ROUTLEDGE STUDIES IN ECOLOGICAL ECONOMICS

Creating a Sustainable Economy

An institutional and evolutionary approach to environmental policy

Edited by
Gerardo Marletto

ROUTLEDGE

Creating a Sustainable Economy

This book is designed for those scholars, students, policy makers – or just curious readers – who are looking for heterodox thinking on the issue of environmental economics and policy. Contributions to this book draw on multiple streams of institutional and evolutionary economics and help build an approach to environmental policy that radically diverges from mainstream prescriptions. No 'silver bullet' solutions emerge from the analyses. Even market-based tools – such as green taxes or tradable pollution permits – are bound to fail if they are not incorporated into an integrated, multi-dimensional and multi-actor policy for structural change.

'Destabilize the old, create the new and support actors for change': this claim sums up the approach proposed by this book. Unsustainable socio-technical systems – such as: internal combustion cars, non renewable energy sources or intensive agriculture – feature a relevant resistance to change, because they are embedded in the very structure of our society and because of the conservative action of dominant stakeholders. This is why no environmental policy will be effective unless it aims at 'unlocking' our societies from them. But this book is mostly targeted to the constructive side of environmental policy, that is, the establishment of new and more sustainable ways of fulfilling our needs. Even if with different foci and backgrounds, all contributors to the book view environmental policy as a combination of actions which is able to trigger – and make viable – those institutional, technological and economic changes which are needed to reach sustainability.

Coalitions of actors for change are at the heart of this vision: environmental policy must actively support their empowerment, legitimacy and social networking. This also means that all groups and individuals – not only dominant stakeholders – should be provided with sufficient capabilities to access the deliberation and decision arena for sustainability.

Gerardo Marletto is Associate Professor at the University of Sassari, Sardinia, Italy.

Routledge studies in ecological economics

1 **Sustainability Networks**
Cognitive tools for expert collaboration in social-ecological systems
Janne Hukkinen

2 **Drivers of Environmental Change in Uplands**
Aletta Bonn, Tim Allot, Klaus Hubaceck and Jon Stewart

3 **Resilience, Reciprocity and Ecological Economics**
Northwest coast sustainability
Ronald L. Trosper

4 **Environment and Employment**
A reconciliation
Philip Lawn

5 **Philosophical Basics of Ecology and Economy**
Malte Faber and Reiner Manstetten

6 **Carbon Responsibility and Embodied Emissions**
Theory and measurement
João F.D. Rodrigues, Alexandra P.S. Marques and Tiago M.D. Domingos

7 **Environmental Social Accounting Matrices**
Theory and applications
Pablo Martínez de Anguita and John E. Wagner

8 **Greening the Economy**
Integrating economics and ecology to make effective change
Bob Williams

9 **Sustainable Development**
Capabilities, needs, and well-being
Edited by Felix Rauschmayer, Ines Omann and Johannes Frühmann

10 The Planet in 2050
The Lund discourse of the future
Edited by Jill Jäger and Sarah Cornell

11 Bioeconomics
Edited by Mauro Bonaiuti

12 Socioeconomic and Environmental Impacts on Agriculture in the New Europe
Post-Communist transition and accession to the European Union
S. Serban Scrieciu

13 Waste and Recycling: Theory and Empirics
Takayoshi Shinkuma and Shusuke Managi

14 Global Ecology and Unequal Exchange
Fetishism in a zero-sum world
Alf Hornborg

15 The Metabolic Pattern of Societies
Where economists fall short
Mario Giampietro, Kozo Mayumi and Alevgül H. Sorman

16 Energy Security for the EU in the 21st Century
Markets, geopolitics and corridors
Edited by José María Marín-Quemada, Javier García-Verdugo and Gonzalo Escribano

17 Hybrid Economic-Environmental Accounts
Edited by Valeria Costantini, Massimiliano Mazzanti and Anna Montini

18 Ecology and Power
Struggles over land and material resources in the past, present and future
Edited by Alf Hornborg, Brett Clark and Kenneth Hermele

19 Economic Theory and Sustainable Development
What can we preserve for future generations?
Vincent Martinet

20 Paving the Road to Sustainable Transport
Governance and innovation in low-carbon vehicles
Edited by Måns Nilsson, Karl Hillman, Annika Rickne and Thomas Magnusson

21 Creating a Sustainable Economy
An institutional and evolutionary approach to environmental policy
Edited by Gerardo Marletto

Creating a Sustainable Economy

An institutional and evolutionary approach to environmental policy

Edited by Gerardo Marletto

Routledge
Taylor & Francis Group
LONDON AND NEW YORK

First published 2012
by Routledge
2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

Simultaneously published in the USA and Canada
by Routledge
711 Third Avenue, New York, NY 10017

Routledge is an imprint of the Taylor & Francis Group, an informa business

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging in Publication Data
Creating a sustainable economy: an institutional and evolutionary approach to environmental policy/edited by Gerardo Marletto.
p. cm.
1. Economic development–Environmental aspects. 2. Environmental policy–Economic aspects. 3. Sustainable development. 4. Environmental economics. I. Marletto, Gerardo, 1961–
HD75.6.C74 2012
338.9′27–dc23 2011047580

ISBN: 978-0-415-61076-6 (hbk)
ISBN: 978-0-203-11798-9 (ebk)

Typeset in Times New Roman
by Wearset Ltd, Boldon, Tyne and Wear

To Giacomo and Nicola, my beloved children, hoping they will be able to cope with a worse world.

Contents

Contributors

Mario Amendola is Senior Professor of Economics at 'La Sapienza', University of Rome. He has been Harkness Fellow at MIT (Cambridge, USA.), Jemolo Fellow at All Souls College (Oxford, UK), Professeur Associè at the University of Strasbourg, and Visiting Professor in many Universities and international economic institutions. He is the author of many books on the theories of capital and technical progress, on dynamic models, on technological innovation and industrial change, and of various papers published in international journals.

Anna Bergek is Associate Professor of Industrial Management at the Department of Management and Engineering, Linköping University, Sweden and førsteamanuensis at the Centre for Technology, Innovation and Culture (TIK), University of Oslo, Norway. Her research interests include industry dynamics, technological innovation systems and corporate technology strategy, and their implications for energy and innovation policy and company strategy. She has published papers in journals such as *Research Policy*, *Energy Policy*, *Industrial and Corporate Change* and *Technology Analysis and Strategic Management*.

Halina Szejnwald Brown is Professor of Environmental Science and Policy at Clark University. Her research focuses on socio-technical transitions, environmental policy, sustainable consumption, and small-scale experimentation and learning; with special interests in energy, housing and transportation. She is Fellow of the American Association for the Advancement of Science and Fellow of the Society for Risk Analysis. She has authored 60 journal articles and two books: *Corporate Environmentalism in a Global Economy* (Quorum 1993) and *Effective Environmental Regulation* (Praeger 2000).

Pablo del Río is Senior (tenured) Researcher at the Consejo Superior de Investigaciones Científicas (CSIC). He received his PhD in Economics from the Universidad Autónoma de Madrid in 2002. His research focuses on the factors influencing environmental technology change in firms, on climate change mitigation measures and renewable energy support schemes. He has collaborated in several EU and national projects and has published his work in international journals (more than 60 international publications).

Timothy J. Foxon is a Reader in Sustainability and Innovation at the Sustainability Research Institute, School of Earth and Environment, University of Leeds, UK, and a member of the ESRC Centre for Climate Change Economics and Policy. His research explores technological and social factors relating to innovation of new energy technologies, and analysis of the co-evolution of technologies and institutions for a transition to a low carbon economy, and has been published in leading academic journals and edited books.

Jean-Luc Gaffard is Professor of Economics at the Institut Universitaire de France, OFCE Sciences-Po, SKEMA Business School. His main research fields are: innovation, competition, growth and structural change. He has authored several scientific papers and four books: *Out of Equilibrium* (with Mario Amendola); *Norme, Fait, Fluctuation* (with Jean Clam); *The Market Way to Riches: Behind the Myth* (with Mario Amendola); *La Croissance économique*.

Audley Genus is Professor of entrepreneurship and Technology Management at Kingston University. His research focuses on the diffusion of renewable energy technologies and energy efficient technologies and practices, and the roles of and relationships among diverse stakeholders within relevant processes of (de-)institutionalization. Audley has published extensively, including articles in *Research Policy*, *Business History*, and *Technological Forecasting and Social Change*. His most recently published book is *Decisions, Technology and Organisation* (Gower 2000).

Geoffrey M. Hodgson is a Research Professor at the University of Hertfordshire Business School. He has published widely in academic journals and his books include *From Pleasure Machines to Moral Communities* (2012), *Darwin's Conjecture* (with Thorbjørn Knudsen), *The Evolution of Institutional Economics* (2004), and *How Economics Forgot History* (2001). He is an Academician of the Academy of Social Sciences and he is editor-in-chief of the *Journal of institutional Economics*.

Jonathan Köhler is Senior Scientist at the Fraunhofer ISI (Institute for Systems and Innovation Research), with special responsibility for aviation and shipping. He is now working on agent-based modeling of transitions and the modeling of innovation systems and processes in transport. He also works with the ASTRA system dynamics model of transport policy and technology. He is involved in the EU Clean Sky research consortium, for which he is developing an aviation module for ASTRA.

Gerardo Marletto is Associate Professor of Applied Economics at the University of Sassari. He has been working for 15 years for private research bodies where he directed more than 20 projects on business strategy, industrial policy, regulation of public services and transport policy. His current research interests are: heterodox economics, environmental economics and policy, socio-technical analysis of transport systems, participated assessment techniques. He recently edited two special issues on heterodox environmental economics and new frontiers of transport research.

Karolina Safarzyńska works as an Assistant Professor at the Institute of the Environment and Regional Development at the Vienna University of Economics and Business. Her research interests concern evolutionary-economic modeling, sustainable development, technological change, complexity, and environment–economy coevolution. She has published several articles on these issues in journals such as *Research Policy*, *Energy Policy*, *Ecological Economics and Futures*.

Gregory Unruh is a Professor of Sustainability and Director of the Lincoln Center for Ethics at the Thunderbird School of Global Management. He holds a PhD in International Environmental and Technology Policy from the Fletcher School at Tufts University. He has been a technical reviewer for the Intergovernmental Panel on Climate Change and has been named a Strategic Partner of the United Nations Global Compact.

Arild Vatn is Thor Heyerdahl Professor at the Department of International Environment and Development Studies at the Norwegian University of Life Sciences (UMB). His main expertise is in institutional and ecological economics, with specific emphasis on various aspects of environmental governance. He has been president of the European Society of Ecological Economics. He was awarded the UMB research prize in 2002 and the joint EAEPE and AFEE Veblen 150 prize in 2007 for his book *Institutions and the Environment*.

Philip J. Vergragt is a Professor Emeritus of Technology Assessment of TU Delft; a Research Professor at Clark University, Worcester, USA; and a Senior Associate at Tellus Institute in Boston, USA. His research interests include technological innovation; sustainable consumption; housing; backcasting; technology assessment. He has widely published in academic journals and co-authored two books: *Sustainable Technology Development* and *The Business of Sustainable Mobility, from Vision to Reality*. He is a member of the Executive Committee of the Sustainable Consumption Research and Action Initiative (SCORAI).

Preface

I am an economist, but I do not feel at all at ease with mainstream economics. This book is designed for those scholars, students, policy makers, practitioners – or just curious readers – who share this feeling and are looking for heterodox thinking on the issue of environmental economics and policy.

My discomfort with mainstream economics results from a striking contradiction. On one side, mainstream economics is manifestly not able to face today's global problems, such as financial instability, stagnation and unemployment, climate change, inequality and poverty, food and water crises, etc. On the other side, old and new streams in economics, sociology, political science, natural science, etc. are out there, available for those who want to draw on them in order to open new research paths, revise courses and academic programs, enact new national and global policies. But this is very difficult, almost impossible, also because mainstream economics dominates both the cultural and the political arena. One might even wonder if it is mainstream economic policy – with its obsession with deflation and liberalization – that helped to generate global crises.

The only relief to my discomfort is that I am in good company: an increasing number of scholars share my feelings and opinions. The most authoritative among them – Elinor Ostrom, Amartya Sen, Joseph Stiglitz – were awarded the Nobel Prize in economics; others gave birth to academic book series and journals, scientific societies, handbooks and courses, think tanks, Internet groups, etc. All over the world, a cultural movement explicitly criticizes mainstream economics and diffuses heterodox thinking.

But the time has come to get out of the niche of heterodoxy and build the new mainstream economics. Obviously this is not an easy task: changing a paradigm may take years, even decades. But new ideas are not generated from scratch; on the contrary, they can 'stand on the shoulders of giants', such as: David Ricardo, John Maynard Keynes, Joseph Schumpeter, Herbert Simon and – with specific reference to environmental issues – William Kapp and Nicholas Georgescu-Roegen.

This book is part of this cultural movement. Contributions to this book draw on multiple streams of institutional and evolutionary economics and help build an approach to environmental policy which radically diverges from mainstream prescriptions. Institutions and technologies – and not only markets – are at the heart of a systemic and dynamic analysis of those structural changes which are needed to create a sustainable economy. Actors – and their ability to influence politics and policy – are explicitly taken into consideration. No 'silver bullet' solutions emerge from the analysis; what matters is the overall approach to policy. Even market-based tools – such as green taxes or tradable pollution permits – are bound to fail if they are not incorporated into an integrated, multi-dimensional and multi-actor policy for structural change.

'Destabilize the old, create the new and support actors for change': this claim sums up the approach proposed here.

Internal combustion cars, coal-fired power plants, intensive farms, energy-inefficient houses: these are just few examples of how most of our needs are currently fulfilled in an unsustainable way. But these are not simply products, production methods or technologies; they are complex systems made of actors, rules, norms, habits, behavior, values, preferences, resources, knowledge, infrastructures, organizations, powers, etc. These 'socio-technical' systems feature a relevant resistance to change, because they are embedded in the very structure of our society and because of the conservative action of dominant stakeholders. This is why no environmental policy will be effective unless it aims at 'unlocking' our societies from the dominance of these unsustainable socio-technical systems.

But this book is mostly targeted at the constructive side of environmental policy, that is, the establishment of new and more sustainable ways of fulfilling our needs. This issue is analyzed from different viewpoints by contributors to the book: some focus on behavior and institutions, others analyze the interaction of economic and technological dynamics; some provide sectoral case studies and others have the ambition to provide the reader with an overall picture. But all authors view environmental policy as a combination of actions that can trigger – and make viable – those institutional, technological and economic changes which are needed to reach sustainability.

Then, policy prescriptions follow consistently: (a) An institutional policy is needed to establish new political discourses, new political habits and new formal norms which may accommodate all actions towards sustainability; (b) A pro-active industrial policy is needed to ease and foster the co-operation between all subjects who can be involved in 'green' innovations (universities, research bodies, authorities, firms, associations, grassroots movements, etc.); (c) An expansive macroeconomic policy – a 'green new deal' – is needed to provide the financial resources that must be invested in new productive capacity and new infrastructures; (d) Local experiments must be implemented in order to protect and strengthen emerging novelties and actors, but wider diffusion is needed to trigger national and international processes of change.

In synthesis, environmental policy must foster and co-ordinate changes towards sustainability which take place in multiple dimensions and multiple scales of social life; only when changes align and mutually reinforce, can policy then play a secondary role and, eventually, quit the scene.

Actors for change are at the heart of this vision, both as subjects and as object of policy: as subjects, because the creation of new and sustainable socio-technical systems is made possible by (coalitions of) actors for change; as object, because environmental policy – to be effective – must actively support the empowerment, legitimation and social networking of such coalitions. This is why so many (heterodox) scholars of environmental issues insist on participation as a crucial feature of effective policies: through participation dominant stake-holders may be tamed and actors for change can enter the policy arena. This also means that environmental policy must say something on the design of political institutions, in particular with reference to two interconnected points: (a) If all groups and individuals – and the people at large – have sufficient capabilities to access the collective processes of deliberation and decision about the issue of sustainability; (b) If open debate, pluralism and free experimentation on sustainable futures are effectively fostered.

Commenting on Amartya Sen's *Development as Freedom*, Mario Vargas Llosa wrote that, without democracy, economic policy is bound to fail. Replace 'economic' with 'environmental' and you will find one – perhaps more stimulating – key to reading this book.

Rome, 30 October 2011

Acknowledgments

First of all, I gladly thank all authors who agreed to share this project. If this book is interesting and stimulating, it is because of their valuable contributions.

I would also like to thank Thomas Sutton and Robert Langham, associate editors of Routledge, for asking me to submit a book proposal, starting from a critical paper on environmental economics and policy that had been prepared for the 2009 EAEPE (European Association for Evolutionary Political Economy) Conference.

That paper was nothing but the extended version of my introduction to the special issue on ‘Heterodox Environmental Economics’ published at the beginning of 2009 by the Italian journal *Economia delle fonti di energia e dell’ambiente* (now *Economics and Policy of Energy and the Environment* – EPEE). Invited contributors to that issue were the Nobel Prize winner Elinor Ostrom, and Xavier Basurto, Damien Bazin, René Kemp, Jouni Paavola and Arild Vatn. I thank all of them for sharing their ideas and stimulating my further reflections. I also thank Luigi de Paoli, Editor-In-Chief of EPEE for accepting to host the special issue.

I thank Cristina Murroni for providing support to (and correcting) my basic English.

Last, but not least, I thank Simon Holt, editorial assistant at Routledge Economics, for his help and patience.

Abbreviations

ARRA	American Recovery and Reinvestment Act
BedZED	Beddington Zero Energy Development
BEV	Battery electric vehicle
BSTE	Bounded socio-technical experiment
CAFE	Corporate Average Fuel Economy
CCGT	Combined cycle gas turbines
CHP	Combined heat and power
COP15	Copenhagen Conference of the Parties of the UNFCC
EAEPE	European Association for Evolutionary Political Economy
eceee	European Council for an Energy Efficient Economy
EEA	European Environment Agency
EPEE	Economics and Policy of Energy and the Environment
ESCO	Energy service company
ETS	Emission trading scheme
FCV	Fuel cell vehicle
FIT	Feed-in tariff
GATT	General Agreement on Tariffs and Trade
GBS	Group B Streptococcus
GHG	Greenhouse gas
HERS	Home Energy Rating System
HEV	Hybrid electric vehicle
HFC	Hydrofluorocarbon
ICE	Internal combustion engine
LEED	Leadership in Energy and Environmental Design
MBI	Market-based instrument
MLP	Multi-level perspective
NESEA	Northeast Sustainable Energy Association
OEM	Original equipment manufacturer
PACE	Property Assessed Clean Energy
PES	Payment for environmental services
R&D	Research and development
RDD&D	Research, development, demonstration and deployment
REC	Regional Environmental Council

RES-e	Electricity from renewable energy sources
RTFO	Renewables Transport Fuel Obligation
SI	System of innovation
ST	Socio-technical
TC	Transaction cost
TDM	Transportation demand management
TGC	Tradable green certificate
TIC	Techno-institutional complex
TIS	Technological innovation system
UNFCCC	UN Framework Convention on Climate Change
VAI	Value articulating institution
WCAC	Worcester Community Action Council
WoHEC	Worcester Housing, Energy and Community

Part I

A dynamic and systemic analysis of economic change

1 Agency and economic change

Karolina Safarzyńska

Introduction

Neoclassical economics provides too narrow a perspective to deal with behavioral and structural changes in the economy (Henrich *et al.* 2001b; Fehr and Gachter 2002; Gowdy 2004; Ayres and Bergh 2005; van den Bergh 2007). It focuses on equilibrium outcomes and rationality of market participants, which ignores dynamics occurring out of the equilibrium, bounded rationality, and path-dependent processes. Socio-technical systems and eco-systems coevolve over time, not always in desirable directions. This relates to the fact that increasing returns associated with material infrastructure, production routines, consumer habits, collective frames and institutions determine directions in which changes in the system are unfolding. Over time, they may render lock-in to a single technology or interrelated technologies, which is often illustrated with an example of lock-in to fossil fuel technologies. In this context, structural change may involve, or even require, overcoming behavioral, institutional and technological inertias.

Evolutionary economics provides theoretical concepts and methodological tools to frame dynamics underlying structural change (van den Bergh and Gowdy 2000; Potts 2001; Hodgson 2004). Changes in evolutionary systems are analyzed as a result of variety-reducing selection and variety-generating innovations operating on a diversity of behaviors, institutions and technologies. Populations of heterogeneous elements constitute a prerequisite for selection to act upon. Selection limits diversity of available options, and so the scope for experimenting with variations and combinations of existing options. It can act on the level of individuals and groups leading to multi-level, complex dynamics. In socio-economic systems, two or more evolutionary populations or subsystems can be linked together through mutual adaption processes, leading to coevolutionary dynamics (Winder *et al.* 2005). Coevolution has been evoked to describe interactions between different populations: industry–technology, gene–culture, ecological–economic systems, demand–supply, behaviors–institutions (van den Bergh and Stagl 2004). For instance, in evolutionary models of demand and supply coevolution, preferences of consumers evolve over time as a result of consumer interactions and technological progress, which in turn affects the direction of innovative activities by firms (Windrum and Birchenhall 1998 and 2005).

Evolutionary economics is one of the pillars of neo-Schumpeterian studies of innovations and technological change. They have inspired a number of policy suggestions regarding how to fuel the process of technological change (Nelson and Winter 1982; Silverberg *et al.* 1998; Malerba *et al.* 2008). This includes insights regarding the optimal allocation of investments in different technological options (van den Bergh 2008), polices for creation of market niches (Unruh 2000), un-locking the market (Malerba *et al.* 2008), or the optimal timing of policy interventions (Zundel *et al.* 2005). Still, lacking is a coherent evolutionary perspective on policies for behavioral, technological and institutional change. This partially relates to the fact that the notion of the individual in evolutionary economics in not well established and builds loosely on stylized facts from various disciplines (Dosi *et al.* 2006). As a result, evolutionary economics provides less clear cut policy recommendations regarding individual behavior than neoclassical economics. The aim of this chapter is to explore the contributions of evolutionary economics to policies aimed at inducing structural change and the role of agency therein. The remainder of this chapter is as follows: next we discuss core mechanisms of evolutionary change; following this, the building blocks of agency in evolutionary economics are discussed; then we discuss different types of evolutionary models for environmental policy; the last section concludes.

Mechanisms of evolutionary change

In this section, we discuss the general mechanisms of change in evolutionary systems. In particular, mechanisms of general Darwinism are discussed, which provide a general framework for framing processes in complex evolving systems. Evolutionary changes in one population can occur in response to changes in another population. Different types of coevolutionary dynamics are also briefly presented. The mechanisms of general Darwinism can be applied to explain changes within as well as between groups, leading to multi-level selection. Path dependence and lock-in demand attention too; these notions explain why it may be increasingly difficult to alter pathways of system development over time.[1]

General Darwinism

Evolutionary economics builds upon insights from general Darwinism, which provides a general framework for dealing with complex evolving systems, consisting of populations of varied and replicating entities (Hodgson and Kundsen 2007, 2008). Accordingly, the interplay of diversity, innovation and selection determines the direction in which changes in the system are unfolding. However, there are concerns that studying economic processes in analogy to natural selection comes at the price of abstraction from details relevant for understanding social systems, such as creativity, intentionality and knowledge accumulation (Levit *et al.* 2011). Witt (2004) argues that general Darwinism should be treated as a meta-theory about evolution in nature rather than general principles applicable to explain changes in social systems.[2] Still, the fact that Generalized Darwinism may need to be augmented by detailed explanations of the specific mechanisms in society and nature, does not imply that the framework is inapplicable to the study of social processes (Hodgson and Knudsen 2006).

A heterogeneous population, consisting of diverse elements or members, is essential for evolutionary dynamics. The greater the heterogeneity or variability of elements upon which selection for fitness can act the greater the expected improvement in fitness. This is captured by Fisher's principle (Fisher 1930). In innovation studies inspired by evolutionary theorizing, maintaining a *diversity* of technologies is often recommend for increasing the resilience of the system to unforeseen contingencies so as to 'keep the options open'. However, at the high levels of policy making, the pursuit of a balanced portfolio of diverse options is not always clearly defined or understood (Stirling 2010). This relates to the fact that diversity is a multi-layered concept. Stirling (2004 and 2007) proposes to analyze diversity as having three properties: variety, balance and disparity. Variety is defined as the number of categories into which a population can be partitioned. As a result, the larger these numbers the larger the diversity is. Balance relates to the distribution of the shares of each category in the population, implying that the more equal the shares, the more even the distribution and the larger the diversity. Finally, disparity refers to the degree to which options differ; it captures the distance between categories. Disparity is a qualitative property, which represents a rather subjective and context-dependent aspect of diversity. Economists often emphasize that diversity may come at other costs, for instance, of foregoing advantages of economies of scale and specialization, conducting a multidisciplinary research or co-ordinating various projects. There is a trade-off between the benefits of diversity and the benefits of specialization, which needs to be addressed by decision-makers (van den Bergh 2008).

Selection encompasses different mechanisms by which certain elements, technologies or policies are chosen from the variety of available options. In the simplest form, selection can be understood in terms of picking a subset from a certain set of elements according to a criterion of preference, referred to as subset selection (Price 1995). Alternatively, selection can be seen by analogy with natural selection as the outcome of two independent processes, namely: replication of an encoded instruction set and differential replication of entities during their interactions (Knudsen 2002). In the economic context, selection can operate on behaviors, technologies and institutions. Selection environments determine which options are more likely to develop and diffuse. For instance, liberalization of the electricity market in the United Kingdom has favored the entrance of new combined cycle gas turbines (CCGT). Although, the technology has been relatively cheap to install due to low capital costs and a short time of setting up CCGT plants, its rapid diffusion cannot be explained solely in this way. A number of policy decisions have been taken that created a selection environment advantageous for the adoption of gas in electricity production. This left behind other promising technologies, such as the fluidized bed boiler (Watson 2004).

Selection acts so as to limit diversity in the system. Ultimately, the system may become dominated by, or locked-in to, a single technology or a constellation of interrelated technologies. The process is counterbalanced by *innovation mechanisms*, which introduce new options to the population. In neoclassical models, innovation processes are typically deterministic or captured by stochastic improvements in input productivity. On the contrary, in evolutionary theories, heterogeneous firms actively search the landscapes of technical or service characteristics for better solutions or imitate existing (profitable) technologies on the market, following the seminal work by Nelson and Winter (1982). This implies that the opportunities for innovation depend on the existing options in the population. In particular, the existing variety of technologies determines the scope for experimentation with variations or combinations of existing designs. The latter can be a source of modular or recombinant innovations, where components of different technologies are recombined into a new technological option. Recombinant innovation has been shown to be an important source of novelty in the past. For instance, the medieval European printers combined six independent existing technologies: paper, movable type, metallurgy, presses, inks and scripts (Diamond 2005); early mill technology incorporated water mill and sailing solutions (Mokyr 1990). A recent study compares short- and long-term costs and benefits of investing in recombinant innovation using a formal model (Safarzyńska and van den Bergh 2011a).

Coevolution

Structural change can be conceptualized as a non-linear process, where economic, social and technological subsystems interact with each other leading to irreversible patterns of change. During the process, different sub-systems (markets, technologies, institutions, scientific knowledge, etc.), and within them different groups of entities with conflicting interests (producers, consumers, investors, policy makers, universities, NGOs, labor unions, etc.), coevolve affecting the evolution of socio-technological trajectories (van den Bergh and Stagl 2004; Geels 2005; Loorbach and Rotmans 2006). By starting from the notion of representative agents, neoclassical economic models do not allow modeling coevolutionary responses, feedback mechanisms and increasing returns between heterogeneous populations. Formally, coevolution requires that heterogeneous populations are linked together through mutual adaptation and pressure mechanisms (van den Bergh and Stagl 2004; Winder *et al.* 2005). Evolutionary modeling techniques build explicitly upon the population approach. They allow the conceptualizing of different types of coevolutionary processes, such as between environments and human strategies (e.g., Noailly 2008), technological coevolution (see Safarzyńska *et al.* 2011), different types of industries (e.g., Malerba *et al.* 2005), demand-supply coevolution (e.g., Windrum and Birchenhall 2005), behavior and institutions (e.g., Bowles *et al.* 2003; Hodgson and Knudsen 2004) so as to explore their properties.

In particular, studying three types of interrelated coevolutionary dynamics can offer insights to mechanisms underlying the process of structural change: technological, industry and supply–demand coevolution. Technological coevolution implies that technologies coevolve together shaping each other's trajectories. For instance, changes in products qualities, the system of their production and use can occur as a result of mutual adjustments and adaptations between two or more technological systems. This can be studied using the NK-model (Frenken and Nuvolari 2004; Caminati 2006; Alkemade *et al.* 2009). The model has been proposed by Kauffman (1993) as a stochastic method for constructing an adaptive fitness landscape. In the framework, each element of the system is assigned a fitness value, which changes depending on the fitness of other elements. In NK models of technological coevolution, technologies are represented by binary bit-strings; each bit depicts a specific technical component or technological characteristic. For instance, in Frenken and Nuvolari's (2004) paper, the NK fitness landscape describes a multidimensional design space of steam power technology, while each string represents a unique steam engine design. The model allows studying adaptations of steam technology to different application domains (sectors). It provides insights to coevolution of technological components and the steam engine technology.

An agent-based technique offers an alternative approach for modeling coevolutionary processes between heterogonous populations, which is currently increasingly popular. For instance, Malerba *et al.* (2005) develop an agent-based model to study coevolution of the computer and semiconductors industries. In the model, firms producing computers buy specialized components, such as semiconductors, from suppliers. The evolution of component technologies affects the design of computers, and thus their performance and price. Technological change is discontinuous: new component technologies displace old ones, which subsequently allows improving the design of computers. Producers of computers may decide to vertically integrate, i.e., produce components in-house, or buy semiconductors on the market. The model proved to replicate well historical patterns of vertical integration and specialization in computer industries. Malerba *et al.* (2008) apply this model to study which policies are effective in preventing a high degree of market concentration and supporting the entry of new firms.

Coevolutionary frameworks of supply and demand has been increasingly employed to study conditions under which technological substitution occurs and the role of evolving consumer preferences in the process (Windrum and Birchenhall 1998, 2005; Janssen and Jager 2002; Oltra and Saint-Jean 2005; Saint-Jean 2006; Windrum *et al.* 2009a, 2009b; Malerba *et al.* 1999, 2005, 2008; Safarzyńska and van den Bergh 2010b). This has been motivated by the fact that producer–consumer interactions play an important role during the innovation process (emergence and diffusion), and in later phases of product development (Malerba 2007). For instance, knowledge generated through learning-by-using can only be transformed into new products if producers have direct contact with consumers (Lundvall 1988). Producers may monitor consumers to assess their competences, i.e., the learning potential of the market to adopt new products. Coevolutionary modeling of demand and supply show that evolution of consumer preferences affects the direction of technological change in the industry (Windrum and Birchenhall 1998, 2005), while network effects in consumption can create an important obstacle to diffusion of new technologies (Safarzyńska and van den Bergh 2010b). Recently, Dijk *et al.* (2011) explored how changing social appraisal of technology options and regulatory support affect the diffusion of 'clean' vehicles in a coevolutionary setting.

Group selection

The economy can be perceived as a complex, hierarchical structure comprising various levels and subsystems linked together through strong feedback mechanisms (Potts 2001). Multilevel or group selection is a theory of evolutionary change which involves selection operating at both individual and group levels (Bergstrom 2002; Wilson 2002; Henrich 2004; Garcia and van den Bergh 2011). It has been shown to explain the evolution of co-operation where selection at the level of individual favors selfish behavior, but groups with more co-operators grow faster or are more likely to win in a multi-group conflict (Bowles *et al.* 2003; Wilson 2002; Van Veelen and Hopfensitz 2007). Group selection addresses the formation, growth and interactions within and between groups. It offers a theoretical perspective to study public decision-making; institutional and organizational change; and socio-economic power (van den Bergh and Gowdy 2009).

Group selection has been much debated in biology and social science (for a summary of the discussion see van den Bergh and Gowdy 2009). Cultural group selection is considered as more relevant for explaining changes in social–cultural contexts. Cultural group selection involves cognitive learning and cultural acquiring of social traits (Boyd and Richardson 1985). It allows combining upward and downward causation between selection operating on habits at the level of individual interactions and on routines at the group level. In this context, Hodgson and Knudsen (2010) suggest thinking of habits as replicators, whose actual replication depends on the fitness advantage they bestow upon those individuals and groups who carry them. Individuals can change habits through imitations of others or due to observational learning within groups. At the higher level, routines can emerge as a result of interactions between individuals. Witt (2008) emphasizes the functional role that routines play in organizations, which can be interpreted in terms of fitness advantages they provide to the group. In particular, routines can enhance coherence and truce within organization, create an organizational identity, set the normative standard of behaviors, and serve to support the sustainability of organizational goals.

As an alternative approach to the analysis of multi-level, evolutionary dynamics, Dopfer (2006) and others propose a three-level framework, which is composed of micro, meso and macro levels. The micro-level is defined here in terms