In (2011)"The Elgar Companion to Recent Economic Methodology",
ed. by John B. Davis and D. Wade Hands, Cheltenham: Edward Elgar.

14 Economics in a cultural key: complexity and evolution revisited

Kurt Dopfer

14.1 THE RISE OF EVOLUTIONARY ECONOMICS

The last three decades have seen an upsurge in the number of publications addressing themes that have come to be grouped under the heading of 'evolutionary economics'. In a recent bibliometric account comprising the abstracts of articles published in all economic journals over the past half-century, Sandra Silva and Aurora Teixeira have been documenting the impressive magnitudes and structural dynamic of this trend – a trend that has accelerated tremendously in the last two decades, considering that 90 per cent of this body of research is recorded as having been published after 1990 (Silva and Teixeira, 2009; EconLit database). There have been related accounts, emphasizing the interpretation and assessment of these trends, that have not shied away from a discourse about the general applicability and adequacy of the term 'evolutionary' itself (Dolfsma and Leydesdorff, 2010; Witt, 2008; Hanappi, 1994; Hodgson, 1993).

In its paradigmatic outlook, the essential difference of evolutionary economics from the neoclassical mainstream is that it gives priority to dynamic rather than static analysis and, more specifically, puts behavioural, institutional, technological and other explanatory variables (rather than exogenous ones) centre stage when coping with the former. It was a great moment for the science of economics, and for evolutionary economics in particular, when the book by Richard Nelson and Sidney Winter entitled *An Evolutionary Theory of Economic Change* appeared in 1982. In their trailblazing contribution, they set out two perspectives: a general one, addressing foundational issues, and a particular one, relating to the construction of specific theoretical models. Addressing the former, they state (Nelson and Winter, 1982, p. 4) that: 'a major reconstruction of the theoretical foundations of our discipline is a precondition for significant growth in our understanding of economic change'.

They acknowledge (p. 399) that they are 'developing a general way of theorizing about economic change'. In turn, their particular endeavour is 'with exploring particular models and arguments, consistent with that approach, focusing on particular features or issues about economic change' (p. 399). When assessing the two, they state (p. 399), significantly:

> Of the two parts of the endeavor, we view the development of the general theoretical approach as by far the more important. The particular models are interesting in their own right, but we regard them primarily as examples of the class of models consistent with our proposed way of theorizing.

The significance of their book lies in the fact that it succeeds in providing an alternative to neoclassical economics by furnishing essential cues for a new 'way of theorizing'.

14.2 EVOLUTIONARY ECONOMICS IN THE FUTURE

When assessing developments in the field since the publication of this book, two trends warrant particular attention. First, there has been a considerable falling short in the ensuing efforts to attain the two goals. Most of the above-mentioned major publications, worthy though they are, have concentrated on devising and refining particular models and theoretical positions, with much less effort being devoted to the goal of constructing viable foundations for the approach. The lack of underpinning has not just left much valuable work unstructured and unrelated, it has also rendered the new discipline as a whole generally weak in terms of its competition with the mainstream.

Second, there has been a growing recognition that the search for better foundations should be informed by integration rather than isolated developments along author-focused approaches based, for instance, on the works of Joseph Schumpeter, Thorstein Veblen, Friedrich Hayek or Alfred Marshall. This applies even to Schumpeter's work, which has probably contributed more to the foundations of the new approach than that of any other author (Hanusch and Pyka, 2007). Marking the boundaries of a modern Schumpeter programme, Andreas Pyka and Horst Hanusch (2006, p. 4) note that: 'that strand of literature which is concerned with industry evolution and technological progress . . . can be coined Neo-Schumpeterian economics'.

Since Nelson and Winter's work bears strong imprints of Schumpeter's thinking, what Nelson and co-author Davide Consoli have said recently when addressing the overall scope of the discipline is particularly noteworthy (Nelson and Consoli, 2010, p. 665):

> Many contemporary economists who consider themselves evolutionary theorists have in mind a narrower and a broader goal. The narrower goal is to meet what we will call 'Schumpeter's challenge', which is to create a theoretical framework capable of analyzing innovation-driven economic growth. While it might be suggested that this narrow goal is rather broad, the still broader goal is no less than the replacement of neoclassical theory with a theoretical alternative . . .

Schumpeter's approach, which originally represented the general reference point, is now seen as a narrow approach in view of a new, broader vision of the discipline. Esben Andersen's (2008, p. 1) general assessment may mirror a view held widely in this school of thought: '[E]volutionary economics has moved beyond Schumpeter's strand . . . and has also moved beyond Marshall and Veblen and many other pioneers'. Although the extended scope has not yet coalesced into a solid, unified theoretical framework, it has already been providing, as will be shown, enormously fertile ground for developing, testing and experimenting with new theoretical approaches, simulation techniques, statistical methods, ways of organizing and collecting data and mathematical representations.

14.3 NATURAL HISTORY: HIERARCHY OF EVOLVED COMPLEXITY

From a global perspective, the question is this: what makes entities specifically economic ones, distinctively different from non-economic ones? Economic entities are part of a natural history that has evolved into a hierarchy of levels with differing complexity. Although complexity scientists have variously addressed the issue of how to define and validate the hierarchy of evolved complexity (Lane, 2006; Holland, 1998), few contributions have been forthcoming so far from the camp of economists, with the notable exception of John Foster (2005).

Construed in elementary terms, the natural hierarchy can be seen as being composed of physical (or physiochemical), biological and cultural levels. Significantly, economic entities are phenomena that, in their evolved complexity, belong to the cultural – not to the physical, biological or any other – level of complexity. To claim empirical validity, economic entities need to be portrayed in such a way that they take into account the characteristics of the level of complexity to which they belong. Economics in this way is, in a very fundamental sense, a cultural science.

14.4 THE NATURAL SCIENCES AS A TOOLBOX

Although empirical validity is clearly of major concern for science, there is another desideratum of equal significance. Scientific statements stand out over non-scientific ones in their logical rigour, formal elegance and openness to falsification. To qualify for appellation as 'scientific', a particular toolbox is required, involving analytical language, various forms of logic, mathematical representation, statistical methods and modelling techniques. In their search for an adequate toolbox, proponents of evolutionary economics have turned variously to physics and to biology. The physics-based approach to economics has benefited much from the early work on complexity done at the Santa Fe Institute (Anderson et al., 1988; Arthur et al., 1997). Through the application of modern physics, the work acquired the status of a new heterodox economics. The new assumptions of non-linearity, feedback, discrete parameters and iteration stood in stark contrast to the well-behaved world of mechanics that informs the neoclassical canon. These nucleic activities have developed into a broader programme under the label 'complexity science' or 'complexity economics' (Colander et al., 2010; Rosser 2010). The complexity approach – arguably the sister discipline of evolutionary economics – has branched into various special strands, in particular into econophysics and econobiology. The generality of the concept has evoked the broad vision of a 'transdisciplinary approach' (Rosser, 2010).

The toolbox of physics has provided mathematical representations for modelling various kinds of economic phenomena, ranging from laser-based synergy for modelling the emergence of collective preferences, fashion patterns or self-organization in firms (Weidlich, 2000; Haken, 2005) to multi-particle physics for modelling the behaviour of various markets, particularly financial ones (Schweizer, 2003; Lux and Kaizoji, 2007), complex regularities of socio-economic networks and collectives (Hollingsworth and Müller, 2008; Sornette, 2008), and to percolation theory for modelling spatial dynamics (Brenner, 2004) or the diffusion of technology under conditions of various consumer demand characteristics (Silverberg and Verspagen, 2005a).

The physics-based models display generally high mathematical abstraction, precision and consistency. To achieve this they use methods that were developed to represent phenomena the complexity of which is lower than that for economic ones. The tools adopted work within a range of empirical assumptions, and importing these tools into economics necessarily means accepting their particular array of assumptions. Accordingly, the need arises to explain what exactly justifies treating physical particles as if they were economic particles with low complexity, and how these then relate to others in the entirety of an economic unit that typically displays features of high complexity. Models of a physico-mathematical nature are premised on a great empirical distance – that between dead matter and economic life – thereby rendering evident the need to justify their empirical content. The methodological crux is this: the empirical distance is great, making the problem large; and, simply because it is large, solutions with regard to vindicating it become difficult. The size of the problem paralleled by the ensuing difficulty to solve it may well represent a major limitation on the development of physics-based economics into an empirically attractive variant.

14.5 BIOLOGY: PARADIGMATIC SIGNPOST AND TOOLS FOR ECONOMICS

The proximity of biology and economics – both deal with living systems – has inspired economists in two fundamental ways. First of all, biology has served as paradigmatic orientation in a world ruled by mechanics. The founding fathers of the discipline, particularly Veblen and Marshall, entertained the vision of economics as a science drawing deep inspiration from biology (Veblen, 1898; Marshall, 1890). The two great precursors held quite different views about how economics should be reconstructed, but they were united in what they were against: the mechanics of neoclassical economics.

Biology may provide paradigmatic guidance for economics in terms of both its static and its dynamic problems. Concerning economic statics (defined as the logic of coordination), biology provides a paradigmatic pillar in the form of the living system approach as, for instance, universalized into 'general system theory' by Ludwig von Bertalanffy (Bertalanffy, 1968; Kapp, 1976). The historical dynamic of that system, as its second pillar, is captured by the concepts of ontogeny and phylogeny. The common denominator is biological knowledge, say *G*. In a state of ontogeny, an organism performs life-maintaining operations on the basis of a given *G*. In phylogeny, *G* changes over time. Gottfried Leibniz, an early discoverer of evolution, spoke – dissenting from Isaac Newton's continuity of equilibrium – of a continuity of change (Leibniz, 1714 [1991], calling it 'Continuity Principle'; Öser, 1974; also Witt, 2004).

The prefix 'biological' in knowledge can, like a constant in mathematics, readily be dropped, and then we get a universal concept of knowledge and of operation. Applied to economics, this means that we have two major levels of theoretical analysis:

- operational level: ongoing operations based on given knowledge.
- knowledge level: structure and evolution of knowledge governing operations.

Evolutionary economics deals with the structure and evolution of knowledge for economic operations. Neoclassical economics analyses ongoing economic operations under the assumption of given knowledge.

Biology is useful as more than just a paradigmatic signpost; it also renders practical services. Like physics, it provides a toolbox incorporating modelling techniques, mathematical representations and statistical procedures. Applying this toolbox, a range of conceptual, theoretical and simulation models have been devised, including genetic algorithm and genetic computing (Alander, 2009), game-theoretic models and replicator dynamics (Gintis, 2009), evolutionary growth and percolation models (Kwasnicka and Kwasnicki, 2006; Silverberg and Verspagen, 2005b) and fitness landscape models (Frenken, 2006). These models shed light on the richness of life in economics in a mathematical form borrowed from biology.

The issue, again, is whether the mathematical representations adequately portray the complexity that is characteristic of economic phenomena. The complexity of life is closer to that of economic phenomena than dead matter, but there is still an empirical distance to be justified (Windrum et al., 2007; Geisendorf, 2007; Foray and Steinmueller, 2001). For instance, genetic algorithm and genetic computing models posit knowledge in terms of algorithms, prompting questions about the extent to which a completely determined technical sequence can capture evolution; Stuart Kaufmann's 'NK fitness landscapes' depict biological environments, inviting the question as to whether or in what way these portray characteristics of economic landscapes with complementary-defined structures anchored in the division of labour and knowledge; and replicator models dealing with genetic knowledge transmission call for clarification as to whether or how empirically meaningful economic knowledge transmission is without considering the behavioural key concept of adoption upon which all communication is premised.

Biology-based models, like physics-based models, require an explanation as to why biological phenomena, such as genes, organisms, replication or selection, should represent the complexity of economic phenomena. There has been an extensive discussion revolving around 'universal Darwinism', a concept introduced by biologist-philosopher Daniel Dennett (1995). It got a warm reception from some economists (Hodgson, 2002; Hodgson and Knudsen, 2006; Aldrich et al., 2008), but little approval from others, who criticized either the weak evidence of homologies, or the irrelevance of its questions (Levit et al., 2010; Witt, 2008, 2004; Nelson, 2006; Cordes, 2006; Vromen, 2007), or the lack of integration of other relevant concepts such as self-organization (Geisendorf, 2009; Buenstorf, 2006). It must suffice here to conclude with a general assessment: the discussion has furnished little in the way of systematic practical criteria to evaluate the question of whether, or to what extent, it is warranted to apply biological models or representations to a clearly defined class of economic cases.

The difficulties with establishing systematic procedures have led some economists to discard a transdisciplinary perspective altogether. Nelson and Winter, whose work has set the pace for much of the significant debate in the last three decades, have pointed out that they generally start with theoretical propositions and use any tools or language that are fit for a particular purpose of economic theorizing. Unlike advocates of universal Darwinism, they contend (Nelson and Winter, 1982, p. 11): 'We emphatically disavow any intention to pursue biological analogies for their own sake, or even for the sake of progress toward an abstract, higher-level evolutionary theory'. Stanley Metcalfe takes the same course when he asserts (Metcalfe, 2005, p. 392) that the various evolutionary concepts employed in economics, 'have nothing inherently to do with biology and related disciplines'.

Indeed, why should one rule out the use of methods, analytical models or mathematical representations if they are useful in economics but lack empirical corroboration in biology? Universal Darwinism cannot set the theoretical agenda of economics. To state that self-generated change and selection are important in economics means preaching to the converted, and to investigate whether or not Darwinian principles hold in physics as they do in biology is, though intellectually highly fascinating, of no great concern for economists. The assessment reached from a practical vantage point is this: encountering universal Darwinism with agnosticism not only allows us to retain the precious legacy of Darwin's work, it also opens up biology as a rich field for economists, ranging from Ludwig von Bertalanffy's grand general system theory to more recent (neo-Lamarckian) approaches involving epigenetics, which explain the adoption of information – the core of a communication-based evolutionary behavioural economics – in a way that Darwinism does not (Knottenbauer, 2009).

14.6 ECONOMICS AS CULTURAL SCIENCE

Economics belongs to the cultural level of the evolved natural hierarchy of complexity. In order to acknowledge the complexity of economic phenomena it is necessary to state them in terms of the complexity of that level.

Looking at the research that has been carried out in evolutionary economics, it is clear that there have been few efforts to confront the problem head-on. The main reason for this reluctance to do so may lie in the difficulties inherent in devising methods, mathematical representation and statistical tools adequate to cope with the level of complexity that the cultural level expounds. In the approach to economic complexity, recourse has been had – as has been pointed out – to lower levels of complexity 'as if' they were the levels that economic phenomena displayed. I am proposing that, if economics is to be empirically meaningful, the starting point of any theoretical endeavour has to be the cultural level, not the physical or biological level. Based on this theoretical premise, any tool may be chosen that renders adequate service.

While there is no broad discourse on economics as a cultural science, some groundwork has been forthcoming from the evolutionary camp. Though still scanty, it may well provide a rough skeleton of a future theoretical agenda setting the pace for further developments. The research includes works by Carsten Herrmann-Pillath (2010), Jason Potts (2008), Richard R. Nelson (2008), Ngai-Ling Sum and Bob Jessop (2011) and Michael Hutter and David Throsby (2008).

The domain of human culture comprises two major constituencies: *Homo sapiens* and cultural artefacts. Captured in their essentials, both are carriers of cultural knowledge: *Homo sapiens* of subjective (subject-related) knowledge and cultural artefacts of objective (object-related) knowledge. This nucleic view of the cultural level yields a classification that is, in many and important ways, useful for economic theory construction and modelling. It distinguishes between carrier and knowledge on the one hand, and between subjects and objects on the other.

Cultural knowledge is used in various cultural contexts. The specificity of and differences between cultural contexts are defined by the kinds of operations that are performed. In this way, economics is defined as the discipline dealing with the cultural context governing economic operations. Economic operations include production, consumption and transaction. This insight starts to put some flesh on the bones of the earlier distinction of the knowledge level and the operational level, specifying the former as cultural knowledge and the latter as economic operations. Cultural knowledge becomes economically relevant – that is, economic knowledge – when used in the context of economic operations.

14.7 HOMO SAPIENS OECONOMICUS

Homo sapiens and cultural artefacts thus acquire particular meanings in the economic context. *Homo sapiens* – in his economic operations – gets specified as a particular disciplinary construal: *Homo sapiens oeconomicus* (HSO; Dopfer, 2004). Seizing upon this concept, various specifications may be allowed for, depending on the faculties required for particular problem solving in economic environments. Essentially, HSO operates in an economic environment that embraces highly complex structures and is subject to continuous novelty-driven change. HSO, accordingly, may be seen as a 'complex individual', coping with problems of structural complexity (Davis, 2008, 2003), or as '*Homo creativus*', meeting the challenges of unpredictable qualitative change in economic environments (Foster, 1987). The former construal may prove particularly useful as an assumption for complexity models, the latter as an assumption for evolutionary models.

Other primates create culture, but *Homo sapiens* – and, for that matter, HSO – excels in three fundamental ways. First, man is a knowledge maker. This faculty unfolds as a process the characteristics of which may be captured by a trajectory that is composed of three phases:

- Phase 1: origination of knowledge.
- Phase 2: adoption of knowledge (perception, understanding, learning).
- Phase 3: retention of knowledge for ongoing economic operations.

Second, *Homo sapiens* can combine different pieces of knowledge into a whole. This faculty is exercised not only on the basis of reacting to environmental conditions but also on that of imagination independent of those external conditions. The cognitive autonomy enables complex knowledge anticipation. Third, humans can share their imagination. Symbolic language is a powerful tool for doing so. Shared imagination, as it unfolds in the process of the generation, adoption and retention of knowledge, lies at the heart of economic evolution.

14.8 MATERIAL CULTURE IN ECONOMICS

With *Homo sapiens*, cultural objects acquire their operational meaning when posited in an economic context. Operationally specified, these represent commodities, products or goods, or similarly operationally specified objects.

By way of an exemplar, archaeologists are excavating objects at a site that furnishes a record of material culture. They apply methods of stratification, which highlight the history of objects, and of geographic information systems (GISs) and related techniques, which place the findings in their spatial context. The material account is visible, measurable and quantifiable, but in itself says nothing about the rationale of the organization of the objects and about their operational use. Although archaeologists agree widely on the usefulness of modern stratification methods, the GISs and related techniques, they are split in their views as to whether or in what way it should be of concern to an archaeologist to give meaning to the objects or, instead, simply to leave them as material witnesses untouched by hermeneutic endeavours.

For the present analysis, it is particularly interesting that efforts have been under way to construct the discipline as evolutionary archaeology employing explanatory schemes from biology, such as Darwinism. These attempts have been challenged on the grounds that the explanations were based on wrong analogies to biology – though, in this process, they have left in limbo the principal question, as to whether or how to explain the material record in general. Starting from the cultural (rather than the biological) level, an approach has been suggested that relates cultural artefacts to human cognition, highlighting the co-evolution of objects and cognition (van der Leeuw and McGlade, 1997). This new kind of complexity-based evolutionary archaeology takes as its departure point the cultural level. It employs principles from biology, such as Darwinian selection, whenever they fit a particular explanatory purpose; but it does not construct archaeology from biology. Given this cultural platform, operational economic contexts may be identified, and the discipline of economics may be given a systematic home in archaeology. Complexity-based evolutionary archaeology, in turn, would seem to be the most natural home for evolutionary economics, which generally emphasizes long-run views and empirical evidence.

In neoclassical economics, cultural objects have no qualitative attributes. It makes for the universality of the demand and supply model in its partial and general equilibrium variants that it abstracts from any characteristics. Qualitative differences between commodities are translated into quantitative differences stated in price ratios of commodities. Heterogeneity turns into homogeneity. The neoclassical model operates not only with the assumption of a representative agent but also – significantly – with that of a representative commodity.

In contrast, evolutionary complexity economics works with both heterogeneous agents and heterogeneous commodities. Admittedly, there are types of multi-agent models that work with heterogeneous agents but retain the assumption of homogeneous commodities, as when analysing the fish market of Marseilles (Kirman and Vignes, 1991). Although these models shed light on market equilibrium under the condition of a single kind of commodity, such as stocks, or indeed fish, they fail to provide new insights when there are many different kinds of commodities. In the case of the economy as a whole (or an equivalent macro context), when, typically, many markets connect qualitatively in complementarities, the assumption of heterogeneous commodities is mandatory. As with an excavation site in archaeology, an economy is composed of heterogeneous objects, and constructing the whole can be accomplished only by putting together the pieces with all their distinct attributes.

14.9 BIMODAL METHODOLOGY

Economic operations are anchored in knowledge. An understanding of the nature of structure and the evolution of knowledge is therefore the key to an understanding of economic operations. A clear analytical exposition of this concept would therefore appear to represent a sensible starting point for the construction of an economic theory or model.

In its archetypical form, knowledge may be seen as representing a knowledge-bit. This elementary analytical unit has two essential properties. On the one hand, it is an idea; it embodies semantic content. As idea, it is timeless and spaceless. On the other hand, ideas do not reside in a Platonic heaven, but are always physically actualized; they have a carrier. Ideas are actualized by matter and energy in time and space. The knowledge-bit therefore typically possesses – ontologically – a bimodal nature (Dopfer and Potts, 2008).

Acknowledging this ontologically anchored characteristic has important implications for the way methodology is approached. Ideas are not observable. They cannot be measured with a metre rule but, instead, have to be interpreted in terms of their meaning – for example, as function or task. The appropriate procedure for coping with qualitative attributes, such as product or technological characteristics, is hermeneutics. In turn, knowledge in its physical actualization is observable. It can be measured on a metric scale and quantified. Its methodology is statistics and other such quantitative measurement.

Conceiving the elementary unit of the knowledge-bit in the entirety of its properties calls for recognition of both quality and quantity: for a bimodal methodology. A monomodal methodology aims either at only a qualitative empirical account or at only a quantitative one. It would be a mistake to associate traditional economics with quantification and distinguish it from evolutionary and complexity economics as an approach that deals only with qualitative analysis. The difference is that the latter strand is premised on concepts such as technological heterogeneity or product characteristics, conducting quantification in recognition of these qualitative attributes. Traditional economics lacks any such hermeneutic guidance. It is therefore good at aggregation (notwithstanding the well-known problems that accompany it), but fails entirely in accounting for structure. Evolutionary economics retains qualitative attributes and, rather than rejecting any aggregation, it performs it in recognition of the qualitatively structured data.

14.10 FROM MICRO TO MACRO

The knowledge approach stands in close kinship with the system approach. A system may be defined as relations between component parts, and knowledge, if conceived of in a very generalized manner, defines both. In this way, the economy as a knowledge-defined macro-system is composed of interrelated knowledge-defined micro-systems.

In simple models, the micro units are treated like physical particles (rather than systems) with fixed behavioural propensities. Complex models, in turn, treat the micro units themselves as systems, and, as a consequence, the macro-system of the economy is composed of interrelated micro-systems. There is a system hierarchy, with an upper level consisting of the total system and a lower level of multiple subsystems. Coping with the intricacies of system hierarchy poses major challenges for complexity science and complexity economics (Lane, 2006).

The analytical problems are compounded when dealing with several levels. Given a continuum of levels, the complexity in the analysis may be reduced by keeping the component parts simple, for instance, as in the mentioned case, by working with non-systemic micro units. Heading in the opposite direction, higher levels may be accounted for by specifying the micro unit, for instance by allowing for HSO in his systemic or similar characteristics. A theory of the firm may thus work with either a simple or a complex model of HSO. Viewed from the angle of its 'micro–micro' assumptions, it will be either a simple or a complex theory of the firm (Leibenstein, 1976a, 1976b; Frantz, 1986, 1997).

14.11 COMPLEXITY MEETS EVOLUTION: MESO

Looking at the economy through the lens of complexity science, we see it as system. Accordingly, the analytical focus here is on aspects such as hierarchy, structure, relations and complementariness. In this way it is, basically, a static view. The further question, then, is this: how does the macro-system move in time? How does the economy as complex system evolve?

We get a first clue when recalling that the micro unit is involved in the process of the generation, adoption and retention of knowledge. Change occurs in the form of a micro trajectory actualized within the boundaries of a subsystem – for example a firm. Since the novel knowledge variant introduces a novel component into an extant structure, structural change takes place. This is an important result; and it is here, where complexity-based analysis usually ends, that evolutionary economics steps in.

From an evolutionary angle, the micro units are, in their process-dynamic, not closed but open systems. Novel knowledge variants cross the boundaries of the generating carrier, 'spilling over' into the environment. Knowledge is encoded and decoded by carriers, and transmitted by communication.

The hallmark of the bimodality assumption is that a single knowledge-bit can be actualized many times. It can be actualized not just by a single carrier but by many carriers; for instance a technology can be adopted by many firms. A single actualization of a knowledge-bit may be possible, but it would be a special case, as opposed to the general case of many actualizations. Complexity economics, reduced to its essentials, assumes a special case to be the general one. Introducing the evolutionary perspective, the analytical unit for the construction of an evolutionary macro is not a single knowledge-bit (a single idea, a single actualization) but, rather, a single idea and many carriers actualizing it. The analytical unit is one knowledge-bit and many actualizations. Evolutionary complexity expounds as both 'one-ness' and 'many-ness'.

This leads us to a theoretical architecture of economics in which the received micro–macro dichotomy collapses. 'Micro' is a member of a population, and it is not the micro unit but, rather, a population of them that is the component part of 'macro'. One may circumvent the population by heading directly from micro to macro, but this represents a valid procedure only if one is dealing with the uniform single-actualization case or if the aim is to ignore the aspects of process altogether.

As it is neither micro nor macro, there is a gap in our terminology. Recognizing the intermediate nature of this analytical unit, we may call it, without challenging our vocabulary excessively, 'meso'. The upshot of the meso unit is the duality of its defining characteristics: it is a structure component and a process component. It is a structure component in that it connects as single knowledge-content or idea with others (section 14.13), and a process component in that it expounds the logic of its physical actualization in time and space (section 14.14).

14.12 ARCHITECTURE: MICRO–MESO–MACRO

The architecture of an evolutionary complexity-based economics is starting to take shape. Its constituent domains are these: micro, meso and macro. The major building block from which macro is constructed is meso. The construction work can start by specifying what the two constituencies of knowledge consist of: knowledge content and actualization process. Constructing macro from knowledge content, we get structure in its semantic characteristics, as ideas; let us call it the 'deep' macro structure. Constructing macro from actualization processes, we obtain an observable structure as it unfolds along the trajectories of the generation, adoption and retention of knowledge; we may call this the 'surface' macro structure.

14.13 INVESTIGATING STRUCTURAL COMPLEXITY

Knowledge content may come in two guises: as a single knowledge-bit or as a structured knowledge composite actualized in a carrier. Depending on which one we choose as our assumption, we will get quite different models.

On the one hand, a meso model may be constructed by turning to the composite knowledge actualized in a carrier – for example a firm. A meso population is then composed of many carriers, such as firms. The macro is construed analogously, from a composite of carrier-defined meso units. It represents the visible surface structure of macro. Most current strands, such as multi-agent models and industrial sector dynamic models, operate on the basis of carriers or agents. In models of the former type the theoretical specification of meso does not play an essential role (Tefsatsion, 2002), but it is a constituent aspect in the latter (Pyka et al., 2006; Pyka and Fagiolo, 2007; Castellacci, 2009).

On the other hand, meso may be viewed as being composed of single knowledge-bits, such as a technology. Unlike in the preceding case, the meso population is now not composed of carriers but, rather, of actualizations of a single knowledge-bit. In this way, for instance, a single technology has a population of actualizations. Models that operate upon single knowledge-bits (rather than carriers) include learning, selective adoption and path-dependent models, as addressed in the following section.

Employing knowledge-bits as the building block, macro emerges as a deep knowledge structure or division of knowledge. The methodological cornerstone of this analysis is mereology. Though not conducted under this label, there is a body of literature (scanty as it is) that explicitly recognizes its theoretical significance (Helmstädter, 2003; Langlois, 2002; Antonelli, 2008). By way of an example, producing a car requires the assembly of various components that stand in complementariness to each other. In contrast, a carrier-based composite approach allows us only to analyse interdependences stated in terms of inputs and outputs – for instance, as a Leontief inverse matrix. Neither the input mix nor the output end result provides any information as to how the component parts are combined. As can be seen, therefore, the conventional composite approach fails to serve as an appropriate basis for depicting the 'deep' structure of knowledge in an economy.

Micro knowledge-bits or carriers may be assembled into a subsystem; or, similarly, a game-theoretic social context may be singled out for partial analysis (Elsner, 2010; Hayden, 2008). In this way, a further level (besides micro and macro) in the continuum of levels of the system hierarchy may be introduced. Analogously, a level of sub-aggregates in a continuum marked by micro (no aggregation) and macro (total aggregation) may be allowed for. Assuming a single (systemic, aggregation) level, it will show up as an intermediate level, and the label 'meso' may be assigned to it. Introducing further levels in the continuum, a sequence of meso levels will result – say, meso 1, meso 2, meso 3 and so on; this is not a satisfactory analytical result.

Within the present framework, for an analytical unit to qualify as meso, two conditions have to be met. On the one hand, the construal must be identified as a component part of a structure. It is inessential that the structure component itself expounds structural features (though this assumption is consistent with the concept). On the other hand, the structure component must be stated in terms of a process dealing with the generation, selective adoption and retention of knowledge. Although in-depth system analysis, game theory or differentiated aggregation procedures are themselves useful, they fail to provide essential cues for a theoretical construction of an evolving macro structure unless they explicate its role as structure component and, as is shown subsequently, as process component.

14.14 THE EVOLUTIONARY CORE

While a systemic account focuses on the synchronic aspects of an economy, evolutionary analysis aims at an enquiry into its diachronic aspects. Dealing in the following with the latter, meso – as building block for macro – needs to be identified as a process component. Until this juncture, change has been viewed as occurring within micro – for example a firm – representing its dynamic as a micro trajectory. This concept may serve as a blueprint for dealing with the meso dynamic – with the only, albeit essential, difference relating to adoption. In the first phase the two concepts match, but in the second phase (dealing with the adoption of knowledge) the distinction is between microscopic and macroscopic – or 'mesoscopic' – adoption. Again, the trajectory may be construed by employing either a single carrier or a single knowledge-bit actualized in distinct populations.

As a master model, the meso trajectory looks as follows:

1. Origination of new knowledge.
2. Macroscopic adoption of new knowledge.
3. Retention of new knowledge.

An enormous amount of work has been done on the various aspects of the trajectory dynamic. In the most recent work, a trend may be observed away from the analysis of 'isolated trajectories' towards looking at 'embedded trajectories', which work out their dynamic in a structured or network environment (Potts, 2000).

With regard to the first phase, novelty generation, though usually considered the engine of economic growth, is still for the most part an under-researched topic (Witt, 2009; Grebel, 2009; Encinar and Muñoz, 2006). An intriguing aspect concerns the complex dynamic relationship between structural complementariness and the generation of novelty, as captured by the concept of 'generative relationship' and micro–meso–macro innovation clusters (Lane and Maxfield, 2005; Brette and Mehier, 2008).

There is a vast literature related to the second phase, the diffusion and macroscopic adoption of knowledge. The work embraces broadly conceived diffusion models (Buenstorff and Klepper, 2009; Klepper, 1997), selection models (van den Bergh and Gowdy, 2009; Knudsen, 2002), path-dependence and network life cycle models (David, 2005; Martin and Sunley, 2006; Arthur, 2009; Pyka, 2000) and learning and networking models (Dosi et al., 2005). These models address different aspects of the meso dynamic, but they all share the feature of conceiving it in a structured environment or network.

The third phase embraces the fields of habits, skills and routines and, in general, the field of institutions. The literature on these topics has expanded ever since the publication of the seminal 1982 contribution by Nelson and Winter (Lazaric and Raybaut, 2005; Becker, 2008). Further developments may be expected along the line of the original strands of American institutionalism – a theoretical potential that is far from being exhausted (Nelson, 2008; Hodgson, 2007; Nelson and Nelson, 2002).

14.15 LOOKING TO THE FUTURE

Schumpeter remarked 100 years ago that economic statics was already well developed and that what was therefore needed was the development of an economic dynamics. Developments in the discipline took a different course, however. The theoretical efforts of the last 100 years or so have resulted in a monumental edifice of economic statics, lacking anything comparable on the side of economic dynamics. The exceptions were (besides Schumpeter's own contribution) the various post-war economic growth theories. While these theories, particularly in their vintage as endogenous growth theories and post-Keynesian models, have furnished important insights, they are built on premises that make it difficult to address economic growth as an endogenously self-generating, self-adapting and continuously self-restructuring process.

A theory conducive to coping with this core problem requires the introduction of a vehicle that allows us to deal with both process and structure. Since structure and process are not isolated but, rather, two sides of a single phenomenon, the meso vehicle would seem to render a useful service in tackling this problem. Although the construction of macro along these lines is still in its infancy, interesting work has already been forthcoming in terms of addressing economic growth as a self-generating process in its causal nexus with a continuous restructuring of the economy (Metcalfe et al., 2006; Saviotti and Pyka, 2004, 2008; Cantner and Krüger, 2008; Malerba, 2006; Silverberg and Verspagen, 2005a).

Further groundwork will be needed to secure the sustainability of this theoretical course. This will include, on the one hand, further theoretical work on the basic relationship between the levels of micro, meso and macro, as well as on taxonomies relating to the various kinds of knowledge and of carriers. Work on the micro–meso–macro architecture may be advanced in various ways such as, for instance, by adopting a unified rule approach that advances taxonomy and the theoretical exposition on the basis of the concept of (complex and evolving) generic rules (Dopfer and Potts, 2008; Dopfer, 2005; Dopfer et al., 2004). Further groundwork is needed, on the other hand, concerning the methods for empirical research. Enquiring into complex evolving systems requires both quantification and hermeneutic methods. These methods apply to empirical data that at any one time have a structure, calling for a Linnean type of taxonomy, and that over time are continuously changing, calling for a Darwinian type of taxonomy. Cladistic and related taxonomies have emerged as a way of reconciling the demands of structural complexity and evolution when charting empirical data (Allen, 2005; Andersen, 2008; Cantner and Pyka, 2001). Scientific advances will be made in the future in this new camp – as they will, arguably, in much of science – along a co-evolutionary path, with theory, method and empirical work receiving their appropriate share of the recognition.

ACKNOWLEDGEMENTS

The author gratefully acknowledges valuable comments and suggestions by Cristiano Antonelli, Stefania Bandini, Georg D. Blind, Stephan Boehm, Wolfram Elsner, Peter Fleissner, Carsten Herrmann-Pillath, Thomas Grebel, Magnus Pirovino, Mike Richardson, Manuel Wäckerle and Hermann Schnabl.

REFERENCES

Alander, J.T. (2009), 'An Indexed Bibliography of Genetic Algorithms in Economics', Vaasa Paper, University of Vaasa, Finland.

Aldrich, H.E., G.M. Hodgson, D.L. Hull, T. Knudsen, J. Mokyr and V.J. Vanberg (2008), 'In Defence of Generalized Darwinism', *Journal of Evolutionary Economics,* **18**(5), 577–596.

Allen, P.M. (2005), 'Understanding Social and Economic Systems as Evolutionary Complex Systems', in K. Dopfer (ed.), *The Evolutionary Foundations of Economics*, Cambridge: Cambridge University Press, pp. 431–458.

Andersen, E.S. (2008), 'Fundamental Fields of Post-Schumpeterian Evolutionary Economics', DRUID (Danish Research Unit for Industrial Dynamics) Working Paper no. 08-25. Copenhagen and Aalborg: Copenhagen Business School and Aalborg University.

Anderson, P.W., K.J. Arrow and D. Pines (eds) (1988), *The Economy as an Evolving Complex System*, Reading, MA: Addison-Wesley.

Antonelli, C. (2008), *Localised Technological Change: Towards the Economics of Complexity*, London: Routledge.

Arthur, B.W. (2009), *The Nature of Technology: What It Is and How It Evolves*, New York: Free Press.

Arthur, B.W., S.N. Durlauf and D.A. Lane (eds) (1997), *The Economy as an Evolving Complex System II*, Reading, MA: Addison-Wesley.

Becker, M. (2008), *Handbook of Organizational Routines*, Cheltenham, UK and Northampton, MA, USA: Edward Elgar.

Bertalanffy, L. von (1968), *General System Theory: Foundations, Development, Applications*, New York: George Braziller.

Brenner, T. (2004), *Local Industrial Clusters: Existence, Emergence and Evolution*, London: Routledge.

Brette, O. and C. Mehier (2008), 'Building on the "Micro–Meso–Macro" Evolutionary Framework: The Stakes for the Analysis of Clusters of Innovation', in W. Elsner and H. Hanappi (eds), *Varieties of Capitalism and New Institutional Deals: Regulation, Welfare and the New Economy*, Cheltenham, UK and Northampton, MA, USA: Edward Elgar, 227–249.

Buenstorf, G. (2006), 'How Useful is Generalized Darwinism as a Framework to Study Competition and Industrial Evolution?' *Journal of Evolutionary Economics*, **16**(5), 511–527.

Buenstorf, G. and S. Klepper (2009), 'Heritage and Agglomeration: The Akron Tyre Cluster Revisited', *Economic Journal*, **119**, 705–733.

Cantner, U. and I.J. Krüger (2008), 'Micro-heterogeneity and Aggregate Productivity Development in the German Manufacturing Sector: Results from a Decomposition Exercise', *Journal of Evolutionary Economics*, **18**(5), 119–133.

Cantner, U. and A. Pyka (2001), 'Classifying Technology Policy from an Evolutionary Perspective', *Research Policy*, **30**(5), 759–775.

Castellacci, F. (2009), 'The Interactions between National Systems and Sectoral Patterns of Innovation', *Journal of Evolutionary Economics*, **19**(3), 321–347.

Colander, D., R.P.F. Holt and J.B. Rosser (2010), 'The Complexity Era in Economics', Working Paper no. 1001, Middlebury, VT: Middlebury College.

Cordes, C. (2006), 'Darwinism in Economics: From Analogy to Continuity', *Journal of Evolutionary Economics*, **15**(5), 529–541.

David, P.A. (2005), 'Path Dependence in Economic Processes: Implications for Policy Analysis in Dynamical Systems Contexts', in K. Dopfer (ed.), *The Evolutionary Foundations of Economics*, Cambridge: Cambridge University Press, pp. 151–194.

Davis, J.B. (2003), *The Theory of the Individual in Economics: Identity and Value*, London: Routledge.

Davis, J.B. (2008), 'Complex Individuals: The Individual in non-Euclidian Space', in H. Hanappi and W. Elsner (eds.), *Advances in Evolutionary Institutional Economics: Evolutionary Mechanisms, Non-Knowledge and Strategy*, Cheltenham, UK and Northampton, MA, USA: Edward Elgar, pp. 123–142.

Dennett, D.C. (1995), *Darwin's Dangerous Idea: Evolution and the Meaning of Life*, London: Penguin Books.

Dolfsma, W. and L. Leydesdorff (2010), 'The Citation Field of Evolutionary Economics', *Journal of Evolutionary Ecoonomics*, **20**(5), 645–664.

Dopfer, K. (2004), 'The Economic Agent as Rule Maker and Rule User: *Homo sapiens oeconomicus*', *Journal of Evolutionary Economics*, **14**(2), 177–195.

Dopfer, K. (ed.) (2005), *The Evolutionary Foundations of Economics*, Cambridge: Cambridge University Press.

Dopfer, K., J. Foster and J. Potts (2004), 'Micro–Meso–Macro', *Journal of Evolutionary Economics*, **14**(2), 263–279.

Dopfer, K. and J. Potts (2008), *The General Theory of Economic Evolution*, London: Routledge.

Dosi, G., L. Marengo and G. Fagiolo (2005), 'Learning in Evolutionary Environments', in K. Dopfer (ed.), *The Evolutionary Foundations of Economics*, Cambridge: Cambridge University Press, pp. 255–338.

Elsner, W. (2010), 'The Process and a Simple Logic of 'Meso': Emergence and the Co-evolution of Institutions and Group Size', *Journal of Evolutionary Economics*, **20**(3), 445–477.

Encinar, M.-I. and F.-F. Muñoz (2006), 'On Novelty and Economics: Schumpeter's Paradox', *Journal of Evolutionary Economics*, **16**(3), 255–277.

Foray, D. and W.E. Steinmueller (2001), 'Replication of Routine, the Domestication of Tacit Knowledge and the Economics of Inscription Technology: A Brave New World?' paper presented at conference in honour of Richard R. Nelson and Sidney G. Winter, Aalborg, 12 June.

Foster, J. (1987), *Evolutionary Macroeconomics,* London: Unwin Hyman.

Foster, J.(2005), 'From Simplistic to Complex Systems in Economics', *Cambridge Journal of Economics*, **29**(6), 873–892.

Frantz, R. (1986), 'X-efficiency in Behavioural Economics', in B. Gilad and S. Kaish (eds), *Handbook of Behavioural Economics*, Vol. I, Greenwich, CT: JAI Press, pp. 307–324.

Frantz, R. (1997), *X-Efficiency: Theory, Evidence and Applications*, 2nd edn, Norwell, MA: Kluwer Academic.

Frenken, K. (2006), 'A Fitness Landscape Approach to Technological Complexity, Modularity, and Vertical Disintegration', *Structural Change and Economic Dynamics*, **17**(3), 288–305.

Geisendorf, S. (2007), *Are Genetic Algorithms a Good Basis for Learning Models?* paper for Agent-Based Economics no. 2007–5, Kassel: University of Kassel.

Geisendorf, S. (2009), 'The Economic Concept of Evolution: Self-organisation or Universal Darwinism?' *Journal of Economic Methodology*, **16**(4), 361–375.
Gintis, H. (2009), *The Bounds of Reason: Game Theory and the Unification of the Behavioral Sciences*, Princeton, NJ: Princeton University Press.
Grebel, T. (2009), 'Technological Change: A Microeconomic Approach to the Creation of Knowledge', *Structural Change and Economic Dynamics*, **20**(4), 301–312.
Haken, H. (2005), 'Synergetics: From Physics to Economics', in K. Dopfer (ed.), *The Evolutionary Foundations of Economics*, Cambridge: Cambridge University Press, pp. 70–85.
Hanappi, H. (1994), *Evolutionary Economics*, Aldershot: Avebury.
Hanusch, H. and A. Pyka (eds) (2007), *Elgar Companion to Neo-Schumpeterian Economics*, Cheltenham, UK and Northampton, MA, USA: Edward Elgar.
Hayden, F.G. (2008), 'Circular and Cumulative Causation and the Social Fabric Matrix', *Journal of Economic Issues*, **42**(2), 389–397.
Helmstädter, E. (ed.) (2003), *The Economics of Knowledge Sharing: A New Institutional Approach*, Cheltenham, UK and Northampton, MA, USA: Edward Elgar.
Herrmann-Pillath, C. (2010), *The Economics of Identity and Creativity: A Cultural Science Approach*, St Lucia: University of Queensland Press.
Hodgson, G.M. (1993), *Economics and Evolution: Bringing Life Back into Economics*, Cambridge: Polity Press.
Hodgson, G.M. (2002), 'Darwinism in Economics: From Analogy to Ontology', *Journal of Evolutionary Economics*, **12**(3), 259–281.
Hodgson, G.M. (2007), 'The Revival of Veblenian Institutional Economics', *Journal of Economic Issues*, **41**(2), 325–340.
Hodgson, G.M., and T. Knudsen (2006), 'Why we Need a Generalized Darwinism and Why a Generalized Darwinism is Not Enough', *Journal of Economic Behavior and Organization,* **61**(1), 1–19.
Holland, J. (1998), *Emergence: From Chaos to Order*, Reading, MA: Addison-Wesley.
Hollingsworth, R. amd K.H. Müller (2008), 'Transforming Socio-economics with a New Epistemology', *Socio-economic Review*, **6** 395–426.
Hutter, M. and D. Throsby (2008), *Beyond Price: Value in Culture, Economics and the Arts*, Cambridge: Cambridge University Press.
Kapp, K.W. (1976), 'The Open System Character of the Economy and its Implications', in K. Dopfer (ed.), *Economics in the Future: Towards a New Paradigm*, London: Macmillan, pp. 90–105.
Kirman, A.P. and A. Vignes (1991), 'Price Dispersion: Theoretical Considerations and Empirical Evidence from the Marseilles Fish Market', in K.J. Arrow (ed.), *Issues in Contemporary Economics: Proceedings of the Ninth World Congress of the International Economic Association, Athens, Greece*, Vol. I, *Markets and Welfare*, New York: New York University Press, pp. 160–185.
Klepper, S. (1997), 'Industry Life Cycles', *Industrial and Corporate Change*, **6**(1), 145–181.
Knottenbauer, K. (2009), 'Recent Developments in Evolutionary Biology and Their Relevance for Evolutionary Economics', Paper on Economics and Evolution no. 0911, Jena: Max Planck Institute of Economics.
Knudsen, T. (2002), 'Economic Selection Theory', *Journal of Evolutionary Economics*, **12**(3), 443–470.
Kwasnicka, H. and W. Kwasnicki (2006), 'Evolutionary Modeling and Industrial Structure Emergence', in J.-P. Rennard (ed.), *Handbook of Research on Nature Inspired Computing for Economy and Management*, Vol. I, Hershey, PA: IGI Global, pp. 281–300.
Lane, D.A. (2006), 'Hierarchy, Complexity, Society', in D. Pumain (ed.), *Hierarchy in Natural and Social Sciences*, Berlin: Springer Verlag, pp. 81–119.
Lane, D.A. and R. Maxfield (2005), 'Ontological Uncertainty and Innovation', *Journal of Evolutionary Economics*, **15**(1), 3–50.
Langlois, R. (2002), 'Modularity in Technology and Organization', *Journal of Economic Behavior and Organization*, **49**(1), 19–37.

Lazaric, N. and A. Raybaut (2005), 'Knowledge, Hierarchy and the Selection of Routines: An Interpretative Model with Group Interactions', *Journal of Evolutionary Economics*, **15**(4), 393–421.

Leibenstein, H. (1976a), *Beyond Economic Man: A New Foundation for Microeconomics*, Cambridge, MA: Harvard University Press

Leibenstein, H. (1976b), 'Micro–Micro Theory, Agent–Agent Trade, and X-efficiency', in K. Dopfer (ed.), *Economics in the Future: Towards a New Paradigm*, London: Macmillan, pp. 53–68.

Leibniz, G.W. (1714 [1991]), *Monadologie* Pittsburgh, PA: University of Pittsburgh Press.

Levit, G.S., U. Hossfeld and U. Witt (2010), 'Can Darwinism Be 'Generalized' and of What Use Would This Be?', Paper on Economics and Evolution no. 1007, Jena: Max Planck Institute of Economics.

Lux, T. and T. Kaizoji (2007), 'Forecasting Volatility and Volume in the Tokyo Stock Market: Long Memory, Fractality and Regime Switching', *Journal of Economic Dynamics and Control*, **31**(6), 1808–1843.

Malerba, F. (2006), 'Innovation and the Evolution of Industries', *Journal of Evolutionary Economics*, **16**(1), 3–23.

Marshall, A. (1890), *Principles of Economics*, Vol. I, London: Macmillan.

Martin, R. and P. Sunley (2006), 'Path Dependence and Regional Economic Evolution', *Journal of Economic Geography*, **6**(4), 395–437.

Metcalfe, J.S. (2005), 'Evolutionary Concepts in Relation to Evolutionary Economics', in K. Dopfer (ed.), *The Evolutionary Foundations of Economics*, Cambridge: Cambridge University Press, pp. 391–430.

Metcalfe, J.S., J. Foster and R. Ramlogan (2006), 'Adaptive Economic Growth', *Cambridge Journal of Economics*, **30**(1), 7–32.

Nelson, R.R. (2006), 'Evolutionary Social Science and Universal Darwinism', *Journal of Evolutionary Economics*, **16**(5), 491–510.

Nelson, R.R. (2008), 'What Enables Rapid Economic Progress: What are the Needed Institutions?' *Research Policy*, **37**(1), 1–11.

Nelson, R.R. and D. Consoli (2010), 'An Evolutionary Theory of Household Consumption Behavior', *Journal of Evolutionary Economics*, **20**(5), 665–687.

Nelson, R.R. and K. Nelson (2002), 'On the Nature and Evolution of Human Know-how', *Research Policy*, **31**(5), 719–733.

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

Öser, E. (1974), *System, Klassifikation, Evolution: Historische Analyse und Rekonstruktion der Wissenschaftstheoretischen Grundlagen der Biologie*, Vienna: Braumüller.

Potts, J. (2000), *The New Evolutionary Microeconomics: Choice, Complexity and Adaptive Behaviour*, Cheltenham, UK and Northampton, MA, USA: Edward Elgar.

Potts, J. (2008), 'Economic Evolution, Identity Dynamics and Cultural Science', *Cultural Science*, **1**(2), available at: http://cultural-science.org/journal/index.php/culturalscience/article/viewArticle/16/54.

Pyka, A. (2000), 'Informal Networking and Industrial Life Cycles', *Technovation*, **20**(11), 25–35.

Pyka, A. and G. Fagiolo (2007), 'Agent-based Modelling: A Methodology for neo-Schumpeterian Economics', in H. Hanusch and A. Pyka (eds), *Elgar Companion to Neo-Schumpeterian Economics*, Cheltenham, UK and Northampton, MA, USA: Edward Elgar, pp. 467–487.

Pyka, A., N. Gilbert and P. Ahrweiler (2006), 'Simulating Knowledge-Generation and Distribution Processes in Innovation Collaborations and Networks', Discussion Paper no. 287, Augsburg: University of Augsburg.

Pyka, A. and H. Hanusch (eds) (2006), *Applied Evolutionary Economics and the Knowledge-Based Economy*, Cheltenham, UK and Northampton, MA, USA: Edward Elgar.

Rosser, B. (2010), 'Is a Transdisciplinary Perspective on Economic Complexity Possible?' *Journal of Economic Behavior and Organization*, **75**(1), 3–11.

Saviotti, P.P. and A. Pyka (2004), 'Economic Development by the Creation of New Sectors', *Journal of Evolutionary Economics*, **14**(1), 1–36.
Saviotti, P.P. and A. Pyka (2008), 'Micro and Macro Dynamics: Industry Life Cycles, Inter-sector Coordination and Aggregate Growth', *Journal of Evolutionary Economics*, **18**(2), 167–182.
Schweizer, F. (2003), *Brownian Agents and Active Particles: Collective Dynamics in the Natural and Social Sciences*, Berlin: Springer Verlag.
Silva, S.T. and A.A.C. Teixeira (2009), 'On the Divergence of Evolutionary Research Paths in the Past 50 Years: A Comprehensive Bibliometric Account', *Journal of Evolutionary Economics*, **19**(5), 605–642.
Silverberg, G. and B. Verspagen (2005a), 'Evolutionary Theorizing on Economic Growth', in K. Dopfer (ed.), *The Evolutionary Foundations of Economics*, Cambridge: Cambridge University Press, pp. 506–539.
Silverberg, G. and B. Verspagen (2005b), 'A Percolation Model of Innovation in Complex Technology Spaces', *Journal of Economic Dynamics and Control*, **29**(1–2), 225–244.
Sornette, D. (2008), 'Interdisciplinarity in Socio-economics, Mathematical Analysis and Predictability of Complex Systems', *Socio-Economic Review*, **6**, 27–38.
Sum, N.-L. and B. Jessop (2011), *Towards a Cultural Political Economy: Taking the Cultural Turn in Economics*, Cheltenham, UK and Northampton, MA, USA: Edward Elgar.
Tesfatsion, L. (2002), 'Agent-based Computational Economics: Growing Economics from the Bottom Up', *Artificial Life*, **8**(1), 55–82.
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*, **72**(1), 1–20.
van der Leeuw, S.E. and J. McGlade (eds) (1997), *Archaeology: Time, Process and Structural Transformations*, London: Routledge.
Veblen, T. (1898), 'Why is Economics not an Evolutionary Science?' *Quarterly Journal of Economics*, **12**(4), 373–397.
Vromen, J. (2007), 'Generalized Darwinism in Evolutionary Economics: The Devil Is in the Details', paper on Economics and Evolution no. 0711, Jena: Max Planck Institute of Economics.
Weidlich, W. (2000), 'Sociodynamics: An Integrated Approach to Modelling in the Social Sciences', in K. Dopfer (ed.), *Economics, Evolution and the State: The Governance of Complexity*, Cheltenham, UK and Northampton, MA, USA: Edward Elgar, pp. 120–139.
Windrum, P., G. Fagiolo and A. Moneta (2007), 'Empirical Validation of Agent-based Models: Alternatives and Prospects', *Journal of Artificial Societies and Social Simulation*, **10**(2).
Witt, U. (2004), 'On the Proper Interpretation of 'Evolution' in Economics and its Implications for Production Theory', *Journal of Economic Methodology*, **11**(2), 125–146.
Witt, U. (2008), 'What is Specific about Evolutionary Economics?' *Journal of Evolutionary Economics*, **18**(5), 547–575.
Witt, U. (2009), 'Novelty and the Bounds of Unknowledge in Economics', *Journal of Economic Methodology*, **16**(4), 361–375.