PAPERS on Economics & Evolution

MAX-PLANCK-GESELLSCHAFT

0902

Evolutionary Policy

by

Jeroen C.J.M. van den Bergh
Giorgos Kallis

The *Papers on Economics and Evolution* are edited by the Evolutionary Economics Group, MPI Jena. For editorial correspondence, please contact: evopapers@econ.mpg.de

ISSN 1430-4716

Max Planck Institute of Economics
Evolutionary Economics Group
Kahlaische Str. 10
07745 Jena, Germany
Fax: ++49-3641-686868

Evolutionary Policy

Jeroen C.J.M. van den Bergh[1]

ICREA, Barcelona, Spain

&

Department of Economics and Economic History & Institute for Environmental Science and Technology
Autonomous University of Barcelona, Edifici Cn - Campus UAB, 08193 Bellaterra (Cerdanyola), Spain
jeroen.bergh@uab.es

and

Giorgos Kallis

ICREA, Barcelona, Spain

&

Institute for Environmental Science and Technology, Autonomous University of Barcelona,
Edifici Cn - Campus UAB, 08193 Bellaterra (Cerdanyola), Spain
giorgoskallis@gmail.com

May 2009

Abstract

We explore the idea of public policy from the perspective of evolutionary thinking. This involves paying attention to concepts like diversity, population, selection, innovation, coevolution, group selection, path-dependence and lock-in. We critically discuss the notion of evolutionary progress. The relevance of evolutionary dynamics is illustrated for policy and political change, technical change, sustainability transitions and regulation of consumer behaviour. A lack of attention for the development of evolutionary policy criteria and goals is identified and alternative choices are critically evaluated. Finally, evolutionary policy advice is compared with policy advice coming from neoclassical economics, public choice theory and theories of resilience and adaptive management. We argue that evolutionary thinking offers a distinct and useful perspective on public policy design and change.

Keywords: Adaptive management, coevolution, escaping lock-in, evolutionary politics, evolutionary progress, innovation policy, optimal diversity, resilience, social-technical transition.

[1] Also affiliated with the Faculty of Economics and Business Administration, and the Institute for Environmental Studies, Free University, Amsterdam, The Netherlands. Fellow of NAKE and Tinbergen Institute.

1. Introduction

Advice on public policy is dominated by rational choice theories. This is clearly illustrated for the cases of environmental and climate policy making, which are predominantly informed by studies applying neoclassical-economic models and insights (e.g., Baumol and Oates, 1988; Peters et al., 1999; Sterner, 2003). Evolutionary thinking, a new set of theories and models that differs from rational choice theories in a number of ways, can offer refreshing insights about public policy making. It emphasizes populations of heterogeneous agents, bounded rationality and learning, innovation, path-dependency and multiple equilibria, thus offering a vocabulary suitable to engage with topical issues like responding to the financial crisis, adapting to climate change, and stimulating energy system transitions. Although the term "evolution" appears regularly in titles of articles in journals on innovation research, the large majority of them mean to denote simply change over time, development or a historical time pattern. Evolutionary economics has generated many studies and insights in the last decades that apply more consistently evolutionary dynamics to social systems. Even so, it lacks a firm, coherent perspective on policy in a broad sense. A recent article gives attention to evolution and innovation policy (Nill and Kemp, 2009), but similarly does not offer a comprehensive perspective on evolutionary policy. The current paper has the dual aim of collecting core insights from evolutionary policy thinking to arrive at a more complete view on evolutionary policy, and of demonstrating its relevance to policy-making and policy change.

The distinctive approach of evolutionary thinking can be characterized in various ways, namely as the interaction of innovation and selection, as changing populations of heterogeneous agents, as the impact of social-economic distribution on social-technical dynamics, and as economic agents adapting through innovation and imitation to changing external conditions. Evolutionary processes are characterized by five features: (i) a population with internal diversity of strategies or technologies, (ii) agents showing bounded rationality, (iii) selection, (iv) some form of inheritance or retention; and (v) innovation.

As we will see later, evolution can be invoked in different ways to clarify policy. First, economic (non-genetic) evolutionary mechanisms, covering market, technological, institutional and organizational aspects, are relevant to virtually all themes within public policy where heterogeneity and dynamics go hand in hand. This is the main motivation for the neo-Schumpeterian approach to evolutionary economics (Nelson and Winter, 1982; Dosi et al., 1989). In addition, there is a considerable literature on human sociobiology and evolutionary psychology which emphasizes human behaviour as genetically evolved in our distant past, implying certain features and biases which policy makers might want to take into account (Penn, 2003; van den Bergh and Stagl, 2003; Manner and Gowdy, 2009). This includes applications of evolutionary game theory which try to address questions regarding social aspects of human behaviour, including altruism and cooperation (Axelrod, 1986; Binmore, 2005; Nowak, 2006). Finally, in the realm of environmental policy analysis biological evolution might be relevant. For example, Munro (1997) studies net present value maximisation of agricultural crop cultivation when pesticide use causes selective pressure on the genetic composition of a pest population. Noailly (2008) extends his model by adding a population of agents with heterogeneous strategies, leading to biological-economic coevolution.

The remainder of the paper is organized as follows. Section 2 elaborates the distinctive attributes of evolutionary socio-economic dynamics to arrive at a precise conceptualization of evolution, which is distinctive from more loose uses of the notion as mentioned above. Section 3 discusses the complex relationship between evolution and progress. This is a necessary prelude to the applications that follow, since misunderstandings of the relationship between evolution and progress have long hampered the use of evolution in social sciences and public policy. Section 4 examines how evolution sheds light on the dynamics of policy change and related politics, i.e. it deals with change at the level of institutions. This allows for an understanding of the opportunities for, and barriers to, designing public policies. Section 5 moves to a lower level and illustrates the implications of evolutionary thinking for policy design in three broad areas, namely technological change, sustainability transitions, and regulation of consumer behaviour. Section 6 addresses the problem that evolutionary analysts often avoid to make explicit, well-motivated choices concerning the normative foundations of their analyses. In turn it discusses critically alternative entry points for developing evolutionary policy criteria and goals. Section 7 compares evolutionary theory with three other, influential approaches to policy analysis, namely neoclassical economics, public choice theory and resilience or adaptive management. Section 8 concludes.

2. Evolutionary dynamics

Evolution refers to any process of system change that involves the selective retention of renewable diversity (Campbell, 1969). Diversity, its renewal (i.e. innovation), its selection and retention are the building blocks of evolutionary explanations of cumulative complexity and improved adaptation of systems to their environment (Nelson, 1995).

Evolution, either genetic or non-genetic involves a number of complementary core elements and processes. The most central assumption is a population of agents, strategies, products, technologies, organization or institutions, which interact and are subject to the same selection environment. The members or elements of the population are characterized by diversity, which Stirling (2007) has decomposed into variety, balance and disparity. Here, variety denotes the number of different elements in the population, balance relates to the (frequency) distribution of the distinct elements, and disparity (or dissimilarity) captures the degree of difference or distance between elements in a population. Diversity is changed by selection and innovation processes. The first includes all processes that reduce existing diversity, while the second is the total of processes that generate new diversity.

The selection environment generally involves physical, physiological and geographical constraints, and in economic systems also technological, organizational, market, institutional and regulatory factors. Selection should not be simplified as ‘survival of the fittest’, but rather as the survival of the sufficiently adapted unit in a changing selection environment.

Knowledge and systematic search are crucial for innovation. Evolutionary theory makes a distinction between mutations and cross-over or recombination as sources of innovation. Our feeling is that in the social realm innovations always result from some combination of existing ideas or technologies. Innovation is gradual or radical, and often if not always caused by serendipity: combining insight, foresight and expertise with chance (Fine and Deegan, 1996).

Systematic search (R&D, science) is a method to increase the chance of useful innovative combinations.

Next, for the previous factors not to result in erratic, unsustainable outcomes, inheritance (retention, transmission) is needed, which represents replication processes involving reproduction (dominant way in biological systems) or copying/imitation (important, though not only mechanism, in social systems). Selection, innovation and inheritance together cause evolution to be associated with a degree of durability and cumulativeness.

Evolution typically is not associated with rational agents (members of the population) but consistent with bounded rationality (Nelson and Winter, 1982): individuals and organizations (groups) have imperfect information, learn, behave according to adapted or selected habits and routines, imitate others, and are myopic (in time and space), that is, search locally for improvements. In this sense, evolutionary thinking is perfectly compatible with recent developments in behavioral economics and psychology (Kahneman and Tversky, 2000; Camerer et al., 2004), adding to those a dimension of population and diversity dynamics.

This basic evolutionary system gives rise to an interaction between an equilibrium force, namely selection, and a disequilibrating force, namely innovation. A non-equilibrium dynamic path of change generally results, due to the nonlinear nature of the complex evolutionary system, multiple attractors, indicating that the system is attracted to equilibria but usually out of equilibrium. Repeated selection typically reduces diversity, causing the population and individuals in it to become better adapted to the selection environment, and their fitness in terms of reproductive potential increases. If repeated selection goes along with increasing returns to scale – e.g., economies of scale in production, learning-by-doing, demand side network effects, and information externalities – then the system is path-dependent, which may mean lost capacity to adapt (a historical constraint). An evolutionary interpretation of this is that a system has so much diversity that it is highly unlikely that it will revisit a previous state, implying extreme sensitivity to initial events and a possibility of the system ending up in a lock-in of an arbitrary, not necessarily socially optimal technology or institution (Arthur, 1989). In brief, it means the system is characterized by history. This entails an essential difference with other, more mechanistic theories of dynamic systems, which at best refer to simpler notions of irreversibility.

The foregoing description represents the core model of evolution. It should be immediately noted that both genetic and non-genetic evolution are immensely more complex. Four important factors and mechanisms need to be mentioned, as they will turn out to be essential for a good understanding of technical and social-economic evolution. First, coevolution means that evolution involves multiple populations each evolving, but in interaction. In particular, part of the selection environment is made up of other biological population, causing the selection force to be variable and even endogenous if there is mutual selection feedback. This can lead to fast evolution as well as extreme features (red queen effect, arms race) (Ridley, 1995). Another interpretation of this is that coevolution means system dynamics involving codynamics between subsystems and evolutionary population dynamics (within subsystems). In other words, coevolution is fundamentally different from traditional codynamics of mechanistic subsystems that lack internal (dynamic) diversity (van den Bergh and Stagl, 2003; Winder et al., 2005). The concept of “niche construction” is related to coevolution. It conveys that populations of agents actively transform their environments, intentionally or accidentally, and in the process change theirs and other agents’ selection environment (Laland et al., 1999). This makes evolution more complex and less predictable, as has been illustrated in mathematical models (Noailly, 2008).

Second, the notion of (spatial or ecological) isolation is very important in biology to explain speciation, i.e. a kind of radical innovation at a high scale. Similarly, in a social-economic setting geographical and institutional isolation may be useful for fostering radical innovations as it creates technological or institutional niches that are protected against the dominant regime.

Third, the notion of modular innovation is an important explanation of the dynamics, speed and complexity of evolution and evolutionary systems. It denotes that pre-adapted or pre-selected complex units are combined resulting in ever more complex units. This can involve a combination of previously separated functions (mobile phone combining camera, internet, music, etc) or the generation of an entirely new function (windmill=watermill technology + sail). Modular evolution has been shown to be an important force or search mechanism of both biological (Maynard Smith and Szathmáry, 1995) and technological (Mokyr, 1990) evolution, since it is the most important source of radical innovations, as illustrated by evolutionary computation (Watson, 2006). The latter is consistent with Potts (2000) view that economic and technological systems are complex “hyperstructures”, i.e. nested sets of connections among components. Economic change and growth of knowledge are in essence a process of changes in connections. New technologies, products, firms, sectors, and spatial structures arise that are more roundabout and complex than the old ones. Firm and economic growth are a process of creation of more complex organization, or new connections, as well as the grouping of those connections. The emergence of more complexity in both biological and human-economic systems has gone along with increased specialization of individuals, units or components, more cooperation and more complexity in communication/interaction between components of systems (at any level).

Finally, the notion of group selection may be important to a complete evolutionary mapping of social-economic systems. It means that evolution not only operates at the level of individuals but also involves interactions within and among groups – group formation, splitting, competition, conflict, take-over, merger, group norms and cultures. This results then in multilevel, namely group plus individual, selection. These two selection processes can point in the same (reinforcement) or opposite direction (countervailing forces). The latter has been well illustrated for the analysis of altruism and cooperation (Traulsen and Nowak, 2006). Genetic group selection has been debated for a long time, but is receiving more support now (Wilson and Wilson, 2007), cultural group selection has been less controversial (van den Bergh and Gowdy, 2009). The reason is that group selection matches well the mounting evidence for humans possessing a large capacity for other-regarding behaviour, sophisticated communication, cultural transmission and social organization (Henrich, 2004). Group selection can be seen to open the old sociobiology debate in various directions, namely multilevel and dual inheritance (genetic and cultural; Boyd and Richerson, 1985). Morover, group selection presents unique and refreshing opportunities to address issues of power and vested interests (Safarzynska and van den Bergh, 2009).

Table 1 summarizes the identified elements or components of evolutionary thinking and also lists a number of important general consequences for each element. This should make clear that evolution is far from a simple framework, and one that is well capable of explaining complexity and change in reality. Arguably, there is no serious competitive framework for addressing dynamic complexity in biological and social systems. This makes evolutionary thinking an exciting and relevant approach to address pressing policy problems at a global scale since here both biological and social complexity reach their pinnacle.

[INSERT TABLE 1 HERE]

Finally, it is perhaps good to say that we are not claiming a biological evolutionary analogy for the social sciences, but rather arguing for a generalized evolutionary approach, as formalized in evolutionary computation and modelling (Eiben and Smith, 2003; Nowak, 2006). A similar perspective emanates from a recent proposal for a "generalized or universal Darwinism" in economics (Hodgson and Knudsen, 2006).[2] In fact, it is well recognized that biological and economic evolution have a number of important differences (see Hodgson, 1993; van den Bergh and Gowdy, 2000). For instance, the genotype-phenotype distinction is not so sharp in social contexts. Where transmission of (genetic) information occurs mainly vertically (parent-offspring) in biological systems, horizon (peers) and oblique (teacher-pupil) transmission is common in social settings. Social-economic evolution generally occurs at a faster pace than biological evolution. Extinction or selection is never so absolute in economics, as ideas can be easily preserved. While gene flow (or transfer of related adaptations) is virtually impossible between biological species, in social-cultural contexts information and ideas can easily be

[2] This algorithmic view is not necessarily inconsistent with a historical view (the "Continuity Thesis") according to which economic evolution is based on conditions that are themselves the outcomes of prior (biological and cultural) evolutionary processes. Nevertheless, a tension between this view and the generalized Darwinism perspective has been suggested (Cordes, 2006).

transferred from one sector or technology to another. Finally, the dynamics of social-economic systems is not only driven by evolutionary mechanisms but also by (imperfect) individual learning, foresight, and (imperfect) planning, at both individual and public levels. Finally, the distinction between genetic change and learning in biological systems is quite sharp, while this is not the case for social-economic systems.

Evolutionary thinking has already been successfully integrated in a number of fields within the social and behavioral sciences. In economics, two approaches are evolutionary theories of technical change (Nelson and Winter, 1982; Dosi et al., 1988; Teubal, 1997; Metcalfe, 1998, Constant II, 2002) and evolutionary game theory (e.g., Friedman, 1998). Evolutionary economics is very much the legacy of Joseph Schumpeter, who first coined the notions of the innovative “entrepreneur” and “creative destruction”. The most influential and cited work since the 1950s has been that of Nelson and Winter (1982), who developed economic evolution around three building blocks, namely organization routines (a complex set of skilled individuals and interactions between them), search behavior and selection environment. Outside economics, the main progress on evolutionary thinking has probably been in anthropology (Boyd and Richerson, 2005) and evolutionary psychology (Buss, 2005).

Evolutionary thinking has also been important in explaining how organizations change over time (McKelvey, 1982; Baum and Singh, 1994a; Aldrich, 1999). Selection acts upon entire organizations (e.g., Hannan and Freeman, 1989) or intra-organizational attributes, such as bundles of routines (Nelson and Winter, 1982), competency units (McKelvey, 1982) or managerial actions (Miner, 1994). Selection of intra-organizational attributes takes place both within the firm and between firms. Variations that are more helpful for the firm in acquiring resources or legitimacy propagate as more firms adapt them, or as the firms that have them grow. Selection forces include competitive market pressures, internal restructuring logics, power relations or conformity to institutionalized norms (Aldrich, 1999). Over time, the features of a population of organizations (e.g. form of organizations, style of management) tend to become isomorphic to the selection environment. But organizational populations also coevolve with their selection environment, as they – intentionally or indirectly - transform it (Baum and Singh, 1994b; Lewin and Volberda, 1999).

Finally, ideas from evolutionary economics have made headways to environmental studies (Norgaard, 1994; Gowdy, 1994; Rammel and van den Bergh, 2003; van den Bergh, 1997). Norgaard and Gowdy were the first to suggest that economy and ecosystems should be seen as two co-evolving systems. In a rare application of a formal model of coevolution, Noailly (2008) examines the interaction of a diversity of pesticide use strategies in a farmer population and diversity of resistance within the pest population, leading to biological-economic coevolution. Kallis (2009) represents change in urban water management as being the result of an interaction between an evolving population of households (with a variety of consumption practices) and an evolving policy system of competing ideas.

3. Evolution and progress

The use of evolution in public policy has been impeded by past misuse of the concept. Social Darwinists equalized progress with survival of the fittest in the social sphere, suggesting that the dominant gender, races, or nations are somehow evolutionary more advanced than subordinate ones. Evolution in some cases has been invoked also to justify *a priori* the status quo, in the sense that if 'what is' has somehow evolved, therefore it should not be changed. At its extreme, this might be taken as an argument against deliberative interference with social policy and institutions. But such uses confound a positive description of evolution with a normative statement that it is for the better. 'What is' does not equal 'what ought to be'.

The relationship between evolution and progress merits some further consideration. In fact, it has received a great deal of attention in biology (see the articles in Nitecki, 1988). According to Maynard Smith and Szathmáry (1995, p4), "the notion of progress has a bad name among evolutionary biologists." They suggest that the history of life is better depicted as a branching tree rather than progress on a linear scale.[3] Many species have changed little over the

[3] Nevertheless, certain authors, notably Conway Morris (2003) and Dawkins (1997), maintain that the broad strokes of evolution are almost inevitable, including the emergence of intelligent organisms such as

course of hundreds of millions of years. There are several reasons why both genetic and non-genetic evolution do not necessarily give rise to progress:

1. The most important reason is that selection is a local search process, which leads at best to a local optimum (not "survival of the fittest", as first coined by Herbert Spencer, but survival of the fitter or relatively fit).
2. Adaptations are often compromises between different objectives, being stimulated by a multitude of selection forces. This suggests that evolution is better regarded as multi-criteria evaluation than as single-objective optimization.
3. Organisms or technologies are locked into historical constraints. In biology, this has been referred to as "bauplan limits" or "development constraint" (Gould and Lewontin, 1979) or phylogenetic inertia (Wilson, 1975, p20). In economics, it is treated under the headings of increasing returns to scale, path-dependence and lock-in (Arthur, 1989). In organization theory, it has been called "structural inertia" and "imprinting" (Hannan and Freeman, 1989, p70 and p205, respectively).
4. Not all evolution is adaptive microevolution: randomness, genetic (molecular) drift, coincidental founder effects, etc. play an important role. In addition, macroevolution creates boundary conditions for adaptation and may destroy outcomes of microevolution, in a way as to set back time ('initialize').
5. Selection can only 'capture' variations that exist. The process of creation of variation is limited and partly random.
6. Agents explore only a minor range or subset of the opportunity space, which is reflected by the notion of bounded rationality.
7. Coevolution and niche construction mean that the environment is not constant and exogenous to the individual species' evolution, but influenced by it. Coevolution means adaptation to an adaptive environment. All straightforward notions of static or dynamic

---

humans. This can be called 'convergence': "… what is possible has usually been arrived at multiple times, meaning that the emergence of the various biological properties is effectively inevitable." (Conway Morris, 2003, preface). He adds the provision that, partly due to limited evolutionary time, the number of evolutionary end points (possible biological structures) is limited.

> optimization are lost, since the boundary conditions in a constrained optimization formulation of evolution are not even known then. Coevolution also has historical, path-dependent features. It can be cast in the adaptive landscape metaphor (Kauffman, 1993), in which case the landscape becomes something like a "… choppy sea rather than something forged in granite. In which case there would be no real progress, for as soon as one climbed a peak it would collapse beneath one." (Ruse, 1999, p118).

Sen (1993) further notes that evolution as improving species does not imply improving the welfare or quality-of-life of each individual. Fitness is not a useful criterion for progress in general, even though the evolution of a species into one that is more efficient in food gathering, moves faster (running, swimming, flying), or is more effective in performing certain functions, can usually be regarded in terms of fitness increase. The reason is simply that a higher fitness and survival do not necessarily imply a happier or more pleasant life. In fact, evolutionary models often show that inequality arises again and again in evolutionary systems, suggesting that structurally at least part of a population is relatively unhappy (e.g., Epstein and Axtell, 1996). This itself has immediate policy implications, namely that one has to be aware of, and possibly continuously counter, tendencies of inequality arising in systems characterized by evolutionary forces. In general then, it is difficult to say under which conditions evolution leads to economic progress, also because the latter is not an evident phenomenon. In fact, there is a longstanding debate in the social sciences about suitable indicators of social welfare and progress, while it is accepted that all available indicators suffer from shortcomings (van den Bergh, 2009).

With regard to the theme of happiness and well-being, evolutionary thinking leads to a perspective that is similar to that of behavioural economics and social and psychology, where bounded rationality, social interactions, status seeking, and basic versus higher needs are emphasized. At the level of psychology, the distinction between basic and higher needs (the good old Maslow's pyramid, also known as lexicographic preferences) is relevant. Once basic needs are satisfied, one is in the realm of the higher needs. With regard to the latter, individual income and consumption cannot be seen separately from other individuals in a relevant social environment (‘peer group’). The notion of relative or context-dependent well-being has been proposed to address this (Tversky and Simonson, 2000). This notion is characterised by a comparison and rivalry with others. This explains the striving for “conspicuous consumption” (Veblen, 1899), “positional goods” (Hirsch, 1976) and “status goods” (Howarth and Brekke, 2003). Evolutionary biology has shown that sexual selection has fixed status-seeking or extravagant, differentiating behaviour in our genes (psychologists call it an ‘automatic’ behaviour). However, conspicuous consumption and the quest for the acquisition of material and scarce social goods as a way to differentiate oneself and climb up the status hierarchy have become a very serious social problem. They relate to large-scale environmental impacts, as a result of unprecedented large numbers of consumers, high living standards and polluting production techniques. Recognizing that – at least part – of such social behaviours has an evolutionary origin is not equivalent to legitimating them (Jackson, 2005). First, selfish, status-seeking or acquisition instincts coexist with, also evolutionary adapted, other-regarding, altruistic instincts and resultant social behaviours of sharing or voluntary restraint. Second, the social expression of instincts is not pre-determined: whereas rivalry consumption and status-seeking differentiation behaviours do show up in different times and human cultures (Buss, 1989), there is also a huge difference between patterns of material consumption, expressions of status and resultant social organizations across cultures and time. The implication is that there is scope: (i) for sophisticated policies that can mould the social environment in ways that will favour certain instincts while suppressing others, and (ii) for social arrangements that will encourage alternative, non-socially destructive, signifiers of difference and status (Jackson, 2005).

Relative welfare and rivalry consumption are closely related to (endogenous) changes in preferences. Many of these are formed or at least influenced by media, steered by commercial, private (business) interests. The rivalry feelings are greatly misused for this purpose, in the direction of both adults and children. Income rises usually go along with new products and changes in preferences. No one, however, guarantees that the creation of new preferences contributes to happier lives. Therefore, the rivalry has been negatively characterized as reflecting a "rat race" and "affluenza virus". It resembles the "Red Queen hypothesis" in evolutionary theory: repeated selection for fitness so as not to be taken over by others (Strickberger, 1996, p511). The phenomenon of relative welfare and rivalry in consumption means that a rise in relative income can increase the well-being of a particular individual, while being neutral or negative for social welfare. The reason is simple: improvements in relative income and welfare come down to a zero-sum game – one person loses what another gains (Layard, 2005).

Concluding, evolution has some elements of directionality and progress. Nevertheless, evolution certainly is not identical with continuous progress. Furthermore, much of what is presented as progress by cultural or technological optimists often possesses mixed blessings.

4. Evolution, politics and policy change

We start with the implications of evolution for the higher, institutional level of change. The simple question here is: how do policies change? Evolutionary theory offers important insights about the dynamic mechanisms underlying policy change. This involves drawing attention to bounded rationality of agents involved in the policy process (Witt, 2003), diversity of policy ideas and selection in a multi-dimensional environment (Kerr, 2002) and path-dependence of policies (Pierson, 2000a). Evolutionary theory introduces the key notions of time and sequence (Mahoney, 2000) and historicizes policy change in comparison to static, comparative equilibrium explanations (Pierson, 2000a).

Because of bounded rationality, political actors are heavily selective in their learning and the way they filter information. Perceptions and hence attention are affected by preferences in a recursive manner that binds together similar-minded political actors into social networks and communities with highly intensive internal communication but relatively insulated from external influence (Witt, 2003). Policy ideas (shared understandings of explanations of problems or specific solutions) and discourses (concepts and categorizations that give meaning to physical and social realities) are important vehicles for simplifying complex information and constructing mental maps that bring together individual actors into communities (e.g. “discourse communities”, Hajer, 1995). Only a few policy problems can garner sufficient public and policy attention (Witt, 2003) This produces an uneven temporality of policy evolution as the early agenda-setting stage becomes critical for subsequent outcomes and heavily attended by political actors. Indeed, political scientists have invoked an analogy to the idea of “punctuated evolution” – controversial in biology – , which denotes periodic phases in policy change where the pace and extent of transformation is significantly accelerated (Hay, 1999; Baumgartner, 2006). Policy activity for some environmental problems exhibits an S-shaped curve of phases of intense activity followed by stability as indicated by public budget spending, media coverage or parliament activity (Baumgartner, 2006). The notion of “crisis” (Hay, 1999) is central in explaining these intense accelerated searches for policy solutions.

At the heart of theories of policy evolution is the notion that political and economic environments impose selective pressures upon alternative political strategies and that political actors, through processes of trial, error and learning, continuously adapt their strategies to this selection environment (Kerr, 2002; Ward, 2003). Of course, since this environment is changing and evolutionary as well, consisting of populations of producers and consumers and other stakeholders, the notion of coevolution may be relevant as well. At any given moment, there are competing ideas and solutions to policy problems, which replicate through imitation and survive through competition in political arenas (John, 1999; Kingdon, 1995). Political actors have multi-dimensional motives and interests which assume meaning by being expressed in specific ideas. Actors struggle in the policy arenas to see their ideas chosen and implemented. The constraining selection environment is multi-dimensional (media, elections, public opinions, power), context-specific and changing over time (John 1999; Kerr, 2002). Hay (1999) inspired by Kuhn, introduces the importance of “policy paradigms”, perceived as packages of affiliated ideas and responses (e.g. Keynesianism or free-market environmentalism), which act as higher-level filters that limit the range of legitimate understandings and responses to problems, and thus selectively constrain lower-level responses, channelling policy change into limited paths (see also Kerr, 2002).

Increasing returns and path-dependence are prominent in political environments. Individual and organizations' investments in specialized skills, relationships and political identities are influenced by existing political arrangements and in turn make them preferable to hypothetical alternatives (Pierson, 2000a). The high-start up and exit costs that characterize collective action and the development of institutions, as well the positive feedbacks involved in the social interpretation of information and the attraction of a critical mass of communicators also create path dependency (Pierson, 2000a, Witt, 2003). The employment of power is also self-reinforcing. Once an institution develops, it empowers certain groups at the expense of others, which in turn further change the institution to favour their interests (Mahoney, 2000). Path-dependence may be more pronounced in political than economic systems, despite the fact that markets are characterized by many increasing returns on demand and supply sides (see Section 2) (Pierson, 2000a). Understanding policy evolution as a path-dependent process shifts the emphasis in analysis to earlier, historical events, which by design or accident may have locked-in institutional development to a certain path. The sequence in which events happen becomes important, which is typical for path-dependence of course (Mahoney, 2000; Thelen, 2000).

Understanding the dynamics of the policy process has implications for (desirable) institutional interventions. For instance, the insights of public choice theory concerning the opportunistic behaviour of policy-makers and vested interests have been used to support institutional changes that limit state intervention in the economy or involve privatization of state competencies. In section 7, we will examine implications for policy design of evolutionary understandings of policymaking dynamics, by comparing evolutionary policy and public choice theories.

5. Evolution and policy design in three selected areas

The studies reviewed in this section operate at the conceptually lower level of policy design, and are typically oblivious of the higher level context discussed in the previous section. The understanding of policy as an evolutionary process complicates paradigmatic assumptions of policy design studies, such as the presence of benign decision-makers and external analysts. We return to these complications in section 7. Here we review key insights from evolutionary economics in three areas of policy design: innovation and technology policy; transition policy; and sustainable consumption policy. This is just illustrative.

Innovation and technology policy from an evolutionary angle

Evolutionary thinking has been most fruitfully applied in the study of technological innovation. In fact, there is not a very sharp dividing line between innovation studies and evolutionary economics. Many analyses of innovation make implicit use of evolutionary notions like selection, diversity and mutation, while a large part of neo-Schumpeterian, evolutionary economics deals with technological change (Dosi et al., 1988; Witt, 1993; Metcalfe, 1998). Studies in this vein address the analysis of processes at the company level (technological innovation), market and sector level (competition and diffusion, structural change) and macro level (growth, long waves and international trade). A minority of studies on technological innovation employ evolutionary concepts and theories in a strict manner. For example, the often applied notion of “innovation system” (Lundvall, 1988; Nelson, 1992) bears no specific relation to evolutionary concepts, even though one could combine the two. As noted in Section 1, even though the term “evolution” appears regularly in titles of articles in this journal, the large majority of them just mean to denote unspecified “change”, “development” or a “historical time pattern”.

The evolutionary perspective stresses bounded rationality in the invention, innovation and diffusion phases, the evolution of technology through local interactions, innovation through recombination, and heterogeneity of innovators. Metcalfe (1994) argues that at the core of the evolutionary-economic approach to technological innovation is asymmetry of knowledge and information due to heterogeneity of firms (potential innovators). Nannen and van den Bergh (2009) translate this into policy recommendations like “prizes” and “advertisement” to stimulate the social network of interactions and useful imitation behaviour. Given lack of knowledge or uncertainty about the distribution and dynamics of this information, policy makers cannot optimize technical change from a social welfare perspective. Instead, the two main strategies open to them are moulding the selection environment to direct selection processes rather than select themselves the optimal technology or technological path, and to create favourable conditions for innovation, using notions like innovation systems and niche management.

Niche management is one evolutionary strategy to foster innovations which has attracted some attention (Kemp et al., 1998). It involves processes of social experimenting and learning, the creation and exploitation of technological niches, increasing variety by niche branching, and assuring stabilization through implementing rules and accepted practices. Policy can try to guide this process, by stimulating diversity, extending the network of actors and stakeholders involved, and by destabilizing the dominant socio-technical regime. Niche markets can be created, for example, through subsidies to consumers or producers. They can accelerate the learning curve and benefits of economy of scale. From an evolutionary perspective, stimulation of niches is a specific case of a general condition that stimulates major innovations, namely isolation. Regional or local (urban) experimentation, like allowing for decentralized energy/electricity provision, is a specific approach to niche management (van den Bergh et al., 2006, 2007).

Technological diversity increases through innovation. This is not a blind, random process, as humans act in intentional, forward-looking ways. The notion of serendipity is relevant here, as it reflects that discoveries or inventions result from a combination of chance, intelligence and knowledge/expertise (Fine and Deegan, 1996). Expertise, lateral thinking and multidisciplinary cooperation are important as innovation often (if not always) takes the route of recombinant or modular innovation, thriving on existing diversity. Choices regarding diversity usually remain implicit, and when made explicit, often involve a conflict between efficiency and diversity aims based on the idea that efficiency relates positively and diversity negatively to increasing returns to scale in markets. An optimal balance between increasing returns to scale (short term benefits of little diversity) and recombinant innovation (long term benefits of much diversity) is needed to arrive at knowledge about how much diversity is desirable (van den Bergh, 2008), taking into account the different components of diversity as discussed in Section

2, i.e. variety, balance and disparity. The government can stimulate a wide range of technologies in terms of variety, disparity and balance, the development of modular technologies which allow many innovative combinations, and information exchange to increase the likelihood of cross-fertilisation and modular innovations. Policy might further stimulate radical innovations by raising the disparity between technological options, notably by directing public R&D at 'deviant' technologies and by funding risky R&D.

Other typical evolutionary perspectives on technological and related economic change involve concepts like growth based on a growing population of firms each increasing in size or capital (Nelson and Winter, 1982), and path-dependence, which may result in a lock-in situation, due to changes in diversity and related positive feedback (Arthur, 1989). The policy relevance of the latter will be discussed next in more detail.

Unlocking and policy for social-technical transitions to sustainability

The problem of lock-in mentioned in Section 2 is an important reason for current discussions about transition policy with an eye to environmentally sustainability (Elzen et al., 2004). This has been conceptualized as a (co-)evolutionary processes operating at multiple levels (Geels, 2002). From an evolutionary angle, the path-dependent trajectory to a state of lock-in involves systematic loss of diversity. Destabilizing the dominant regime and maintaining or enhancing diversity are key to escaping a state of lock-in. The environmentally most significant examples of lock-in are the dependence of electricity generation and modern transport systems on fossil fuels and fuel combustion engines. Relevant questions are how regime shifts occur, how they can be stimulated, and how a new lock-in of a socially undesired technology can be avoided.

Un-locking generally cannot be realized by simply 'correcting prices' for environmental externalities, but requires dealing with increasing returns on demand and supply sides. This has been referred to as an extended level playing field where alternative technologies, organizations and institutions are able to compete with the dominant social-technological regime (van den Bergh et al., 2006, 2007). It requires a combination of environmental policies (externality regulating), innovation policy and unlocking shocks. Examples of the latter are setting a stringent long run policy goal (such as 'zero emissions' in California) to meet the requirement of reducing policy uncertainty, stimulating pathway and complementary technologies (e.g., electric batteries, fuel cells), and stimulating diversity and adaptive flexibility to increase evolutionary potential (Rammel and van den Bergh, 2003). Unruh (2002, p.323) proposes "a countervailing critical mass or social consensus for policy action" through education of the general public. He suggests that providing information on extreme climate events ('disasters') may create critical support for strict climate policies and changes in current institutions.

Stimulating unlocking requires in addition that all explicit and implicit stimuli of the dominant technology are removed (subsidies, knowledge, experience), and that preferential treatment (e.g., in public choices and purchases) be given to desirable alternatives. This is difficult, not only because humans are habitual and learn slowly, but also because of vested interests which are usually well-organized or powerful, and create create political resistance against necessary changes. In addition, both private and public agents tend to look for short-term gains and cost-effectiveness, which frustrates promising technologies which are still low on the learning curve. Nill and Kemp (2009) mention time strategies as suitable for escaping a situation of lock-in. This means that innovation policy varies over time on the basis of diagnosed time-varying states, which may be characterized by little, very little or no diversity (Sartorius and Zundel, 2005). In addition, various authors focus on niche-creation as a strategy to foster a transition (Schot and Geels, 2007).

Regulation of consumer behaviour

Regulation of consumers is relevant for environmental, public health (e.g., contagious diseases, smoking, drinking) and safety (insurance, traffic) reasons. Traditional theories of regulation depend very much on representative agent models. Evolutionary approaches combine various aspects of bounded rationality with populations of interacting and heterogeneous agents. Bounded rationality involves social interactions like imitation, reputation and status seeking (relative income effects), and habitual behaviour, decisions under uncertainty and myopia. Evolutionary thought can help here in assessing effective as well as efficient policies, or even suggest new instruments (next to standards, taxes and subsidies), such as prizes and specific tools of information provision (Nannen and van den Bergh, 2009).

Penn (2003) argues that from an evolutionary angle individual incentives are the most effective way of environmental policy. This seems to be consistent with the main policy message of environmental economics (Baumol and Oates, 1988), but Penn adds the provision that these incentives go beyond narrow economic, monetary interests. They should, for instance, also take social interactions (e.g., reputation effects) into account. This is consistent with findings of economic psychology and experimental economics, as well as of group selection theory (Section 2). Group phenomena can be linked to a variety of social – non-selfish or other-regarding – preferences: reciprocal fairness, inequity aversion, pure altruism, altruistic punishment and spite or envy (Fehr and Fischbacher, 2002).

Against this background, Hausfather (2006) considers the well-known Coase theorem (Coase, 1960), which states that, in the presence of pollution, a socially optimal outcome may result through bargaining between polluter and victim, regardless of initial property rights (in the absence of transaction costs). He argues that this result may fail to occur when fairness norms and legal property rights are incongruent, since then altruistic punishment is likely. Kahneman et al. (1990), relating psychological property rights (equivalent with fairness norms) to endowment effects, show that the latter can explain why the willingness to accept the loss of environmental goods and services will be considerably higher than the willingness to pay for them. They also conclude that Coasian bargains are less likely when fairness norms and legal property rights are inconsistent. In view of this, it is not surprising that persistent conflicts rather than swift bargains are a common response to environmental externality problems (Martinez-Alier, 2005).

Consumers cannot be seen in isolation from producers, investors and innovators on the supply side of markets. In order to understand the impact of direct regulation of consumers, one may want to take into account evolutionary processes and heterogeneity on both sides of markets. There is a small literature of resulting models of coevolving consumers and producers. One policy-relevant insight is that status-seeking can be exploited by policy makers to stimulate the emergence of product niches that can counter lock-in or dominant regimes. On the other hand, imitation behaviour tends to reinforce tendencies of lock-in. Different sub-groups showing different types of average social strategies, including poor versus rich with different peer groups for income or welfare comparison, may require specific policy strategies. In other words, the diversity of consumers translates into diversity of policies (Janssen and Jager, 2002; Windrum and Birchenhall, 2005; Safarzynska and van den Bergh, 2007).

Finally, as already discussed in section 3, evolutionary analysis allows for a better understanding of consumers as it emphasizes interactions between consumers in populations. In particular, the notions of relative income, conspicuous consumption, positional goods and rivalry for status as a zero-sum game are relevant here, and imply a very different perspective than traditional, mainstream views of consumers. This has obvious implications for welfare-improving policy, including concrete suggestions like taxation of conspicuous consumption and regulation of commercial advertising.

6. The search for normative foundations: policy criteria and goals from an evolutionary perspective

In many of the evolutionary analyses reviewed in the previous section, there is an implicit normative assumption that the maintenance of evolution itself is a desirable state of affairs (Witt, 2003). For example, in evolutionary studies of technological change, technological diversity and innovativeness (generation of new variety) are appraised as desirable per se. This is hard to justify as evolutionary outcomes are not necessarily beneficial in any particular sense (Witt, 2003) and diversity or innovation may come at the expense of other social goals (Kallis, 2007). Innovation moreover does not appear without cost, but requires expensive R&D of some sort, and the additional diversity may come at a cost in terms of lost increasing returns to scale associated with specialization (van den Bergh, 2008).

An alternative normative framing that some evolutionary works have opted for is constraining themselves to a positive analysis, which illuminates alternative possible future states (Verspagen, 2009). An agnostic position is maintained with respect to the criteria and valuation schemes according to which these alternative states can be compared. CBA, multi-criteria evaluation and deliberative assessments are all in principle applicable. This is also unsatisfactory, as one implicitly always adheres to a normative position if one performs an analysis to enlighten or inform policy. A theory of ethics or a social philosophy that can fit the type of evolutionary dynamics described here is missing and there is little research in this direction (Witt, 2003). Without making a choice for the moment, we can see a number of partly consistent entry points to resolve this issue and advance evolutionary policy analysis and assessment.

First, although evolutionary processes do not assume any goal or target, normative elements can be added by policy-makers. In this sense evolutionary policy analysis allows for the same distinction between positive and normative as neoclassical-economic policy theory: the normative goals can be the same (e.g., maximum social welfare or minimum cost of regulation), but they do not have to be. Even though one may adopt the same normative principle, the positive approaches evidently differ between evolutionary and neoclassical economics, namely evolutionary processes versus market equilibrium processes, respectively. As a result, the outcomes of the confrontation of normative goal and positive model may, and are likely to, differ between the two approaches (see Section 7 for more details).

A second consideration is that evolution introduces the element of system complexity, uncertainty about the future, unpredictability and limited policy control. This could suggest two specific choices of policy goal_(1) a focus on effectiveness: better to inefficiently reach a target than efficiently miss it: or (2) a focus on risk-aversion: a precautionary principle, for example, operationalized via a “minmax regret” approach.

A third relevant consideration is that a definition of evolutionary progress can provide more explicit normative guidance. As argued in Section 3, such progress is not inevitable nor always occurring in evolutionary systems. Nevertheless, one can still aim at using policies to bring about evolutionary progress. When choosing this route, a problem is that there are different interpretations or criteria of evolutionary progress in use (e.g., Gowdy 1994, Chapter 8; Gould, 1988; Potts, 2000): increasing diversity and increasing complexity, extended division of labour, new ways of transmitting information, population growth, adaptation to the environment (Dawkins, 1982), and increasing efficiency of energy capture and transformation (Schneider and Kay, 1994). Taking several of these into account and seeing (hoping) for a degree of consistency would be a way to go forward. When different indicators sketch different pictures one can add weights or make a clear choice.

A fourth consideration is more fundamental in nature. It starts from the insight that evolution involves the assumptions of bounded rationality of individual economic agents and changing preferences. This has implication for the notion of social welfare and consumer sovereignty. Most importantly perhaps, one can argue that the famous Arrow (1950) paradox, stating that aggregation of individual preferences into social preferences is impossible if both types of preferences are to satisfy a minimum set of reasonable conditions, looses relevancy under the behavioural-evolutionary view on reality. The reason is that preferences and norms (values) reflect bounded rationality and are themselves evolving (Witt, 2003; Norton et al., 1998; Norgaard, 1994).[4] Individuals and political actors learn about, and modify, preferences based on previous actions and experienced outcomes. As a result, there can be no fixed aggregation, even if the Arrow paradox were not true. More specifically, because of changing individual preferences there can certainly not be any constant intergenerational social welfare function. Intertemporal and intergenerational comparisons are also problematic since the policy actions taken on the basis of present comparisons will influence future preferences (Norgaard, 1994; Witt, 2003).

We do not aim to settle the difficult issue of evolutionary policy criteria here. Our stance is that the first consideration is attractive, but hampered by the fourth consideration. Nevertheless, a clear distinction between normative and positive is desirable. In addition, the normative goals could be multiple, including ones independent of evolution (such as presently much discussed measures of subjective well-being or happiness) as well as ones more closely

[4] Ostrom (1990) has considered the endogenous character of norms in a common pool resource context using evolutionary thinking and later studies have employed formal evolutionary models to analyse self-organizing solutions of common dilemmas, notably relating to renewable resource use (Sethi and Somanathan, 1996; Noailly, 2006).

related to evolutionary processes, such as suggested under the second and third considerations. The resulting three types of criteria could fulfil complementary roles.

7. Evolutionary policy: differences with other approaches

Here we compare policy from an evolutionary angle with important alternative views on policy, namely neoclassical-economic policy theory (based in rational choice theory), public choice theory, and theories of resilience and adaptive management. Neoclassical economics and public choice theory weigh heavily on public policy design in areas such as economic, health and environmental policy. Resilience theory bears affinity to evolutionary theory as it also offers a policy and management framework that attempts to deal with complexity and diversity in systems – whether environmental, socioeconomic or political. We argue that evolutionary thinking offers a distinctive, and in several aspects improved, perspective on public policy and change.

Evolutionary- vs. neoclassical-economic views on policy

The traditional economic theory of public policy is the result of applying neoclassical welfare theory, which comes down to connecting a competitive equilibrium and a social welfare optimum (or, less ambitiously, Pareto efficient situation). The positive part of this approach, i.e. the competitive equilibrium supported by representative or average, rational consumers and producers, is contested by evolutionary economics, which emphasizes a population of diverse agents, bounded rationality, and as a result persistent disequilibrium, multiple attractors and path-dependence. This in general means a much less optimistic view on policy. In addition, as discussed, the normative part of neoclassical economics may be contested from an evolutionary perspective. Disputing both the normative and positive basis of neoclassical economic policy analysis means that the correspondence between market equilibrium and a social welfare optimum is lost. In turn, the two fundamental theorems of welfare economics[5] no longer hold.

[5] The first theorem states that in the absence of market failures, any (Walrasian) competitive market

As a result, planning or market solutions cannot be guaranteed to realize socially optimal outcomes.

The economic theory of environmental policy offers an approach to evaluate, compare and design of instruments of regulatory policy. This focuses attention on the efficiency (either welfare maximization or cost-minimization) such instruments (Baumol and Oates, 1988). It assumes rational producers and consumers, and markets in equilibrium and clearing. The approach neglects selection other than through market competition, innovation, changing diversity of technical options, irreversibility due to path-dependence, and diversity of policy experiments in regions and countries. Neoclassical-economic policy analysis addresses certain aspects of diversity, namely heterogeneity of abatement options and related costs of polluters, and shows that if firms are profit-maximizing or cost-minimizing total (national or sector) abatement costs will be minimized if regulation employs price-based instruments like taxes, charges or levies. The latter will make sure that marginal abatement costs will be equal among polluters, even though some polluters may pollute less, namely those with relatively expensive options, than others. This approach nevertheless assumes static heterogeneity and does not take dynamic diversity – typical of evolutionary processes – into account. Resource economics, dealing among others with renewable resources such as fisheries and forestry (Johansson and Löfgren, 1985; Clark, 1990), tends to search for optimal exploitation without taking into account evolutionary or selection effects of resource exploitation. Neither does mainstream resource economics give much attention to the evolution of norms, for example, through local interaction of resource users. Finally, economic growth theory does not take the heterogeneity of firms and technologies into account as is the case in evolutionary (differential) growth theory. In addition, it does not allow for much policy detail in terms of innovations, selection environment and lock-in. Whereas evolutionary economic approaches emphasize dynamics due to innovation and selection, neoclassical economics focuses on static equilibria or dynamic

equilibrium gives rise to a socially optimal or (Pareto) efficient allocation of resources. According to the second theorem, any efficient allocation can be realized by a certain competitive equilibrium. In the case of market failures, government regulation needs to assure that market outcome and social optimum coincide (e.g., Varian, 1992).

equilibria characterized by representative or aggregate agents and dynamics due to accumulation (mainly of productive and human capital).

Closely related to policy theory is cost-benefit analysis (CBA) which is used to evaluate public investment projects. This requires the application of monetary valuation techniques, both revealed and stated preference techniques, to assess non-market effects like environmental damages and health impacts in monetary terms (Johansson, 1987). Both environmental policy and monetary valuation theories depend essentially on assumptions like rational behaviour of agents and market equilibrium. Evolutionary insights, however, underpin that individuals are boundedly rational as well as other-regarding, which may explain phenomena like 'protest bidders', 'warm glow', 'cold prickle', and 'altruism' (Andreoni, 1990).

Evolutionary policy vs. public choice theory

Public choice theory transfers the utilitarian axioms of the rational, maximising agent of the neoclassical economic model to political science. Yet public choice theory is less-interventionist than neoclassical economic policy theory. Cost-benefit analysis or public policies to correct market failures assume benign decision-makers acting to maximize social welfare. As opposed to such a normative approach, public choice theory offers a positive, descriptive (and thus complementary) approach, which depicts policy-makers as being selfish like other rational economic agents (Witt, 1992; O'Neill, 1998). In addition, it identifies multiple stakeholders, bureaucrats, voters, politicians and interest groups, which rationally assess the costs and benefits of alternative actions and seek rents from policy change (Buchanan et al., 1980). Policies, even sub-optimal ones, do not change as long as potential benefits of change are outweighed by costs. Public choice theory seeks to analyze the costs and benefits different instruments imply for different actors and predict outcomes on the basis of the power that particular actors have, and how this power is wielded in the political process (Hahn, 1999). Although transaction and information costs are recognized as sources of sub-optimal policy outcomes, public choice theory denies state intervention to reduce them, as policy action is likely to be captured by rent seeking interests (Buchanan, 1986). Competitive market pressures in the public and economic sphere are expected to increase efficiency. The implication in terms of institutional design is then that the role of the State should be constrained to the establishment or redefinition of property rights. The privatization of public management and the introduction of competition in administration are also advocated.

The theory of evolutionary policy change shares with public choice theory a concern for intentional actors struggling in the policy arena to promote their interests. But they differ in important ways. First, the attention given by evolutionary theory to bounded rationality contrasts with public choice theory's assumptions of perfect rationality. Bounded rationality produces agenda-setting effects, which highlight the importance of learning and communication between actors, factors often underplayed in public choice models (Witt, 2003). Second, given bounded rationality and limitations in the capacity to process information, actors often are not capable of defining and articulating clearly their interests (Witt, 2003). Evolutionary theory recognizes altruistic and other motivations alongside selfishness. Political ideas and discourses assume a role beyond representing well-articulated interests; they are the glue that articulates such interests. This view allows more optimism for political mediation, compromises and collaboration, than the zero-sum competitive view of public choice. It fits well with insights from the adaptive management literature (discussed below), concerning the critical role of information brokers, learning or communication agents and boundary organizations that bring together disparate sources of information and help create new discourses around conflicting problems that can produce new, previously unforeseen, political alliances and solutions (Feldman et al., 2006). Third, path dependency provides a plausible counter to the functionalist mode of explanation that underlies public choice theory, under which existing political arrangements are the equilibrium outcome of the rational choices of individual actors. Increasing returns create causality in contingent historical events: present institutions are not inevitable or necessarily superior in some functional sense (Pierson, 2000b; Kerr, 2002). Power asymmetries and learning effects may have entrained policy evolution in undesirable paths.

Some evolutionary theorists share the Hayekian anti-interventionist view, according to which, policy arrangements and institutional norms have evolved over time through complex processes, that no central coordinating agency, given its limitations in information processing, should ever try to change (Hayek, 1967; Pelikan and Wegner, 2003). Public choice theory added more fuel to Hayekian arguments by breaking down the State to particular rent-seeking interests ready to direct and capture the benefits of new policies to their advantage. Hayek´s and Buchanan's theories underpinned 1980s political programs that sought to reduce State interventionism and privatize its competencies. Yet many evolutionary theories recognize that the State agencies are not just an average stakeholder or agent and that they are perhaps more rational and less self-interested than the average economic agent. Furthermore, power asymmetries and other sources of increasing returns and lock-in call for decisive, structural interventions to change the selection environment that only public administrations are capable of.

This is somewhat at odds with the recognition that, because of political path dependence, the capacity to change public policy is much more limited than conventionally thought (Pierson, 2000b). There is in general a tension between understandings of evolution at a higher level as a complex product of the struggle between different interests, and evolutionary policy design recommendations that assume benign policy-makers with the capacity to design and control the policy system. One way out of this tension is to see evolutionary policy as being about designing institutional procedures (rather than choosing instruments), which provide incentives for experimentation, learning and adaptive policy making (Witt, 2003). The recent literature on transition management and policy (Section 5) reflects this insight, and therefore comes up with rigorous proposals – convincing or not – to re-conceptualize policy problems and reform policy practice.

A second tension revolves around what Witt (1992, 2003) calls the endogenization of the theorist-analyst within evolutionary accounts of policy change. Public choice theory is somewhat contradictory since its own recommendations, such as outsourcing and privatization, are to be implemented by the bureaucrats and politicians themselves. Bureaucrats are thus seen as self-interested except when it comes to applying the policy proposals of public choice theory. An evolutionary perspective resolves this tension by perceiving the theorist/analyst as a participant in the policy process, who generates information and seeks to attract attention (Witt, 2003), i.e. a partisan in the struggle of ideas for survival. A political process that facilitates a plurality of contributions enhances scientific contestability and is more likely to lead to better outcomes (Witt, 2003; Norgaard, 1994). In this sense, policy design recommendations from an evolutionary perspective are not infallible, but rather tentative ideas to experiment with.

Evolutionary policy vs. resilience and adaptive management

Resilience has two alternative interpretations: (i) the time necessary for a disturbed system to return to its original state (Pimm, 1984); and (ii) the amount of disturbance that a system can absorb before moving to another state (Holling, 1973, 1986). The concept was first born in ecology: the dynamics of ecosystems and natural resources involves reversible as well as irreversible dynamics. The reversible dynamics relate to population growth and ecosystem succession, while the irreversible changes are partly the result of evolutionary changes, in the short run especially covering selection processes. Irreversibility further involves systems being able to move to alternate equilibria. Some authors have proposed analogies of resilience in socio-economic systems, dealing with the impact of bureaucracy on resilience, the comparison of social and market economy systems, the shortcomings of policies aimed at tight control and optimal trajectories rather than experiments, diversity, flexibility and adaptability (see Levin et al., 1998; Gunderson and Holling, 2002) and the capacity of businesses to renew strategies ahead of turbulent times (Hamel and Valinkangas, 2003). Resilience may be a useful basis for a policy theory if certain conditions are satisfied (Walker et al., 2002): systems are not convex, i.e. they contain thresholds, exhibit hysteresis and show irreversible change. Whereas within traditional economics this has been approached with nonlinear models providing aggregate descriptions of systems, evolutionary approaches might shed light on the underlying microlevel mechanisms involved.

The capacity of a system to adapt is an important component of resilience. Adaptive management refers to policies which are run like hypotheses and experiments, continuously monitored, updated and adjusted. Adaptive policies are not designed to control a system but to provide opportunities for learning in order to accommodate changing circumstances (Walters, 1986; Folke et al., 2005). Collaboration between scientists from different disciplines, policy-makers and stakeholders is a hallmark of adaptive management (Poff et al., 2003; Folke et al., 2005). Adaptive institutional forms include polycentric institutional arrangements bringing together agencies with different sectoral competencies often operating at different administrative or geographical levels (McGinnis, 2000), informal networks between actors at different levels of decisions and new, so-called flexible or boundary organizations that span existing competencies (Westley, 1995; Feldman et al., 2006). These rather generic principles have been influential in actual ecosystem management policies and programs (Poff et al., 2003; Kallis et al., 2009; Stankey et al., 2003; Lee, 2000).

Evolutionary and resilience/adaptation policy theory are complementary, rather than antagonistic models. They share an emphasis on uncertainty and surprise, diversity as capacity to adapt, and experimentation and learning. This is no surprise since their intellectual roots, evolutionary theory on the one hand, and ecology and self-organization (complex adaptive systems) theory on the other, are interlinked. But there are also some important differences. First, whereas resilience focuses on interaction between system components where it recognizes complementary diversity of functional groups of species (Walker et al., 2006), evolution is more concerned with diversity within populations giving rise to competition and selection. In addition, resilience theory notes that resilience is higher the larger is “response diversity” (or “functional redundancy”), which denotes the range of responses to disturbance within species or agents belonging to the same functional group, i.e. contributing to the same function in the system. Attention for both functional and response diversity provides a possible connection with evolutionary theory that deserves elaboration, notably in the context of social-economic applications of resilience. Like the evolutionary theory of the policy process, adaptive management sees the scientist/analyst as part of the policy process. It puts, however, more emphasis on her role in monitoring and evaluating experiments, than in the generation and selection of new ideas, highlighted by evolutionary accounts (Witt, 2003).

Resilience policy theory focuses on the capacity of systems to adapt during periods of turbulence and the attributes that will help them to do so. But it does not have a theory about the factors that might inhibit the evolution of adaptive organizations/institutions. Historical path-dependency, increasing returns of past policies or technologies and spatial lock-in may help explain why it is so hard for adaptive organizations to succeed and diffuse. Resilience theory and adaptive management are also somewhat oblivious of the broader political, economic or technological context within which adaptive organizations or institutions come to operate. Evolutionary emphasis on the selection environment (regulatory, market), and the need for policies to influence it, is a useful complement and goes well with the observation of empirical studies of adaptive management experiments, concerning the importance of supportive political institutions and regulations (Kallis et al., 2009). The evolutionary idea also of creating protected niches for new (policy or technological) experiments is also distinctive from resilience approaches.

Like in recent writings on transition management (Section 5), resilience theory recognizes that certain systems function at multiple scales characterized by critical multilevel or cross-scale effects (Gunderson and Holling, 2002). This is referred to as “panarchy”, to reflect nested adaptive cycles across space and time scales, some slow and some fast. The term “hierarchy” was regarded as being too much associated with a rigid and top-down structure. Panarchy-resilience theory can be compared with multilevel evolutionary theory which combines individual and group selection, recognizing that individuals join to form groups, and that groups influence individual behavior (e.g., through cultural transmission, norms, constraints and hierarchies).

Table 2 summarizes the main differences between the four policy perspectives.

[INSERT TABLE 2 HERE]

8. Conclusion

We have explored the idea of how public policy is shaped if one adopts the perspective of evolutionary thinking. For this reason we have first given a brief overview of (mainly non-genetic) evolutionary thinking. It involves a framework developed around the notions of diversity, population, selection, inheritance, innovation, coevolution, group selection, path-dependence and lock-in. In particular, we stressed that diversity is a multidimensional concept. We discussed the complex and often misunderstood relationship between evolution and progress. Here 'what is' is often confused with 'what ought to be'. The long standing debate on evolutionary progress suggests that evolution has some elements of directionality and progress, but certainly is not identical with continuous progress. There are many reasons for the latter. Selection is a local search process which gives rise to a local optimum, adaptations are often compromises between different objectives, historical constraints limit the range of evolutionary change, and coevolution means that the environment is dynamic so that the notion of optimization even starts to drift.

To illustrate the relevance of evolutionary thinking for policy, we considered evolutionary policies at two levels: institutional, i.e. policy change itself, and policy design. Central at the first level is the idea that political and economic environments impose selective pressures upon alternative political strategies and that political actors adapt their strategies to this selection environment which is multi-dimensional (media, elections, public opinion, power and lobbying). Moreover, since this environment is changing and evolutionary as well, it is best described by a process of coevolution. In addition, historical constraints or path-dependencies are relevant, leading to the notion of "policy paradigm", which reflects that earlier, historical events greatly influence and hamper political and institutional developments at a later stage.

We examined evolutionary policy design in three areas, namely technical change, sustainability transitions, and regulation of consumers. The first of these is most developed, as in fact much of the innovation studies literature implicitly or explicitly adopts an evolutionary angle of thought. Insights focus on innovation policies, diversity management, exploiting status seeking behaviour of consumers to stimulate escape from lock-in, etc.

We recognized that there are tensions between the two levels of analysis, i.e. understanding the policy process as an evolutionary process itself, where policymakers or scientists are mere actors in the struggle for policy selection, and evolutionary policy-design, which assumes a more top-down design and control of policies. An understanding of evolutionary policy as being primarily about the design of institutional procedures that enable learning and experimentation and a recognition of policy proposals – including evolutionary ones – as tentative contributions to the struggle of ideas, somewhat relieve these tensions.

Next, we identified the problem that current evolutionary approaches lack a consistent and systematic elaboration of policy, and in particular do not employ clear criteria and goals. For this reason, we suggest a number of possible approaches in this respect, among others, using the same criteria as in neoclassical economics, or focus on effectiveness of policy given the complexity, uncertainty and limited control of evolutionary systems, and questioning the notion of a fixed social welfare function in view of bounded rationality (individual inefficiency) and evolving preferences. Finally, we compared evolutionary theory with three other, influential approaches to policy analysis. These are the neoclassical-economic theory of externality regulation, public choice theory, and adaptive management and resilience. Evolutionary policy turns out to be the closest in spirit to the latter, and the most distant to the first of these approaches.

Whatever one may think of the relevance of the notion of evolutionary policy, we hopefully have made convincing that evolutionary thinking offers a distinct perspective on public policy design and change.

Acknowledgements:

Ulrich Witt and an anonymous referee provided useful comments on a previous draft.

References

Aldrich, H. (1999). *Organizations Evolving*. Sage, London.

Andreoni, J. (1995). Warm-glow versus cold-prickle: the effects of positive and negative framing of cooperation in experiments. *Quarterly Journal of Economics* 60: 1-14.

Arrow, K.J. (1950). A difficulty in the concept of social welfare. *Journal of Political Economy* 58(4): 328-346.

Arthur, B. (1989). Competing technologies, increasing returns, and lock-in by historical events. *Economic Journal* 99: 116-131.

Axelrod, R. (1986). An evolutionary approach to norms: *American Political Science review* 80(4): 1095-1111.

Baumgartner, F.R. (2006). Punctuated equilibrium theory and environmental policy. In Repetto, R. (ed), *Punctuated equilibrium and the dynamics of U.S. environmental policy*. Yale University Press. New Haven, pp. 24-46.

Baum, J.A.C. and Singh, J.V. (1994a). Organizational hierarchies and evolutionary processes; some reflections on a theory of organizational evolution. In Baum, J.A.C. and Singh J.V. (eds). *Evolutionary Dynamics of Organizations*. Oxford University Press, New York, pp. 3-20.

Baum, J.A.C. and Singh, J.V. (1994b).Organization-environment coevolution. In Baum, J.A.C. and Singh J.V. (eds). *Evolutionary Dynamics of Organizations*. Oxford University Press, New York, pp 379-402.

Baumol, W.J. and W.E. Oates (1988). *The Theory of Environmental Policy*. 2nd ed. Cambridge University Press, Cambridge, UK.

Binmore, K.G. (2005). *Natural Justice*. Oxford University Press, New York.

Boyd, R., Richerson, P. (1985). *Culture and the Evolutionary Process*. University of Chicago Press, Chicago.

Boyd, R. and P. J. Richerson (2005). *Not By Genes Alone: How Culture Transformed Human Evolution*. The University of Chicago Press, Chicago.

Buchanan, J. (1986). *Liberty, Market and the State: Political Economy in the 1980's*. Wheatsheaf, Sussex.

Buchanan, J., Tollison, R. and G. Tullock. (1980). *Toward a Theory of the Rent-seeking Society*. College Station: Texas A&M University Press.

Buss, D.M. (1989). Sex differences in human mate preferences: evolutionary hypotheses tested in 37 cultures. *Behavioral and Brain Sciences* 12: 1-49.

Buss D.M. (2005) (ed.). *Evolutionary Psychology Handbook.* Wiley, New York.

Camerer, C.F., G. Loewenstein and M. Rabin (eds.) (2004). *Advances in Behavioral Economics.* Princeton University Press, Princeton, NJ.

Campbell, D.T. (1969). Variation and selective retention in socio-cultural evolution. *General Systems* 14: 69-85.

Clark, C.W. (1990). *Mathematical Bioeconomics: The Optimal Management of Renewable Resources.* 2nd edition. John Wiley &Sons, New York.

Constant II, E.W. (2002). Why evolution is a theory about stability: constraint, causation, and ecology in technological change. *Research Policy* 31(8-9) 1241-1256.

Coase, R.H., 1960. The problem of social cost. *Journal of Law and Economics*. 3: 1-44.

Cordes, C. (2006). Darwinism in economics: from analogy to continuity. *Journal of Evolutionary Economics* 16(5): 529-541.

Dawkins, R. (1982). *The Extended Phenotype*. Oxford University Press, Oxford.

Dosi, G., et al. (eds.) (1988). *Technical Change and Economic Theory*. Pinter Publishers, New York.

Eiben, A.E., and J.E. Smith (2003). *Introduction To Evolutionary Computing*, Springer, Berlin.

Elzen, B., Geels, F.W., and Green, K. (eds.) (2004). *System Innovation and the Transition to Sustainability: Theory, Evidence and Policy*. Edward Elgar, Cheltenham.

Epstein, C., and R. Axtell (1996). *Growing Artificial Societies: Social Science from the Bottom Up*. The MIT Press, Boston, Mass.

Eriksson, E.A., and K. M. Weber (2008). Adaptive foresight: Navigating the complex landscape of policy strategies. *Technological Forecasting and Social Change* 75 (2008) 462–482

Fehr, E., and U. Fischbacher (2002). Why social preferences matter - the impact of non-selfish motives on competition, cooperation and incentives. *Economic Journal* 112: C1-C33.

Feldman, M.S., Khademian, A.M., Ingram, H., and A.S. Schneider (2006). Ways of knowing and inclusive management practices. *Public Administration Review*. 89-99.

Fine, G., and J. Deegan (1996). Three principles of serendipity: insight, chance and discovery in qualitative research. *International Journal of Qualitative Studies in Education* 9 (4): 434-447.

Folke, C., Hahn, T., Olsson, P., Norberg, J., (2005). Adaptive governance of social–ecological systems. *Annual Review of Environment and Resources* 30, 441–473.

Friedman, D. (1998). On economic applications of evolutionary game theory. *Journal of Evolutionary Economics* 8(1): 15-43.

Geels, F.W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy* 31: 1257–1274.

Gould, S.J. (1988). On replacing the idea of progress with an operational notion of directionality. In: M. Nitecki (ed.). *Evolutionary Progress.* University of Chicago Press, Chicago.

Gould, S.J., and R.C. Lewontin (1979). The spandrels of San Marco and the Panglossian paradigm: A critique of the adaptationist programme. *Proceedings of the Royal Society of London B* 205: 581-98.

Gowdy, J. (1994). *Coevolutionary Economics: The Economy, Society and the Environment.* Kluwer Academic Publishers, Dordrecht.

Gunderson, L., and C.S. Holling (2002). *Panarchy: Understanding Transformation in Human and Natural Systems*. Island Press, Washington D.C.

Hajer, M. (1995). *The Politics of Environmental Discourse: Ecological Modernization and the Policy Process*. Clarendon, Oxford.

Hannan, M.T., and J. Freeman (1989). Organizational Ecology. Harvard University Press, Cambridge, Mass.

Hausfather, Z. (2006). Implications of strong reciprocal behavior on coasian bargains. Module 4 Paper, Masters programme "Environmental and Resource Management", Institute for Environmental Studies, Free University, Amsterdam.

Hay, C. (1999). Crisis and the structural transformation of the state: interrogating the process of change, *British Journal of Politics and International Relations* 1(3): 317-344.

Hahn, R.W. (1990). The political economy of environmental regulation: Towards a unifying framework. *Public Choice* 65: 21–47.

Hamel, G., and Valikangas, L. (2003). The Quest for Resilience, *Harvard Business Review* 68(3): 52-63.

Hayek, F.A. (1967). Notes on the evolution of systems of rules of conduct. In: Studies in Philosophy, Politics and Economics. University of Chicago Press, Chicago, pp. 66-81.

Henrich, J. (2004). Cultural group selection, coevolutionary processes and large-scale cooperation. *Journal of Economic Behavior and Organization* 53: 3-35.

Hirsch, F. (1976). *Social Limits to Growth*. Harvard University Press, Cambridge, MA.

Hodgson, G.M. (1993). *Economics and Evolution: Bringing Life Back into Economics*. Polity Press, Cambridge.

Hodgson, G. M., & Knudsen, T. (2006). Why we need a generalized Darwinism, and why generalized Darwinism is not enough. *Journal of Economic Behavior and Organization* 61(1): 1-19.

Holling, C.S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecological Systems* 4: 1-24.

Holling, C.S. (1986). The resilience of terrestrial ecosystems: Local surprise and global change. In: W. C. Clark and R. E. Munn (ed.). *Sustainable Development of the Biosphere.* Cambridge University Press, Cambridge, UK.

Howarth, R.B., en K.A. Brekke (2003). *Status, Growth and the Environment: Goods As Symbols in Applied Welfare Economics* Edward Elgar Publishing, Cheltenham.

Jackson, T. (2005). Live better by consuming less? Is there a “double dividend” in sustainable consumption? *Journal of Industrial Ecology* 9(1–2): 19–36.

Janssen M.A., and W. Jager (2002). Simulating diffusion of green products: Co-evolution of firms and consumers. *Journal of Evolutionary Economics* 12: 283-306.

Johansson, P.-O. (1987). *The Economic Theory and Measurement of Environmental Benefits*. Cambridge University Press, Cambridge.

Johansson, P.O., and K.G. Löfgren (1985). *The Economics of Forestry and Natural Resources.* Basil Blackwell, Oxford.

John, P. (1999). Ideas and interests; agendas and implementation: an evolutionary explanation of policy change in British local government finance. *British Journal of Politics and International Relations* 1(1): 39-62.

Kahneman, D. and A. Tversky (eds.) (2000). *Choices, Values and Frames.* Cambridge University Press, Cambridge, UK.

Kahneman, D., J.L. Knetsch and R.H. Thaler (1990). Experimental tests of the endowment effect and the Coase theorem. *Journal of Political Economy* 98: 1325-1348.

Kallis, G. (2007) When is it coevolution? *Ecological Economics* 62: 1–6.

Kallis, G. (2009). Coevolution in water resource development. The vicious cycle of water supply and demand in Athens, Greece. *Ecological Economics*. Forthcoming

Kallis, G. Norgaard, R. and M. Kiparsky (2009). Adaptive Governance and Collaborative water policy. Lessons from the California Bay-Delta. *Environmental Science and Policy*. Forthcoming.

Kauffman, S.A. (1993). *The Origins of Order: Self-Organization and Selection in Evolution.* Oxford University Press, Oxford.

Kemp, R. (1997). *Environmental policy and Technical Change: A Comparison of the Technological Impact of Policy Instruments.* Edward Elgar, Cheltenham.

Kemp, R., Schot, J.W. and Hoogma, R. (1998), Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management, in: *Technology Analysis and Strategic Management* (10): 175-196.

Kerr, P. (2002). Saved from extinction: evolutionary theorising, politics and the state. *British Journal of Politics and International Relations* 4(2): 330 -358.

Kingdon, J.W. (1995). *Agendas, Alternatives, and Public Policies*, 2nd ed. Longman, New York.

Laland, K.N., Odling-Smee, F.J. and Feldman, M.W., 1999. Evolutionary Consequences of Niche Construction and their Implications for Ecology. Proc. Natl. Acad. Sci. U.S.A., 96: 10242-10247.

Layard, R. (2005). *Happiness: Lessons from A New Science*. Penguin, London.

Lee, K. N. (2000). Appraising adaptive management. In Buck, L. Geisler, C., Schelhas, J. and L. Wallenste (eds), *Biological diversity: Balancing interests through adaptive collaborative management*, CRC Press, New York, pp. 3- 36.

Levin et al. (17 authors) (1998). Resilience in natural and socioeconomic systems. *Environment and Development Economics* 3(2): 222-235.

Lewin, A.Y. and Volberda, H.W. (1999). Prolegomena on Coevolution: a Framework for Research on Strategy and New Organizational Forms. *Organization Science* 10 (5): 519-534.

Lundvall, B.Å. (1988). Innovation as an interactive process: from user-producer interaction to the national system of innovation. In: G. Dosi et al. (eds.). *Technical Change and Economic Theory*, Pinter Publishers, London, New York (1988), pp. 349–369.

Mahoney, J. (2000). Path dependence in historical sociology. *Theory and Society* 29: 507–48.

Manner, M. and J. Gowdy (2009). The evolution of social and moral behavior. Evolutionary insights for public policy. *Ecological Economics* forthcoming.

Martinez-Alier, J. (2005). *The Environmentalism of the Poor: Ecological Conflicts and Languages of Valuation*. Oxford University Press, New Delhi.

Maynard Smith, J., and E. Szathmáry (1995). *The Major Transitions in Evolution.* Oxford University Press, Oxford.

McGinnis, M. (2000). *Polycentric Governance and Development.* University of Michigan Press, Ann Arbor, Michigan.

McKelvey, B. (1982). *Organizational Systematics*. University of California Press, Berkeley.

Metcalfe, J.S. (1994). Evolutionary economics and technology policy. *Economic Journal* 104: 931-944.

Metcalfe, J.S. (1998). *Evolutionary Economics and Creative Destruction*. Routledge, London.

Miner, A.S. (1994). Seeking adaptive advantage: evolutionary theory and managerial action. In Baum JAC and Singh JV, eds. *Evolutionary dynamics of organizations*. New York: Oxford University Press.

Mokyr, J. (1990). *The Lever of the Riches: Technological Creativity and Economic Progress*. Oxford University Press, Oxford.

Munro, A. (1997). Economics and biological evolution. *Environmental and Resource Economics* 9: 429-449.

Nannen, V., and J.C.J.M. van den Bergh (2009). Policy instruments for evolution of bounded rationality: Application to climate-energy problems. MPRA Paper 13818, University Library of Munich, Germany.

Nelson, R., and S. Winter (1982). *An Evolutionary Theory of Economic Change*. Harvard University Press, Cambridge, MA.

Nelson, R.R. (1992). National innovation systems: a retrospective on a study. *Industrial and Corporate Change* 1(2): 347–374.

Nelson, R.R. (1995). Recent Evolutionary Theorising About Economic Change. *Economic Journal* XXXIII: 48-90.

Nill, J., and R. Kemp (2009). Evolutionary approaches for sustainable innovation policies: From niche to paradigm? *Research Policy* 38(4): 668-680.

Nitecki, M.H. (ed.) (1988). *Evolutionary Progress*. University of Chicago Press, Chicago.

Noailly, J. (2008). Coevolution of economic and ecological systems. *Journal of Evolutionary Economics* 18(1): 1-29.

Noailly, J., J.C.J.M. van den Bergh and C. Withagen (2009). Local and global interactions in an evolutionary resource game. *Computational Economics* 33(2): 155-173.

Norgaard, R.B. (1994). *Development Betrayed: The End of Progress and a Coevolutionary Revisioning of the Future*. Routledge, London and New York.

Norton, B., R. Costanza and R.C. Bishop (1998). The evolution of preferences. Why 'sovereign' preferences may not lead to sustainable policies and what to do about it", *Ecological Economics* 24: 193-211.

Nowak, M.A. (2006). *Evolutionary Dynamics. Exploring the Equations of Life*. Harvard University Press, Cambridge, Mass.

O'Neill, J. (1998). *The Market: Ethics, Knowledge and Politics* Routledge, London.

Ostrom, E. (1990). *Governing the Commons: The Evolution of Institutions for Collective Action.* New York. Cambridge University Press, Cambridge.

Pelikan, P. and G. Wegner (Eds.) (2003). *The Evolutionary Analysis of Economic Policy* Edward Elgar, Cheltenham.

Penn, D.J. (2003). The evolutionary roots of our environmental problems: towards a Darwinian ecology. *The Quarterly Review of Biology* 78(3): 275-301.

Peters, I., F. Ackerman and S. Bernow (1999). Economic theory and climate change policy *Energy Policy* 27: 501-504.

Pierson, P. (2000a). Increasing Returns, Path Dependency, and the Study of Politics. *American Political Science Review* 94: 251—67.

Pierson, P., (2000b). The Limits of Design: Explaining Institutional Origins and Change. *Governance*, 13 (4): 475–99.

Pimm, S.L. (1984). The complexity and stability of ecosystems. *Nature* 307: 321-326.

Poff, N. L., J. D. Allan, M. A. Palmer, D. D. Hart, B. D. Richter, A. H. Arthington, J. L. Meyer, J. A. Stanford, and K. H. Rogers (2003). River flows and water wars? Emerging science for environmental decisionmaking. *Frontiers Ecol. Environ.*, 1: 298– 306.

Potts, J. (2000). *The New Evolutionary Microeconomics*. Cheltenham, Edward Elgar.

Rammel, C., and J.C.J.M. van den Bergh (2003). Evolutionary policies for sustainable development: adaptive flexibility and risk minimising. *Ecological Economics* 47 (2): 121-133.

Ridley, M. (1995) *The Red Queen: Sex and the Evolution of Human Nature*. Penguin Books,

London.
Ruse, M. (1999). *Mystery of Mysteries: Is Evolution a Social Construction.* Harvard University Press, Cambridge, Mass.
Safarzynska K., and J.C.J.M. van den Bergh (2007). Policy for system innovation: demand-supply coevolution with multiple increasing returns. IVM, Vrije Universiteit, Amsterdam, the Netherlands.
Safarzynska, K., and J.C.J.M. van den Bergh (2009). Evolving power and environmental policy: Explaining institutional change with group selection. *Ecological Economics*, forthcoming.
Sartorius, C., Zundel, S. (Eds.) (2005). *Time Strategies, Innovation and Environmental Policy*. Edward Elgar, Cheltenham.
Schneider, E.D., and J.J. Kay (1994). Complexity and thermodynamics: Towards a new ecology. *Futures* 24: 626-647.
Schot, J.W. and Geels, F.W. (2007). Niches in evolutionary theories of technical change: A critical survey of the literature. *Journal of Evolutionary Economics* 17(5): 605-622.
Sen, A. (1993). On the Darwinian view of progress. *Population and Development Review* 19(1): 123-137.
Sethi, R., and E. Somanathan (1996). The evolution of social norms in common property resource use. *American Economic Review* 86(4): 766-788.
Stankey, G.H., Bormann, B.T., Ryan, C., Shindler, B., Sturtevant, V., Clark, R.N., Philpot, C. (2003). Adaptive management and the Northwest Forest Plan: rhetoric and reality. *Journal of Forestry* 101 (1), 40–46.
Sterner, T. (2003). *Policy Instruments for Environmental and Natural Resource Management*. Resources for the Future, Washington D.C.
Stirling, A. (2007). A general framework for analysing diversity in science, technology and society. *Journal of the Royal Society Interface* 4 (15): 707-719.
Strickberger, M.W. (1996). *Evolution*. 2nd ed. Jones and Bartlett Publishers, Sudbury, Mass.
Teubal, M. (1997). A catalytic and evolutionary approach to horizontal technology policies (HTPs). *Research Policy* 25(8): 1161-1188.
Thelen, K. (2000), Timing and Temporality in the Analysis of Institutional Evolution and Change, *Studies in American Political Development*, 14:101-108.
Traulsen, A., and M. A. Nowak (2006). Evolution of cooperation by multilevel selection. *Proceedings of the National Academy of Sciences* 103, 10952 – 10955.
Tversky, A., en I. Simonson (2000). Context-dependent preferences. In: D. Kahneman en A. Tversky (eds.), *Choices, Values and Frames*. Cambridge University Press, Cambridge, pp. 518-527.
Unruh, G.C. (2002). Escaping carbon lock-in. *Energy Policy* 30: 317-325.
van den Bergh, J.C.J.M. (2009). The GDP Paradox. *Journal of Economic Psychology* 30: 117–135.
van den Bergh, J.C.J.M. (2008). Optimal diversity: Increasing returns versus recombinant innovation. *Journal of Economic Behavior and Organization* 68(3-4): 565-580.
van den Bergh, J.C.J.M. (2007). Evolutionary thinking in environmental economics. *Journal of Evolutionary Economics* 17(5): 521-549.
van den Bergh, J.C.J.M., A. Faber, A.M. Idenburg and F.H. Oosterhuis (2006). Survival of the greenest: Evolutionary economics and policies for energy innovation. *Environmental Sciences* 3(1): 57-71.
van den Bergh, J.C.J.M., A. Faber, A.M. Idenburg and F.H. Oosterhuis (2007). *Evolutionary Economics and Environmental Policy: Survival of the Greenest*. Edward Elgar Publ., Cheltenham.
van den Bergh, J.C.J.M., and J.M. Gowdy (2000), Evolutionary theories in environmental and resource economics: approaches and applications. *Environmental and Resource Economics* 17(1): 37-57.
van den Bergh, J.C.J.M., and J.M. Gowdy (2009). A group selection perspective on economic behavior, institutions and organizations. *Journal of Economic Behavior and Organization*, forthcoming.

van den Bergh, J.C.J.M., and S. Stagl (2003). Coevolution of economic behaviour and institutions: towards a theory of institutional change. *Journal of Evolutionary Economics* 13 (3): 289-317.

Varian, H.R. (1992). *Microeconomic Analysis.* W.W. Norton, New York.

Veblen, T. (1899). *The Theory of the Leisure Class.* Penguin Books, New York.

Verspagen, B. (2009). The use of modeling tools for policy in evolutionary environments *Technological Forecasting and Social Change* 76(4): 453-461.

Walker, B. H., L. H. Gunderson, A. P. Kinzig, C. Folke, S. R. Carpenter, and L. Schultz (2006). A handful of heuristics and some propositions for understanding resilience in social-ecological systems. *Ecology and Society* 11(1): 13. [online] URL: http://www.ecologyandsociety.org/vol11/iss1/art13/

Walker, B., S. Carpenter, J. Anderies, N. Abel, G. S. Cumming, M. Janssen, L. Lebel, J. Norberg, G. D. Peterson, and R. Pritchard (2002). Resilience management in social-ecological systems: a working hypothesis for a participatory approach. *Conservation Ecology* 6(1): 14. [online] URL: http://www.consecol.org/vol6/iss1/art14/

Walters, C. (1986). *Adaptive Management of Renewable Resources*. MacMillan, New York.

Ward, H. (2003). The Co-evolution of Regimes of Accumulation and Patterns of Rule: State Autonomy and the Possibility of Functional Responses to Crisis. *New Political Economy* 8(2): 179 – 202.

Watson, R.A. (2006). *Compositional Evolution: The Impact of Sex, Symbiosis, and Modularity on the Gradualist Framework of Evolution*. MIT Press, Cambridge, Mass.

Westley, F. (1995). Governing design: the management of social systems and ecosystems management. In Gunderson, L. H., Holling, C. S. and S. Light (eds). *Barriers and bridges to the renewal of ecosystems and institutions.* Columbia University Press, New York. pp 391–427.

Wilson, D. and E.O. Wilson (2007). Rethinking the theoretical foundation of sociobiology. The *Quarterly Review of Biology* 82, 327-348.

Winder, N., B.S. McIntosh and P. Jeffrey (2005). The origin, diagnostic attributes and practical application of co-evolutionary theory. *Ecological Economics* 54(4): 347-361.

Windrum P., and C.T. Birchenhall (2005). Structural change in the presence of network externalities: a co-evolutionary model of technological successions. *Journal of Evolutionary Economics* 15: 123-148.

Witt, U. (1992). The endogenous public choice theorist. *Public Choice* 73: 117–129.

Witt, U. (ed.) (1993). *Evolutionary Economics*. The International Library of Critical Writings in Economics, Vol. 25, Edward Elgar, Cheltenham, UK.

Witt, U. (2003). Economic policy making in evolutionary perspective. *Journal of Evolutionary Economics* 13: 77 - 94.

Table 1. Components of evolution and their consequences

Components of evolution	**Consequences**
Population	Population growth, cyclic patterns, splitting (group selection), extinction, gradual change
Bounded rationality (routines, habits, imitation, myopia, learning, status seeking)	Sluggishness, socially undesirable lock-in, herd behaviour, distinction (status)
Diversity (variety, balance and disparity)	Options for future development, potential for recombination, defines range for selection and fitness improvement
Selection (market, R&D, institutions, regulation, physical-geographical-climate)	Adaptation Repeated selection in the presence of increasing returns to scale (positive feedback) can give rise to path-dependence and lock-in (historical constraints)
Innovation (mutation, recombination, serendipity, modularity)	Emergence of new levels (nested or hyperstructures), unlocking
Inheritance (reproduction, imitation)	Stability, accumulation of adaptations, historical constraints (path dependency)
Isolation (geographical, institutional)	Radical innovation, unlocking ('speciation')
Coevolution	Complexity, sensitivity, less predictability, positive feedback (red queen effects, arms race), Conflict/antagonism evolving into mutualism/cooperation
Group selection	Parochialism, emergence of (group) norms and institutions, group conflict (war), multilevel evolution, power and hierarchy

Table 2. A comparison of evolutionary with other policy relevant theories

	Neoclassical Economics	**Public Choice Theory**	**Resilience Theory**	**Evolutionary theory**
Agents and behaviour	Representative agent Rational – utility or profit maximising	Multiple stakeholders Rational choice Rent-seeking	System of complementary agents Experimenting, learning	Population of diverse and interacting agents Bounded rationality Searching, learning
Policy criteria / goals	Optimal allocation Efficiency Cost-effectiveness	Efficiency Individual freedom of choice	Resilience or extended stability Maximum scale	Agnostic, or Diversity Evolutionary potential Precautionary principle
Emphasis in policy instruments	Price instruments such as taxes and tradable permits	Property rights	Adaptive management including experiments Maintaining diversity for flexible response	Information diffusion Maintaining or stimulating diversity
Real-world policy proposals	Full cost pricing Cost-benefit evaluation of policies Taxing externalities	Privatization Identify stakeholder conflicts Control rent-seeking	Poly-centric, collaborative institutions and programs	Protected niches for new technologies or institutions Avoiding or escaping dominance of one technology (lock-in)
Policy Analyst	External to policy	External to policy	Performs experiments, monitors, evaluates and learns	Generator of ideas/diversity Participant in struggle of policy ideas