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Evolution and Complexity in Economics Revisited

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Abstract

The paper discusses recent trends in the sister sciences of evolutionary economics and complexity economics. It suggests that a unifying approach that marries the two strands is needed when reconstructing economics as a science capable of tackling the two key questions of the discipline: complex economic structure and evolutionary economic change. Physics, biology and the cultural sciences are investigated in terms of their usefulness as both paradigmatic orientation and as toolbox. The micro–meso–macro architecture delineated puts meso centre stage, highlighting its significance as structure component and as process component alike, thereby allowing us to handle the key issues of structure and change.

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 since 1990 (Silva and Teixeira 2009; EconLit database). There have been related accounts, emphasising 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 (Hodgson 1993; Witt 2008; Dolfsma and Leydesdorff 2010).

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 treating them exogenously) centre stage when coping with the former. It was a great moment for the science of economics, and for evolutionary economics in particular, when *An Evolutionary Theory of Economic Change* was published, in 1982, by Richard Nelson and Sidney Winter. 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: 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 (399) that they are 'developing a general way of theorizing about economic change'. In turn, their particular endeavour (399) is 'with exploring particular models and arguments, consistent with that approach, focusing on particular features or issues about economic change'. When assessing the two, they state (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'.

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 (Silva and Teixeira 2009), 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: 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: 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 bearing in mind the new, broader vision of the discipline. Esben Andersen's (2008: 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 organising and collecting data and mathematical representations.

3 The recurrence of complexity

Developments in the field of evolutionary economics have been paralleled by research activities and publications that have come to be grouped together under the label of 'complexity science' or 'complexity economics'. Complexity economics is the offspring of a scientific movement that has its roots in a variety of disciplines, such as physics, biology, neurology, psychology, linguistics and economics. Its origins may be traced back to the establishment of the 'Society for General Systems Research' in the 1950s, the founders of which included the mathematician and musician Anatol Rapoport (Rapoport and Horvath 1959), the biologist Ludwig von Bertalanffy (1968) and the economist Kenneth Boulding (1956). More recently, the approach received particular attention because of the work done by scholars (often with a physics background) at the Santa Fe Institute (Anderson, Arrow and Pines 1988; Arthur, Durlauf and Lane 1997). The complexity approach has extended into various specialised strands, branching most recently into econophysics and econobiology. The generality of the approach has invoked the broad vision of a 'transdisciplinary perspective' (Rosser 2010).

Over half a century ago Rapoport and Horvath noted in a survey article that members of the camp 'proclaim the dawn of [a] new era as being ushered in by a preoccupation with "organized complexity", the region between the extremes of "organized simplicity" and "chaotic complexity", with which the exact scientist has been hitherto exclusively concerned' (Rapoport and Horvath 1959: 100). In our time, Colander, Holt and Rosser (2010: 1) have evoked a vision of the role of complexity in economics quite akin to that of the founding fathers, contending that

> [t]he neoclassical era in economics has ended and is being replaced by a new era. What best characterizes the new era is its acceptance that the economy is complex, and thus that it might be called the complexity era.

4 *De pluribus unum*

There is a close kinship between evolutionary and complexity approaches, which share variously analytical concepts, theoretical terms and methods (Foster 2004; Foster and Hölzl 2004). In fact, the affinity is so close that we can often observe a similarity in the general perception of the subject matter. Silva and Teixeira (2009: 605), for instance, define

> [e]volutionary economics … as a hybrid framework of evolutionary theory, complex systems theory, self-organization theory and agent-based computational theory.

Clearly, 'complex systems theory' and 'self-organisation theory', as well as 'agent-based computational theory', hold equally prominent places in whatever may be defined as the research agenda of complexity economics. In turn, conceptual, analytical and theoretical notions routinely employed in works of complexity economics, such as heterogeneous agents, bounded rationality, fitness landscapes, selection and replication, are, again, part and parcel of the scientific programme of evolutionary economics.

The close kinship is easy to understand if we recognise that both approaches share the basic tenet that knowledge is the key to understanding economic phenomena. The proponents of both schools of thought deal with the structural and evolutionary complexity of knowledge of the economy. Why, then, are there two approaches? Essentially, they are distinct because they entertain different perspectives when addressing major problem areas: evolutionary economics featuring traditionally the continuity of novelty-driven evolutionary change, and complexity economics putting centre stage the structure-focused systemic aspects of the knowledge-based economy. Nonetheless, irrespective of the extant differences in analytic focus, they represent only two variations of a common and recurrent theme: the evolving complexity of knowledge as it relates to economic operations. The study of knowledge, to paraphrase Marshall, is the Mecca of economists, and the twin strands of evolutionary economics and complexity economics are the two main roads heading towards this destination.

5 Natural history: hierarchy of evolved complexity

From a global perspective, the question is this: what makes specifically economic entities 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 (Holland 1998; Lane 2006), 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 three levels: the physical (or physiochemical), the biological and the cultural. 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. Seen in this way, economics is, in a very fundamental sense, a cultural science.

6 Instrumental adequacy versus empirical validity

Scientific statements stand out over non-scientific ones in their logical rigour, formal elegance and openness to falsification. In order to qualify for scientific status, a particular 'toolbox' is required, such as analytical language, various forms of logic and mathematical paradigms, statistical methods or modelling techniques. Just as a hammer, screwdriver or saw can be used for different purposes, so a tool from the scientific toolbox can be employed for the analysis of phenomena of different levels of complexity in the evolved hierarchy. Nevertheless, although tools can be applied for the analysis of many phenomena of different kinds, they cannot be applied for the analysis of all phenomena of all kinds: scissors can be used for operating on paper or a similar material, for example, but they will be of no help at all in polishing a diamond. As you might expect, the tools have to be adjusted to suit the nature of the reality they deal with.

This may sound quite self-evident, but we often encounter situations in which highly sophisticated tools that have been developed in the natural sciences, such as mathematical models, statistical methods, conceptual frames or modelling techniques, are, in effect, ready and waiting to be used by economists as well. From a scientific standpoint, it is mandatory to employ the most sophisticated tools available. To apply this postulate to the fullest, it is not the tools but the perception of reality that may have to be adjusted accordingly. Uncomfortable though it may be to accept this point, it is certainly not unheard of for economists (like other scientists) to find themselves in effect endorsing Georg Hegel's dictum that, if the facts are a certain way, then so much the worse for them. There is, therefore, a trade-off between scientific rigour, consistency and mathematical elegance on the one hand and the empirical content and possible practical relevance of a scientific theory on the other.

As indicated earlier, there has been an enormous scientific dynamic in the two camps – a dynamic whose acceleration in the past 10 to 20 years has been chiefly tool-led, propelled either by enhancements to existing mathematical representations and modelling techniques or the introduction of novel ones. This dynamic is to a large extent attributable to developments in related disciplines, which typically deal with phenomena of an order of complexity significantly lower than those dealt with in economics. Drawing on these sources, complexity economics has turned mainly to strands of modern physics, such as multi-particle physics, synergy or dissipative structures, while evolutionary economics has had resort to advances in the toolbox of biology, turning to formal-analytical concepts of Darwinian evolution, theorems of selection, replicator dynamics, population models, and so forth. Various references that are quoted subsequently provide ample evidence of advances in the areas of analytical conceptualisation, mathematical exposition, methods of data measurement and analysis, and simulation techniques. It is important to point these developments out, as not only do they signify genuine scientific progress, they also provide a weapon with which to counter the repeated assertions of supremacy in this regard by mainstream economists. Unlike most earlier heterodox approaches, evolutionary and complexity economics defy the neoclassical mainstream at the instrumental plane.

The new heterodoxy does more than just compete at the plane of formal-analytical exposition, however; it also challenges the neoclassical orthodoxy by claiming to be superior in representing economic reality. This assertion is by no means marginal, since the claim to deal adequately with the phenomena of complexity and of evolutionary change lies at the very ontological core of the perception of economic reality. Given the fundamental significance of this claim, then, the issue at hand – whether or not the physical and the biological levels are sufficient to serve as benchmarks for theorising or modelling in economics – is of the utmost relevance.

7 Philosophy of 'als ob'

The formulation of a scientific theory, $\boldsymbol{T}$, may be viewed in general as an inductive effort to capture a particular reality, $\boldsymbol{R}$, and the ensuing application of $\boldsymbol{T}$ as a deductive inference to obtain statements about a class of singular instances comprised in $\boldsymbol{R}$. In the standard case, induction ($\boldsymbol{R}^i$) and deduction ($\boldsymbol{R}^d$) apply to the same reality, $\boldsymbol{R}$. In this way, for instance, economic theory ($\boldsymbol{T}_e$) always revolves empirically around economic reality: $\boldsymbol{R}_e$, $\boldsymbol{R}_e^{\,i} = \boldsymbol{R}_e^{\,d}$.

The particular feature of a physics- or biology-based economic theory is that the general premise of symmetry regarding the empirical perception is dropped: $\boldsymbol{R}_e^{\,i} \neq \boldsymbol{R}_e^{\,d}$. The reality that informs the formulation of economic theory is extended to include characteristics of reality that are typically non-economic ones: $\boldsymbol{R}_\alpha$. $\boldsymbol{R}_e^{\,i}$ is substituted by $\boldsymbol{R}_\alpha^{\,i}$, where $\alpha = p, b$, with p and b denoting the reality actualised at the physical level and at the biological level, respectively. The conjecture is entertained '*as if*' non-economic reality represented a valid inductive base for economic theory or model construction: $\boldsymbol{R}_e^{\,i} \approx \boldsymbol{R}_\alpha^{\,i}$. The method of the 'as if' was introduced by Hans Vaihinger in his *Philosophie des Als Ob* (*Philosophy of the As If*) a century ago, and little of this formal exposition and mathematical representation would survive today without recognition of his seminal work (Vaihinger 1911; Zimmermann 2009). While the employment of the 'as if' method fosters scientific advance at the formal-expositional level, the procedure also incurs a cost in terms of what can be called the *critical empirical distance* (CED): the distance between the perception of reality that furnishes the empirical material for the construction of the theory and the reality that the theory is actually designed for. Any economic theory or model claiming empirical relevance requires the 'as if' to be vindicated with a view to the CED employed.

This opens up a wide field, and, in an attempt to cut what appears to be something of a Gordian knot, two major kinds of justification can be distinguished. Given the hierarchy of different complexity levels, reductionism means that the nature of the complexity of economic particles can be explained validly in terms of the nature of physical ones. Economic phenomena are explained in terms of biological laws, which, then, are explained again in terms of physical laws, espousing the view that knowing the physical laws is a necessary condition (weak reductionism) – or, more radically, a sufficient condition (strong reductionism) – for dealing with complexity in economics. A vindication of the CED by reductionism is premised on an outdated ontology (see the next section), and, in consideration of this fundamental flaw, it is ill-fitted to serve the task envisaged for it.

Besides these wholesale approaches to reductionism, there is a related, second, kind of justification of the CED. As closer scrutiny reveals, it is of a quite different nature, however. This justification is based on the premise that economic phenomena are emergent properties of levels of lower complexity, and that 'traces' of earlier, simpler forms of complexity are manifest in economic phenomena. The analysis proceeds by singling out certain economic phenomena or aspects of economic reality that display an order of simple complexity. By so doing, it retains the premise that economic reality in its entirety is much more complex than what constitutes the subject matter of a particular analysis. These models intend to reduce a complicated problem to a simpler one, but for that they cannot be dismissed flatly as being purely reductionist.

8 Physics as traditional Mecca: neoclassical economics and econophysics

Turning to the level of complexity assumed to prevail at the physical level, it is conjectured 'as if' the complexity of physical particles corresponds to that of economic particles. Atoms, molecules and equivalent physical particles display a kind of complexity that can be identified in economic systems, employing the inductive base $\boldsymbol{R}_p^{\,i} \approx \boldsymbol{R}_e^{\,i}$.

This may lead us to assume that modern econophysics and complexity approaches share with neoclassical economics common roots in physics. Although this is certainly true as far as their common level of abstraction is concerned, there is a fundamental difference in the kind of interpretation as to what these roots actually mean. For the purposes of the present study, the distinction between an old and a new canon of physics (of $\boldsymbol{p}$ in $\boldsymbol{R}$) may render useful service.

The old – or, in familiar parlance, 'mechanistic' – canon can be seen to embrace Newtonian physics, classical (Ludwig Boltzmann's) thermodynamics and Albert Einstein's general theory of relativity. The old canon operates on a uniform perception of matter and energy and invariant laws. The distinction is not between the whole of an ensemble and its individual particles but, rather, between large and small quantities measured with the metrics of mass on the scale of a space–time continuum.

Two major hallmarks of the mechanistic model may be identified. The first resides in the proposition that the particles separate rather than associate, producing relations between them. No structure ever exists in the model unless imposed by outside factors. An economy is composed of many economic agents whose behaviour is governed by the law of rational decision-making and a set of commodities that – in application of the law – are reallocated according to particular changes in the exogenous conditions, such as preferences or technical opportunities. A statement about the nature of the economy may be obtained by a superposition of the decision-making trajectories of the agents or by an aggregation of the indexed individual commodity bundles. Aggregation may take various forms depending on the theoretical purpose being pursued; for instance, microeconomics proceeds by aggregating individual or partial market equilibria into a 'general' market equilibrium, macroeconomics by aggregating the outcomes of individual decisions that pertain to macro variables, such as investment, saving, consumption and employment, discussing an economy's total income in a schema of relationships between sub-aggregates. The method of (dis-)aggregation can be used as a tool in any fashion, but, however it is used, it will never yield any endogenous explanation of economic structure or change.

The second proposition holds that the uniform cognitive or behavioural disposition (or propensity) of agents is given as a fixed datum. Methodologically, this means that we dispose of a law that, knowing the initial conditions, allows us to calculate precisely the kind of decision trajectory and resultant reallocation in the commodity space. The determinism of the model, in suggesting that we can predict precisely the future and 'retrodict' precisely the past, has been rightly criticised, and stochastic models have been proposed to remedy the deficiency. The problem is not with the degree of precision in determinism, however, but, rather, with the fundamental observation that real phenomena at all levels of complexity *do* change over time.

Seizing upon this, the central premise of time symmetry collapses. The recognition of time asymmetry – that is, historical time – in the basic set-up of theory construction has profound implications for major methodological issues, most significantly for theory validation. In the nomological case a theory counts as being valid if it allows us to calculate a path precisely, provided that relevant information about the initial conditions is furnished. In the non-nomological case this is different: neither the propounded law nor the kind of conditions to which it applies repeat universally over time.

How, then, can we test or falsify a theory or model under the assumption of universal non-repeatability? Complexity economics and evolutionary economics deal, essentially, with models that operate under the aegis of this very assumption. It may be taken as an indication of the difficulties of dealing with this methodological problem if we recognise that we do not even have a term equivalent to that of 'nomological' (a bridgehead of positivism). One suggestion is to call it 'histonomic', whereby 'nomic' carries the meaning of 'generalised' or 'law-like', and 'histo(r)' may be seen as expressing the historicity of real phenomena (for further discussion, see Dopfer 1986). Major concepts employed in the two camps, such as emergence, evolutionary dynamics, path dependence and structural change, are premised on the recognition of the general historicity of economic phenomena – thus calling for histonomic analysis.

9 The new (post-neoclassical) physics-based economics

Modern physics-based economics, such as that from the Santa Fe Institute, is premised on the concept of many heterogeneous economic agents that interact. A primary concept is feedback, which typically (though not necessarily) operates across different scales. The technical hallmark is non-linearity, which stands in contrast to the equilibrium statics and linear dynamics of the received doctrine. Based on complex non-linear dynamics, the ensemble as a whole displays emergent properties. The physics toolbox has been utilised to describe various kinds of economic phenomena. For instance, the concept of synergy, developed in laser physics, has been applied to model the emergence of collective preferences, fashion patterns and self-organisation in firms and markets (Weise 1998; Weidlich 2000; Haken 2005). Similarly, methods and techniques have been borrowed from multi-particle physics to model the behaviour of markets, particularly in the financial sector (Schweizer 2003; Lux and Kaizoji 2007). Other borrowings from physics relate to the analysis of complex regularities of socio-economic networks and collectives (Hollingsworth and Müller 2008; Sornette 2008), to percolation theory for modelling spatial dynamics (Brenner 2004) or to models of diffusion of technology under conditions of various consumer demand characteristics (Silverberg and Verspagen 2005a). These approaches usually apply physics to a somewhat narrow domain, such as preference formation or financial markets, leaving largely unaddressed the issue of how to deal with the complexity of the economy as a whole.

The physics-based models generally display 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, as has been mentioned. 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 – that is, $\boldsymbol{R}_p^{\,i} \approx \boldsymbol{R}_e^{\,i}$ – 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 the greatest 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 in solving it, may well represent major limitations on the development of physics-based economics into an empirically attractive variant.

10 The biological connection

Biology-based economic models operate with a conjecture analogous to the physics-based ones: that the analytical concepts, modelling techniques and mathematical representations used in biology represent a kind or level of complexity that can portray that of certain economic phenomena, or of certain aspects of economic reality: $\boldsymbol{R}_b^{\,i} \approx \boldsymbol{R}_e^{\,i}$.

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 (Marshall 1890; Veblen 1898). These 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 problems 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, universalised into 'general system theory' (GST: see section 12 below) by Bertalanffy (1968). The historical dynamic of that system, as its second pillar, is captured by the concepts of ontogeny and phylogeny (see section 13).

There is a common denominator that unifies all concepts: biological knowledge – say $\boldsymbol{G}$. In a state of ontogeny, an organism performs life-maintaining operations on the basis of a given $\boldsymbol{G}$. In phylogeny, $\boldsymbol{G}$ 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 the 'continuity principle' (Öser 1974; see also Witt 2004).

Meagre as it is, the discussion allows us to take a first step towards delineating a general analytical framework for economic theory. The prefix 'biological' in knowledge can, like a constant in mathematics, be readily 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.

The second way in which biology has proved inspiring is that it deserves its reputation as the 'Mecca of the economist' for practical reasons. It is useful as more than just a paradigmatic signpost; as has been mentioned, 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 (Silverberg and Verspagen 2005b; Kwasnicka and Kwasnicki 2006) 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 – $\boldsymbol{R}_b{}^i \approx \boldsymbol{R}_e{}^i$ – to be justified (Foray and Steinmueller 2001; Windrum, Fagiolo and Moneta 2007; Geisendorf 2007). 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 questions 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.

11 Biological archetypes

It is certainly an extraordinary challenge for an economist to deal with the essentials of biology, but the proposition of making it the Mecca of economists calls precisely for this. Rising to this challenge, major elementary biological terms are introduced first, and then they are discussed with a view to their relevance for economics.

Given the enormous quantity and different meanings of the theoretical terms applied in modern biology, it would seem necessary to find a way into the problem that has the virtue of some degree of familiarity. Looking for a course that is intuitively appealing, yet not grossly at odds with the major findings of modern biology, the archetype of a history of life is what is portrayed.

Taking dissipative structure (Prigogine 2005) – which applies to both the physical and the biological levels – as a point of departure, life may be seen to emerge with the capability of that structure to generate a twin configuration within one ensemble of particles. This primitive creature indeed emerged as a double membrane, and so, it may be further conjectured, its division led to the important characteristic of replication for the first time. This process was then repeated, and thus information came to be preserved over time.

Replication can be subject to error, however, and in this way change occurs in the molecular structures. There is repeatability, as in the nomological model, but – unlike that model – it takes place only within a limited historical time range. On a global scale there is a continuity of change. Thus we have an evolutionary trajectory defined by the dynamic of

novelty → replication → retention

How do physical ensembles differ from biological ones? At the physical level, particles have a propensity to associate and to change, and in this way they form structure and evolve. These remarkable, non-classical, properties are attained on the basis of the invariant behavioural propensities of the individual particles. Given a particular thermodynamic environment, self-organisation, phase transitions and bifurcations occur in the ensemble spontaneously. Despite the ensemble's remarkable properties, though, the individual particles themselves are passive and reactive: they respond only to external conditions. The case is entirely different with a biological ensemble: each of the particles is active in generating and processing information. Order and change comes, paraphrasing Schumpeter, 'from within' the particles of the ensemble. Activities in the ensemble still depend on external conditions, but there is – beyond a behavioural law – an internal incidence of order and of change. In a biological ensemble, unlike a physical one, the particles exercise autonomy, at a very fundamental level.

The new properties of the biological ensemble give information an entirely new meaning: the particles of the ensemble are informationally open. Unlike physical particles, biological particles can exchange information. This attribute has two major consequences. On the one hand, information has to be acknowledged in its semantic property. It cannot be reduced to a physico-thermodynamic parameter, but needs to be stated in terms of its qualitative content. On the other hand, given the ability of the particles to code (to encode and to decode), communication becomes relevant. In a physical model there is no communication between particles at the level of information, as there is no semantic information in the first place (Eigen and Schuster 1979; Küppers 2000).

It should be clear from this archetypical exposition that it makes a major difference whether an economic model is physics-based or biology-based. The familiar concept of multi-agent models may be given an entirely different theoretical meaning depending on how we devise the conceptual framework and how we define the properties of the particles. In their outward appearance they resemble each other, like eggs, since they all start with the assumption of heterogeneous agents. The touchstone is the kind of distinction made between carrier and information, however, and the particular meanings given to them. In particle-physics-based multi-agent models, the information carried by the particles collapses to a 'dummy' variable. There is no theoretical explication of the complex process underlying the individual information trajectory or of the communication between the particles. Multi-agent models that have moved away from their physics origins have introduced the distinction between carrier and information, however, and have elaborated on the distinct properties of each.

In an analogous vein, the semantic content of information may be addressed differently from a theoretical point of view. As we have seen, although semantics drops out in econophysics it is retained in biology-based models. For instance, genetic algorithm models and genetic computing put 'genetic' information centre stage, thus rectifying the aforementioned deficit. While it is exactly this property that allows for their mathematical representation, it also calls for a vindication of the CED in terms of evidence for a class of decision-making procedures that follow a completely determined sequence of decision-making steps.

12 Biological Mecca I: link to general system theory

There is an important implication that follows from the concept of replication errors: the emergence of heterogeneity. Replication errors occur randomly. Qualitatively different information is generated in this way, which, as a consequence, may well be ready for a new use. Starting again with the propensity to associate, the particles generally have the capability for associating in terms of relations defined by their qualitative attributes. The particles are defined not only by their physical characteristics but also by the particular tasks or functions they can accomplish in an ensemble. In this way they are complementary – that is, heterogeneous information A is complementary to heterogeneous information B, and that to C, and so forth, forming a whole defined by a set of particles and their complementarities. The concept of complementariness is absolutely essential for grasping the meaning of what constitutes a system.

In biology, the systemic focus is on organisms – generalised by Bertalanffy into the concept of general system theory (see section 10 above). The concept of an organism or a living system immediately suggests a homology to the firm and the economy, and, indeed, biology-based self-organisation and open living system models have been proposed both in the management sciences (Ulrich and Probst 1984; Schwaninger 2010) and in economics, often in direct application to ecological issues (Georgescu-Roegen 1971; Kapp 1976; Ayres 1994; Maréchal 2007).

The pivotal question for economics is this: can the concept of biological system be useful, for instance in its GST variant, for representing the economy as a whole? Can the characteristics of an organism be transposed onto the macro level? There are early attempts by the German historical school and its predecessors to construct the economy as organism (Hutter 1994; Hodgson 2000). Along a quite different line, Roy Weintraub has interpreted general equilibrium theory in terms of a system of simultaneous equations proposed by Bertalanffy for representing relations among component parts of a living system (Weintraub 1974). This conjecture is particularly useful in that it allows us to highlight the limitations of the orthodox master model. A Walrasian or analogous simultaneous equation system posits the allocation of all commodities under equilibrium conditions. The essential point is that there are no complementarities between the commodities. All the qualitative attributes required for stating them have been eliminated (see section 17). To construct a model with complementarities requires the assignment of qualitative attributes to some variables of the model. This can be accomplished by introducing quality into the extant endogenous variables (basically, product characteristics and heterogeneous agents) and/or by importing into the model extant exogenous variables, such as preferences and technology, preserving their qualitative status. Although considerable efforts have been made with a view to relaxing the received assumptions, such as when operating (even in mainstream models) with the assumption of heterogeneous agents, a systemic approach – certainly anything along the line of Bertalanffy's GST – allowing for functions, distributed tasks or equivalent qualitative attributes is not yet available.

13 Mecca II: evolutionary biology

Turning to evolutionary – such as Darwinian – biology, the question is whether this branch of the discipline can contribute anything to the representation of structure in economics. Evolutionary biology is concerned with phylogeny. The forces of variation and selection produce a highly structured environment populated by many organisms and species of various kinds. The living beings are embedded in a highly complex web of interdependencies, realised, for instance, as hunter–prey or symbiotic relationships. There is nothing of the kind of complementarities that are characteristic of an economy in the overall system of 'Mother Nature', however. There are highly complex interdependencies but these do not represent complementarities. As Adam Smith aptly remarked, nobody has ever seen dogs exchanging bones – but, there again, neither has anybody seen dogs cooperate with members of other species to achieve a common output. It is precisely this kind of cooperation on the basis of distributed differential tasks that is characteristic of an economy but is non-existent in nature. Putting the two into a single pot would mean committing the fallacy of a major misplaced homology. Interpreting an economy through the lenses of evolutionary biology could thus lead to a fundamental misinterpretation of its systemic nature and the particular character of its evolutionary dynamic.

Two major positions developed in evolutionary biology have been of relevance for economics. Jean-Baptiste Lamarck saw evolutionary change as a process in which organisms' adaptations are inherited. In biology this hypothesis has not been corroborated by empirical evidence, in view of the absence of a mechanism that would transpose information from the cortical level to that of sexual reproduction, but it represents a good approximation to what happens in firms or how agents behave. They adapt to their environment by learning. When highlighting this process in the firm, Nelson and Winter have, quite appropriately, interpreted their analysis as being 'unabashedly Lamarckian' (1982: 11). Significantly, Lamarck's theory leads to the general inference that information is adopted (not simply replicated) – a concept with little meaning in modern biology but central to the analysis of phenomena at the cultural level, where economics resides (see section 15).

The second position is, of course, that of Charles Darwin. Besides adapting to an environment, economic agents also generate novelty that is not a mere response to adaptive requirements but, rather, originates in a locus independent from these. Darwin provided a theory that propounds that heritable changes occur in organisms and that the adaptations to the environment occur ex post. In Lamarck's model, evolution stops when organisms are optimally adapted; in Darwin's, randomness in replication is a source of novelty, propelling evolution. The element of randomness is a relatively accurate approximation of the trial and error methods driving research and development and other explorative activities in an economy (on 'new combinations', see, for example, Schumpeter 1912, Nelson and Winter 1982 and Witt and Cordes 2007).

On reading the work of Thomas Malthus, Darwin became familiar with the concept of scarcity, which led him to his central proposition: that only the better-adapted – not just any adapted – organisms or species will survive. Selection was moved from the cortical level of the organism to that of the natural environment. This redefined the environment as a place in which scarcity and competition prevail.

Up to this juncture, the discussion has furnished three building blocks that describe evolution in modern evolutionary biology. These can be combined into a sequential order with distinct phases – specifying the evolutionary trajectory introduced earlier:

phase 1	generation of novel genetic information
phase 2	replication, subject to natural selection; formation of population
phase 3	retention

The trajectory describes the evolution of a species. It does not describe the evolution of an organism, or that of nature as a whole. A species is defined as a population whose members share the same kind of genetic information. The centrality of this concept has led Ernst Mayr to propose 'population thinking' as an overriding principle of evolutionary biology, and to contrast it with 'typological thinking', as exemplified by Carl von Linné's taxonomy (Mayr 1982). The key concept of 'population thinking' has also been introduced into economics by Stanley Metcalfe (2001), who suggests that the distinction between population and typological thinking marks the ontological watershed between evolutionary and mechanistic approaches in economics. As we shall see in the next section, the population concept is a major – *meso* – building block in the construction of a new theoretical architecture of economics.

14 Mecca III: testing the critical empirical distance

Although life is, arguably, closer to economics than dead matter, recourse to biology still requires justification. Considering the fact that most evolutionary economists would fully endorse Marshall's plea that biology (rather than mechanics) be the Mecca of economics, it must seem somewhat surprising that little systematic discussion about the problems related to the vindication of $\boldsymbol{R}_b^{\,i} \approx \boldsymbol{R}_e^{\,i}$ has been forthcoming. There is the exceptional case of 'Universal Darwinism', though, which originates from a particular variant of the field of biology. The unusual vigour with which that discussion has surfaced recently may be attributed to the fact that it stood in place for a broader discussion embracing the discipline of biology as a whole.

Introduced by biologist-philosopher Daniel Dennett (1995), universal Darwinism got a warm reception from some economists (Hodgson 2002; Hodgson and Knudsen 2006; Aldrich et al. 2008; Stoelhorst 2008), but little approval from others, who criticised either the weak evidence of homologies, and/or the narrow scope of its questions (Witt 2004, 2008; Nelson 2006; Cordes 2006; Vromen 2007; Levit, Hossfeld and Witt 2010) or the lack of integration of other relevant concepts, such as self-organisation (Buenstorf 2006; Geisendorf 2009) or epigenetics (Callebaut and Rasskin-Gutman 2005, Knottenbauer 2009). 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 theorising. Unlike advocates of universal Darwinism, they contend (Nelson and Winter 1982, 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: 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 concepts, methods, analytical models or mathematical representations if they are useful in economics but lack empirical corroboration in biology?

15 Economics as cultural science

As mentioned above, economics belongs incontestably 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: $\boldsymbol{R}_c^{\,i} = \boldsymbol{R}_e^{\,i}$.

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 may lie in the difficulties inherent in devising methods, mathematical representations and statistical tools that are 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. My proposition is that, if economics is to be empirically meaningful, the starting point of any theoretical endeavour has to be the cultural level, not the physical level or the biological level. On the basis of 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 to set the pace for further developments. The research includes works by Richard Nelson (2008), Carsten Herrmann-Pillath (2010), Jason Potts (2008), Michael Hutter and David Throsby (2008), Viktor J. Vanberg (2004); Nils Goldschmidt and Bernd Remmele (2005); and Ngai-Ling Sum and Bob Jessop (2011).

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.

16 *Homo sapiens oeconomicus*

Homo sapiens and cultural artefacts thus acquire particular meanings in the economic context. *Homo sapiens* – in his/her economic operations – is 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 2003, 2008), 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.

17 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, consider archaeologists 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 organisation 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; justified as this critique may be, however, it has left in limbo the principal question, as to whether or how to explain the material record. Starting from the cultural (rather than biological) level, an approach has been suggested that relates cultural artefacts to human cognition, highlighting the coevolution 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 emphasises 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.

18 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 time-less and space-less. On the other hand, ideas do not reside in a Platonic heaven, but are always physically actualised; they have a carrier. Ideas are actualised 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 actualisation 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 solely 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.

19 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 generalised 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/her 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).

20 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 actualised 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 systems 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 actualised many times. It can be actualised not just by a single carrier but by many carriers; for instance, a technology can be adopted by many firms. A single actualisation of a knowledge-bit may be possible, but it would be a special case, as opposed to the general case of many actualisations. 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 macro is not a single knowledge-bit (a single idea, a single actualisation) but, rather, a single idea and many carriers actualising it. The analytical unit is one knowledge-bit and many actualisations. 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-actualisation 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. Recognising 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 13), and a process component in that it expounds the logic of its physical actualisation in time and space (section 14).

21 Architecture: micro–meso–macro

The architecture of an evolutionary complexity-based economics is starting to take shape. Its constituent domains are these:

micro

meso

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 actualisation 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 actualisation 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.

22 Investigating structural complexity

Knowledge content may come in two guises: as a single knowledge-bit or as a structured knowledge composite actualised 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 actualised 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 2005), but it is a constituent aspect in the latter (Pyka, Gilbert and Ahrweiler 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 actualisations of a single knowledge-bit. In this way, for instance, a single technology has a population of actualisations. 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 recognises its theoretical significance (Schnabl 2000; Langlois 2002; Helmstädter 2003; Chen 2005; Reinstaller 2007; Antonelli 2008; Neffke and Henning 2009). 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 (Hayden 2008); or, similarly, a game-theoretic social context may be singled out for partial analysis (Elsner 2010). 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 and 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.

23 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 as 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 actualised 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 more 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, although this is usually considered to be the engine of economic growth, it is still for the most part an under-researched topic (Encinar and Muñoz 2006; Witt 2009; Grebel 2009; Endres and Woods 2010). An intriguing aspect concerns the complex dynamic relationship between structural complementariness and the generation of novelty, as captured by the concept of 'generative relationship' (Lane and Maxfield 2005; Lane et al. 2009; Antonelli 2010), innovation systems, dominant designs and development blocs effective in the context of an experimentally organised economy (Lundvall and Borrás 2005; Murmann and Frenken 2006; Eliasson 2010; Johansson 2010) and institutionally and spatially structured micro–meso–macro innovation clusters (Werker and Athreye 2004; Brette and Mehier 2008; Uyarra 2010).

There is a vast literature related to the second phase, the diffusion and macroscopic adoption of knowledge. The work embraces broadly conceived product diffusion and cross-sectoral models (Peneder 2003; Buenstorff and Klepper 2009), selection models (Knudsen 2002; van den Bergh and Gowdy 2009), path dependence and network life cycle models (Pyka 2000; David 2005; Martin and Sunley 2006; Arthur 2009) and experiment-based diffusion, learning and networking models (Dosi, Marengo and Fagiolo 2005; Tyran and Sausgruber 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 Nelson and Winter's seminal 1982 contribution (Lazaric and Raybaut 2005; Parra 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 and Nelson 2002; Hodgson 2007; Nelson 2008).

24 Looking to the future

Schumpeter remarked a hundred 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 hundred 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 (Saviotti and Pyka 2004, 2008; Metcalfe, Foster and Ramlogan 2005; Silverberg and Verspagen 2005a; Malerba 2006; Cantner and Krüger 2008; Foster 2011).

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, 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, Foster and Potts 2004; Dopfer 2005; Dopfer and Potts 2008). 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 Linnéan 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 (Cantner and Pyka 2001; Allen 2005; Andersen 2003). Scientific advances will be made in the future in this new camp – as they will, arguably, in much of science – along a coevolutionary path, with theory, method and empirical work receiving their appropriate share of the recognition.

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