the fitness of a particular genotype or technology depends on its frequency in the population. Positive frequency dependence means that the fitness of a genotype or technology increases with the number of copies in the population. Though not very common in biological evolution, most technologies are positively frequency dependent, because of increasing returns to adoption: the more a technology is used, the higher its utility for users becomes [46,47]. Well-known examples are telephone, fax and email, or more generally, communication technologies, for which utility increases as with the number of adopters. Though most apparent in communication technologies, increasing returns to adoption are relevant to virtually all technologies for various reasons: more users render production costs and prices to be lower, standardization increases compatibility with other technologies, more users generate more information about the technology reducing the risk in adoption, more users generate related markets for auxiliary products and services, and more users generate more political power to change institutions as to support the further development and use of a technology.

Formally, increasing returns to adoption imply that Fisher's differential equation [41], in which the frequency of particular genotype/technology changes solely according to the difference between its fitness and the fitness of competing entities, needs to be extended for application in the analysis of innovations. The original Fisher's equation is characterised by a *unique equilibrium* as the fittest technology will eventually come to fully dominate the population. When increasing returns are present, fitness is not only dependent on the ‘intrinsic’ fitness of the technology, but also on its frequency in the population. As a result, a new technology with higher intrinsic fitness but few adopters, will have difficulty to invade the population, even though adopting the new technology by all adopters, would lead to a fitness gain for all. In this case, the economy is said to be ‘locked in’ in a sub-optimal Nash equilibrium. A differential equation selection model of this kind is characterised by *multiple equilibria* with the dominance of