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Complexity Thinking and Evolutionary Economic Geography

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Abstract

Thus far, most of the work towards the construction of an evolutionary economic geography has drawn upon a particular version of evolutionary economics, namely the Nelson-Winter framework, which blends Darwinian concepts and metaphors (especially variety, selection, novelty and inheritance) and elements of a behavioural theory of the firm. Much less attention has been directed to an alternative conception based on complexity theory, yet in recent years complexity theory has increasingly been concerned with the general attributes of evolutionary natural and social systems. In this paper we explore the idea of the economic landscape as a complex adaptive system. We identify several key notions of what is being called the new 'complexity economics', and examine whether and in what ways these can be used to help inform an evolutionary perspective for understanding the uneven development and adaptive transformation of the economic landscape.

Key Words: complexity theory, evolution, economic landscape, networks, emergence, regional adaptation

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1. Evolutionary Economic Geography: In Search of Conceptual Foundations

Over the past few years the outline of a new evolutionary paradigm has begun to take shape in economic geography (see, for example, Rigby and Essletzbichler, 1997; Boschma and Lambooy, 1999; Lambooy and Boschma, 2001; Bathelt and Boggs, 2003; Boschma and Frenken, 2003, 2006; Essletzbichler and Rigby, 2004; Hassink, 2005; Martin and Sunley, 2006). Although this paradigm is still in its infancy, certain concepts and approaches have already assumed a prominent role in geographic-evolutionary interpretations of the economic landscape. In particular, most of the work towards the construction of an evolutionary economic geography has drawn upon a particular version of evolutionary economics, which blends Nelson and Winters evolutionary theory of the firm with neo-Darwinian (evolutionary biology) analogies and metaphors (especially variety, selection, novelty and inheritance).¹ Without doubt, the neo-Darwinian approach has been a highly influential perspective within evolutionary economics, and it is therefore not surprising that it has served as a major source of inspiration for evolutionary economic geographers.

But the neo-Darwinian framework is not the only possible one. Nor indeed, is evolutionary biology necessarily the most appropriate source of concepts, analogies and metaphors (Wimmer, 2006; Chattoe, 2006). In fact, there is debate within evolutionary economics itself about drawing on Darwinian concepts and the ideas of evolutionary biology.² And this is not a new debate. On the one side, for example, Alfred Marshall once famously concluded that “the Mecca of the economist lies in economic biology rather than economic dynamics” (Marshall, 1930, p. xiv).³ Others, however, have urged caution about borrowing ideas from biology. Penrose (1952, p. 819) for instance, argued that

In seeking the fundamental explanations of economic and social phenomena in human affairs the economist, and the social scientist in general, would be well advised to attack his [sic] problems directly and in their own terms rather than indirectly by imposing sweeping biological models on them.

More recently, even Hodgson (1993), a strong protagonist of an evolutionary approach to economics, has emphasised that while biological analogies are far more appropriate than the mechanistic ones that underpin mainstream economics, they have to be used cautiously. Further, as Lawson (2003) points out, there is the important question of whether it is ontologically meaningful to abduct notions from evolutionary biology into the socio-economic realm (see also Chattoe, 2006). In his view this question has yet to be adequately

¹ The original Nelson-Winter draws on Lamarckian rather than Darwinian evolutionary ideas. Although the processes of selection, mutation and inheritance are invoked not as biological metaphors but as real economic processes, they nevertheless explicitly acknowledge that there is an analogy between biogenetic process and firm dynamics.

² Note that we are not arguing against the use of analogies and metaphors *per se*. In fact, virtually all explanatory accounts make use of both. What matters of course is the relevance and appropriateness of the analogies or metaphors that are used. In this context, it is curious that Newtonian mechanistic analogies and metaphors should have dominated mainstream Neoclassical economics for so long when they are clearly at odds with how actual socio-economic systems are constituted and develop.

³ Elsewhere in the *Principles of Economics*, Marshall acknowledges his debt to the writings of Herbert Spencer, and goes on to emphasise that “biological conceptions are more complex than those of mechanics” (op cit, p. xiv).

answered. Others, however, are more optimistic. For example, Witt (2003) advances a so-called ontological 'continuity hypothesis' of evolutionary economics, the suggestion that while the Darwinian notion of natural selection is only one form in which evolution occurs in nature, it is that form which, "historically, has shaped the ground and still defines the constraints for man-made, or cultural evolution" (Witt, 2003, p.15). Somewhat between these two different viewpoints other authors have suggested that concepts such as variety, natural selection, inheritance and the like, do not have to carry over strict biological connotations when used as in economics, but can be used to identify 'generic' features of evolution that can be given specific meaningful economic interpretation (see Metcalfe, 1998; Witt, 1999). And so the discussion continues. All in all, it seems to us that the jury is still out on the question of whether a viable evolutionary economics - and thus by implication, a viable evolutionary economic geography - can be based solely on principles drawn from evolutionary biology.

It is not our intention to pursue this intriguing issue further here, however (for two such discussions, see Frenken and Boschma, 2007, in this journal issue; and Essletzbichler and Rigby, 2007, also this journal issue). Instead, our aim is to explore the potential scope – and limits – of a second approach to constructing an evolutionary perspective within economic geography, one based on what we shall call 'complexity thinking'. Interest in complexity and complex systems goes back at least to the 1940s, but in the 1970s and 1980s work on the dynamical properties and structural transformation of non-linear, 'far-from equilibrium' systems in the natural and physical sciences led to the development of a new field that quickly became labelled as the 'science of complexity' or 'complexity theory' (Nicolis and Prigogine, 1977, 1989). Over the past two decades or so, this area of research has developed apace, focusing among other things on the evolutionary behaviour of 'self-organising systems', 'self-regenerating ('autopoietic') systems', 'complex adaptive systems', and 'complex evolutionary systems' (for example, Holland, 1992, 1995; Kauffman, 1995; Bak, 1996; Schweitzer, 1997). At the same time, 'complexity thinking' and 'complexity ideas' have diffused into several areas of the social sciences (Byrne, 1998), including not only economics (Anderson, Arrow and Pines, 1988; Arthur, Durlauf and Lane, 1997; Metcalfe and Foster, 2004; Ramlogan and Metcalfe, 2006), but also economic and social history (Frenken and Nuvolari, 2004; McGlade, 2006), archaeology (Bentley, and Maschner, 2001, 2003), political theory (Rosenau, 1995), organisational and management theory (Stacey, Griffin and Shaw, 2000), and computing science (Bullock and Cliff, 2004)⁴. It has had less impact on human geography, although recently it has begun to receive attention there too (for example, Thrift, 1999; Gattrell, 2005; Harrison, Massey and Richards, 2006; Manson and O'Sullivan, 2006; Plummer and Sheppard, 2006).⁵ Such has been the growth of the field that some talk of a new episteme that challenges conventional epistemological and ontological assumptions about the nature and behaviour of natural and social phenomena (Wolfram, 2002).

This expanding interest and increased participation in the 'discourse of complexity' has not yet resulted in any clear, precise or generally agreed definition of the term, however; and to refer to complexity 'theory' is perhaps to exaggerate the degree of conceptual coherence and explanatory power associated with the notion. The main reason for this is that by its very nature as a holistic concept the notion of complexity resists easy reduction to a set of law-like statements or universal theoretical principles. As its two leading exponents put it, "complexity is one of those ideas whose definition is an integral part of the problems that it raises" (Nicolis and Prigogine, 1989, p. 36). Nevertheless, there are some apostles of complexity who believe there are general principles that apply to all complex systems and that eventually it should therefore prove possible to construct a sort of unified theory of complexity. This has been the central thinking behind the Santa Fe Institute programme of

⁴ Sawyer (2005) argues that the interest in complex dynamical or adaptive systems represents the third wave of social systems theory. The first wave was structural functionalism, and general systems theory the second.

⁵ In their contribution, Harrison, Massey and Richards (2006) explore the scope for using the ideas of complexity theory as a common basis for bridging human and physical geography

research on the ‘science of complexity’. The aim of the Santa Fe studies has been to explore the possibility of a formal theory of complexity – or more precisely, a theory of ‘self-organisation’ - that applies equally to both natural and social systems. Notable examples have included the work of Allen (1982, 1985, 1992) and Arthur (1988, 1989, 1994; and Arthur, Daly and Lane, 1997) on social and economic-technological systems.

Interestingly, Arthur’s work in particular contained a number of applications to geographic phenomena, such as the development of urban and industrial location patterns. Subsequent to, and somewhat similarly to Arthur’s work, Krugman has used complexity theory as one of the conceptual strands of his so-called ‘new economic geography’ (Krugman, 1994, 1996, 1997). Following the Santa Fe *Zeitgeist*, Krugman has sought to show how

Models of self-organisation can be applied to many economic phenomena – how the principle of ‘order from instability’ which explains the growth of hurricanes and embryos, can also explain the formation of cities and business cycles; how the principles of ‘order from random growth’ can explain the rules that describe the sizes of earthquakes, meteorites and metropolitan areas (1996, p. vi).

The main argument underpinning Krugman’s thesis is that common principles of self-organisation can be shown to operate across all sorts of systems - physical, biological and socio-economic - and that these principles provide a new view of how the economy structures itself in space and time.⁶

We should emphasise immediately where we agree and where we disagree with Krugman. A survey of the literature on complexity thinking does indeed suggest that natural, physical and social systems display certain similarities in ‘complex behaviour’, that is the emergence, under certain conditions, of self-organised complexity at a macroscopic scale in the form of spatial patterns or temporal rhythms. But the actual processes involved in the emergence of self-organised complexity obviously differ as between, say, cellular biology, the human brain, societal organisation and economic systems. This implies that distinct limits are likely to exist to the construction of a single, unified ‘meta-theory’ of complexity that is equally applicable to such diverse phenomena. Such a theory would perhaps only be possible at a very high level of abstraction and generalisation, which presumably is why some adherents of complexity thinking – including the Santa Fe school, and many others (such as Krugman, 1996) - seek to establish formal mathematical principles of complex behaviour.⁷ However, it is our view that a formal (mathematical) modelling methodology is neither necessary nor of itself sufficient for understanding the complex behaviour of the economic landscape; evolutionary processes in the social-economic sphere are not easily reduced to, nor rarely can be adequately represented by, formal models.⁸ Thus while we might share Krugman’s view that the economic landscape can be viewed as a complex evolving system, we do not subscribe to the argument that this automatically requires the adoption of a model-based methodological strategy. Our task here, instead, is more ontological in purpose, namely to explore how far and in what ways some of the ‘generic’ aspects of evolutionary behaviour that are held to characterise complex systems can inform how we think about and conceptualise the economic landscape and its evolution. As in the case of borrowing ideas from evolutionary biology, so there are questions concerning the interpretation of metaphors and analogies transferred from ‘complexity theory’ to economic geography. The paper is intended to throw some light on this issue. We begin, then, in the next section, with identifying some of these generic principles or properties that are held to characterise complex systems.

⁶ It should be noted that Krugman’s excursion into ‘complexity theory’ is limited in scope and makes no links with the ideas and concepts of evolutionary economics.

⁷ Indeed, ‘complexity theory’ is often portrayed as, and defined in terms of, the mathematics of non-linear dynamic stochastic systems, particularly physico-chemical systems.

⁸ Even in the physical and natural world, mathematical models typically fail to convey the precise nature of the specific *processes* at work.

2. ‘Complexity Thinking’: Some Generic Concepts and Principles

At the very outset, we need to distinguish between ‘complexity’ and ‘complication’. The description ‘complex’ is often inappropriately attributed to systems by virtue of their having a large number of component parts, when these systems are merely complicated. A system of this kind can be understood by taking it apart and rebuilding it, like a clock or a car – the system is explicable through a description of its component parts. On the other hand a system is complex when it comprises non-linear interactions between its parts, such that an understanding of the system is not possible through a simple reduction to its component elements. A complicated system, then, need not be

Table 1: Some Key Generic Properties of Complex Systems

Property	Attributes
Distributed nature and representation	The functions and relationships are distributed across system components at a whole variety of scales, giving the system a high degree of distributed connectivity.
Openness	The boundary between a complex system and its environment is neither fixed nor easy to identify, making operational closure dependent on context (and observer). Such non-isolated systems tend to be dissipative – subject to constant interaction and exchange with their environments.
Non-linear dynamics	Complex systems display non-linear dynamics because of various complex feedbacks and mutually self-reinforcing interactions amongst components. Complex systems are thus often characterised by path dependence.
Limited functional decomposability	Because of its high degree of connectivity, and the open, dynamic nature of its structure, there is limited scope for decomposing a complex system into stable components
Emergence and self-organisation	There is a tendency for macro-scale structures (including spatial structures) and dynamics to emerge spontaneously out of the micro-scale behaviours and interactions of system components.
Adaptive behaviour and adaptation	The same processes of self organisation imbue complex systems with the potential to adapt their structures and dynamics, whether in response to changes in the external environment, or from within through co-evolutionary mechanisms or in response to ‘self-organised criticality’.
Non-determinism and non-tractability	Complex systems are fundamentally nondeterministic. It is not possible to anticipate precisely their behaviour even if we completely know the function of their

Property	Attributes
	components. This does not imply, however, that the behaviour of such systems is random, in the sense of being haphazard.

Sources: Based on Horgan (1995), Pavard and Dugdale (2000), Adami (2002), McGlade and Garnsey, 2006, among others

complex, in the sense of exhibiting complex behaviour: of course, a complex system may also be complicated.

As mentioned above, while there is as yet no generally agreed set of well-defined ‘law-like’ statements that together constitute a universal theory of complexity, nevertheless what distinguishes complex systems is the way they exhibit emergent self-organizing behaviour, driven by co-evolutionary interactions, and an adaptive capacity that enables them to rearrange their internal structure spontaneously (Pavard and Dugdale, 2000). More specifically, seven generic properties can be identified as characteristic of complex systems (see Table 1).

First, a complex system has a *distributed* nature and representation, in the connectionist sense, whereby the system’s resources are physically or virtually distributed across various sites, and its functions and the relationships and feedbacks that exist among its elements occur over various spatial ranges and scales: complex systems are characteristically multi-scalar. Second, it is often supposed that a system changes only inside its own frontier: this is the definitional notion of ‘operational closure’. In contrast, it is typically difficult to determine the boundaries of a complex system: the boundary between a complex system and its environment is usually dependent on the purpose of the analysis, or on the context, and not on any intrinsic property of the system itself. In short, *openness* (or *non-isolation*) is an inherent feature of complex systems. This in turn is closely related to the idea that such systems tend also to be *dissipative*, in the sense that they are in constant interaction and exchange with their environments, and thus experience a continual inflow and outflow of energy, matter and information. When these characteristics are combined with *non-linear dynamics*, arising from the mutually reinforcing feedbacks among a complex system’s parts, the result is an *irreversibility* of change and a tendency towards path dependence in the system’s trajectory and behaviour. At the same time, however, openness implies a susceptibility to externally induced fluctuation and perturbation, and such forces can cause a shift to a new regime. In other words, “the passage to complexity is intimately related to the *bifurcation* of new branches of solutions [trajectories] following from the *instability* of a reference state, caused by the nonlinearities and [environmental] constraints acting on an open system” (Nicolis and Prigogine, 1989, p. 73; original emphasis). Because of its inherent connectivity, non-linearity and openness, a complex system also affords *limited functional decomposability*; that is, its overall (macro-level) functioning cannot be deduced from knowledge of the function of its sub-components.

Yet further, the pattern and nature of interactions (non-linear and distributed) between the elements of the system allow it to functionally restructure itself over time. Indeed, the properties of *self-organisation and emergence* are often held to be the primary distinguishing features of complex systems.⁹ These ideas refer to the observation that there are many systems that at one level can be described as consisting of numerous micro-scale components that are individually ‘simple’ and which interact with each other in limited, simple ways, often only influencing neighbouring components, yet at another scale are able to exhibit some complex overall system-level structure and behaviour. In broad terms, it is those systems that exhibit the ‘emergence’ of macro-scale structure and dynamics spontaneously from the micro-level behaviours and interactions of their components that are referred to as ‘complex systems’. These same processes, including co-evolutionary mechanisms amongst different system components and levels, give complex systems an *adaptive quality*, whereby their structures change in response either to changes in a system’s external environment, or from within through what some have termed ‘self-organised criticality’ (Bak, 1996), in which the system evolves to a particular ‘critical’ state that then generates chain reactions between components to produce a major change in the system’s structure and/or dynamics (a sort of ‘punctuated equilibrium’ form of system evolution).

Finally, because of these various attributes, complex systems are fundamentally *non-deterministic*. Even if we have complete information on the function and inter-relationships of components, it is not possible to anticipate their behaviour precisely. Complex systems are inherently stochastic in nature. But that does not mean their behaviour is random in the sense of being haphazard. There are causal processes at work, but they operate through complex, distributed feedback and self-reinforcing mechanisms that are unlikely to be detected by standard measures of association (correlation) between assumed determinants and presumed effects (McGlade and Garnsey, 2006).

According to some exponents, together these various characteristics form a sort of ‘vocabulary of complexity’ (Nicolis and Prigogine, 1989; Lissack, 1999). In effect, they constitute a ‘complexity ontology’, a particular view of how reality (from physical systems to biological systems to social systems) is structured and behaves (evolves). Of itself this ontology does not imply a specific set of methods or ‘tools’ of analysis, though as mentioned above, many advocates of complexity do seek to express complex systems and their dynamics in terms of formal mathematical models. This distinction between the ontological and methodological aspects of complexity thinking is an important one, as developments and debates within economics demonstrate.

3. Economics and Complexity Thinking

⁹ A complex system can simply be chaotic, and is not necessarily self-organising. A complex adaptive system, however, is necessarily self-organising.

In recent years complexity theory has attracted increasing interest from economists, and is now believed by many to be a novel and powerful framework of thought capable of challenging the fundamental principles of the mainstream economic canon (see, for example, Krugman, 1996; Arthur, Durlauf and Lane, 1997; Auyang, 1998; Colander, 2000a, 2000b; Potts, 2000; Schenck, 2003; Foster and Metcalfe, 2004; Rosser, 2004).¹⁰ According to one of its main advocates, “complexity changes everything; well maybe not everything, but it does change quite a bit in economics” (Colander, 2000a, p. 31). It is suggested that complexity ideas “are beginning to map out a radical and long-overdue revision of economic theory” (Buchanan, 2004, p. 35). In one such manifesto, for example, Beinhocker (2006) suggests the term ‘complexity economics’ as an umbrella for a number of streams of theoretical and empirical work that can be linked directly or indirectly with ‘complexity thinking’. Whilst he stresses that ‘complexity economics’ is still more a research programme than a single synthesised theory, he identifies five key dimensions - or what he calls ‘big ideas’ - that mark out ‘complexity economics’ from ‘traditional economics’ (Table 2): the economy as a open, non-linear system; made up agents with bounded rationality, who learn and adapt; who interact through constantly changing networks; whose micro behaviours and interactions are the source of emergent pattern and order at the macro-level; and who are the source of the constant novelty that imbues the economy with its evolutionary momentum.

The problem, however, is that different economists approach the idea of ‘complexity’ in quite different ways. According to Perona (2004), two sharply divergent versions of ‘complexity economics’ can be distinguished: ‘theoretic’ and ‘ontic’.¹¹ The term ‘theoretic’ refers to those versions of

¹⁰ Indeed, there have also been attempts to trace embryonic ‘complexity thinking’ ideas in the history of economic thought, and to reinterpret the work of previous major economists – from Marx to Marshall - from a ‘complexity perspective’ (see Colander, 2000b).

¹¹ Perona takes these terms directly from Lawson:

If I can use the term *theoretic* to denote the quality of being a feature of a model and the term *ontic* to denote the quality of being features of the world the economist presumes to illuminate, a more succinct way of describing the problem that arises through the prioritisation of the modeling orientation is a conflation of the theoretic and ontic, with the latter reduced to the former (Lawson, 2003, p.4).

Table 2: Beinhocker’s Five ‘Big Ideas’ that Distinguish ‘Complexity Economics’ from Traditional Economics

	Complexity economics	Traditional economics
Dynamics	Open, dynamic, nonlinear systems, far from equilibrium	Closed, static linear systems in equilibrium
Agents	Modelled individually; agents use inductive rules of thumb to make decisions; have incomplete information; are subject to errors and biases; and learn and adapt over time	Modelled collectively; agents use complex deductive calculations to make decisions; have complex information; make no errors and have no biases; and have no need for learning and adaptation (are already perfect)
Networks	Explicitly models interactions between individual agents; networks of relationships change over time	Assumes agents only interact indirectly through market mechanisms
Emergence	No distinction between micro- and macro-economics; macro patterns are emergent result of micro-level behaviours and interactions	Micro- and macro-economics remain separate disciplines
Evolution	The evolutionary process of differentiation, selection and amplification provides the system with novelty and is responsible for growth in order and complexity	No mechanism for endogenously creating novelty or growth in order and complexity

Source: Beinhocker (2006, p. 97).

complexity economics that treat nonlinearity, instability, self-organisation, emergence, adaptive behaviour and the like, as features of the mathematical *model*, the equation or system of equations, used to *represent* a particular type of reality. Perona contrasts this to ‘ontic’ versions of complexity economics, that is where complexity is seen as a property of real economic systems and phenomena. Though we agree with the general thrust of Perona’s argument, to our mind the label ‘theoretic’ in this context is not altogether helpful, since not all theories are cast in terms of mathematical deductive models; and, some might argue, what is an ontology if not a particular theory of how the world is structured? What Lawson (2004) elsewhere refers to as a distinction between ‘scientific-ontological’ and ‘social-ontological’ approaches to complexity might be more appropriate, where the former is concerned with the nature or structure of entities posited or presupposed by some scientific model, and the latter is concerned with the nature of socio-economic existence apart from any such model. Arguably, the key distinction is between epistemological (methodological) and ontological approaches to complexity. In complexity theory, epistemology has dominated over ontology, with the latter often reduced to the former (in the manner discussed by Lawson). The assumption has

been that the same formal (thermodynamic and chemico-physical) models can be applied across numerous different fields, including the economic.

In Perona's view, the efforts of Arthur (and, we would add, Krugman) to construct a complexity economics, are of this mode-based ('theoretic', or 'scientific-ontological') kind. Thus we find both authors postulating an abstract economic landscape which is viewed as an adaptive system, consisting of many agents who interact continuously among themselves, whilst being allocated to a pre-given geometry of locations and immersed in an overall 'evolutionary' environment (Krugman, 1994, 1996; Arthur, 1994; Arthur *et al.* 1997), all represented by some system of non-linear equations, power law functions and the like. In these models, agents' interactions and location decisions are usually described by means of (predetermined nonlinear) rules, which are repeated through several steps, thus accounting for the system's 'dynamic' nature and spatial development. Complexity in these treatments is not a characteristic of how causal processes are connected to each other, but a characteristic of the behaviour of the spatial-temporal series of a particular variable, typically represented not by actual data but by the solution sequence of a computational or simulation model (see not only Arthur, 1994; Arthur, et al, 1997; and Krugman, 1997; but also Rosser, 2004). According to Viskovatoff (2000), although this approach to complexity economics (and complexity 'economic geography' as formulated by Arthur, Krugman and other economists) may well abandon some of the artificial assumptions of Neoclassical economics (such as the rational behaviour of agents, and an inherent tendency to a single, unique equilibrium), it remains committed to deductive theorizing, in this case as formulated by non-linear models (and it should be added, to the idea of equilibrium, even if the latter is now no longer unique but dependent on the 'initial conditions' or 'starting point' of the economic system). In effect, the complex economy becomes identified with the simulation model and solution sequence used to represent it.

The problem is that there are far fewer examples of an ontological ('ontic') perspective. One of the most concerted efforts in this direction is that of Potts (2000), for whom complex systems theory is the most suitable basis for constructing an evolutionary economics:

The hypothesis of evolution towards complexity is a conjecture to the effect that a balance between order and chaos, between stasis and change, is the ultimate principle underlying all evolutionary processes. Where equilibrium is the expression of 'balance' in an inert, mechanical world of point-like existence, complexity is the expression, the structural signature, of balance in a world of interacting dynamic systems. The hypothesis of evolution towards complexity is the logical principle that interlinks the geometry of all economic systems (2000, p. 91).

Following Kauffman's (1993) contention that there is no strong reason to attribute the emergence of order in biological systems solely to the force of selection, Potts argues that much of the order and coordination in an economic system may not be the result of 'market selection' at all, but a spontaneous order of self-organised

systems. According to Potts, the concept of complexity - and more specifically the hypothesis of evolution towards complexity - contains within its meaning a number of high-level connecting principles that are prominent in heterodox economic theories: “evolutionary economics is an eclectic rubric centred around the paradigm of the complexity of open systems processes, and its basic substance is both more encompassing and more protean than a simple transferral of metaphor” (2000, p. 186).

For Potts, the ontology of methodological individualism, social atomism and equilibrium of traditional economics is replaced in complexity economics by an ontology of ‘connectivity’:

Generally connections are specific direct relationships between elements and are ubiquitous in the economic system. They exist in the structure of interdependencies and interactions between agents. They exist in the modalities of technology and the forms of organisation and competence. They exist as contracts. They exist in the structure of decision rules and the way that information is processed, In all such events, the dynamics of economic systems can be seen to occur most in the space of connections (Potts, 2000, p. 3).

Potts goes further and suggests that knowledge in all of its multifarious forms is in fact about connection. For Potts, as for many evolutionary economists, it is the growth of knowledge that drives the process of economic evolution (Foster, 1993, 1994, 1997; Metcalfe, 1997, 1998; Foster and Metcalfe, 2004). Similarly, Foster pieces together a vision of evolutionary economics based not on biological analogy, but on principles of complex self-organisation in which knowledge plays a formative role: “economic self-organisation involves acquired energy and acquired knowledge, which in combination, yield creativity in economic evolution” (Foster, 1997, p. 444). According to such authors, the structure of knowledge is a structure of connections, and the various instances of knowledge – such as technology, routines, habits, competences and the like - are instances of specific connections, that is of networks, that seem to work in a particular environment. Thus, from this perspective, economic evolution – and hence complexity economics - is about the emergence and evolution of multiple connections in the form of networks.¹²

However, notwithstanding the efforts of Potts, Foster and others to forge a ‘heterodox’ complexity economics, for the most part much of complexity thinking in economics commits the conflation referred to by Lawson, that is it reduces the ontological to the epistemological. The economy is taken as constituted by scale-invariant laws or dynamics that apply not just to the economy but to all sorts of complex systems: self-organizing systems reach a state of spontaneous order and then “follow a dynamic pattern that is lawful in its own right” (Batten, 2001, page 94). Typically these laws and dynamics are identified by the presence of behavioural and statistical signatures or hallmarks such as power laws, punctuated equilibria, and

¹² This leads Potts to conclude that graph theory could be a useful methodology to deal with economic complexity at the representational level.

phase transitions, and attractors (see Krugman, 1994).¹³ In many cases, it is the belief in these universal complex dynamics that is used to justify both mathematical formalism and, in an economic context, agent-based computer simulations.

The belief that different types of complex systems all show signature behaviours and common emergent patterns runs through all versions of complexity economics to some degree. Yet, such a conceptualisation overlooks the obvious but important fact that social and economic systems show different and distinctive forms of complexity: social, spatial and historical context shape the nature of the economy and its behaviour. According to Foster (2005), all economic systems are ‘third-’ or ‘fourth-order’ complex.¹⁴ In ‘third order’ systems individual agents modify their environments to increase access to energy and resources, reduce their effort costs, or seek out free information to increase their knowledge. In ‘fourth order’ complex systems individual agents form beliefs about the beliefs of others (collective understandings) that are critical for their survival. More specifically, in the modern economy they seek out information about the beliefs/knowledge of others in order to co-operate to modify the environment. This implies that there will be particular forms of complexity in economic systems that are beyond any ‘natural laws’ of complexity but which are highly social, institutional and historical. However, this is only a starting point. Foster goes on to argue that “Economic self-organisation is not the same as biological self-organisation, despite the fact that they share common properties” (2000, p. 235). The principles and rules of first and second order complex systems can be applied to economic systems, but they operate ‘somewhat differently’ because of the greater role of knowledge and foresight (Foster 2004, p. 11).

In similar fashion, complexity economics also synthesizes evolutionary approaches with complexity thinking on dissipative systems. In Beinhocker’s (2006) account, for example, the essential complexity framework that spans both natural and social systems is an adaptive, iterative evolutionary algorithm. In this algorithm, the universal evolutionary mechanisms are those that act to differentiate, select and replicate, and allow adaptive agents co-evolve with their environments. He suggests that there has been “too much loose analogizing about how the economy might be *like* an evolutionary system” (p. 12). He adds “Modern efforts to understand the economy as an evolutionary system avoid such metaphors and instead focus on understanding how the universal algorithm of evolution is literally and specifically implemented in the information-processing substrate of human economic activity. While both biological and economic systems share the core algorithm of evolution and thus have some similarities, the realizations of evolution are in fact very different and must be understood in their individual contexts” (ibid, p. 12).

Thus in recent complexity economics, most authors have been at pains to

¹³ For example, Batten writes that “The footprints of power laws can be found everywhere” (p. 96).

¹⁴ In Foster’s (2005) typology, ‘first-order’ complexity refers to the imposition of energy onto chemical elements such that patterns form in the dissipation of energy, whilst ‘second-order’ complexity refers to reception of information that is translated into a knowledge structure that permits control over the acquisition of energy. This is the level of complexity operating in the biological domain.

emphasise that economic systems display forms of complex behaviours that are distinct from, and yet build upon and resemble, the versions of complexity identified in the physical and biological worlds. But the argument that there are both shared common patterns and yet very distinctive social and economic versions of evolutionary complexity, creates several tensions and unresolved questions. Complexity economics insists that economic systems are distinctive, yet, as we will see, when convenient, it continues to import complexity dynamics and models identified in natural science and suggests that analogous patterns can be identified in the economic system. How much complexity science can we translate into the economic sphere, and how exactly should it be mediated and modified? How many of the principles and axioms that are distinctive and characteristic of complex natural evolutionary systems carry over and extend to social forms of complexity? Given the lack of agreement on such questions, it is not surprising – as Perona points out – that whilst complexity ideas are thriving in economics, there remains confusion between epistemological and ontological aspects of complexity economics. A complexity approach to evolutionary economic geography will need to address and resolve this confusion if it is to provide a convincing new approach. In addition, as we now go on to discuss, when we move from the economy to the economic landscape there are further issues that need clarification.

4. Emergent Economic Landscapes?

Complexity economics at present says very little about space and geographical differences. Admittedly, existing models of self-organizing economic landscapes demonstrate that relatively simple rules of agglomeration and centrifugal forces can produce emergent spatial orders that resemble edge cities and clusters or show statistical regularities (Arthur, 1994; Krugman, 1994; 1996; Batty et al, 2004). At best, they may generate selected ‘stylised facts’ in economic geography and ‘space’ appears in these models as a patterned outcome, but the models tell us little that is new about complex economic change and system adaptation over space. And the nature of geographic space in these modelling exercises is either wholly abstract or empirically crude. As noted earlier, some of the characteristics of non-linear, path-dependent system change have also been applied to geographical entities such as clusters, regions and nation-states (see Arthur, 1994; Krugman, 1996; Garnsey, 1998; Martin and Sunley, 2006). However, we should start by carefully considering whether such spatial entities can legitimately be described as complex adaptive, self-organizing systems.

The dynamics of complex adaptive systems depend upon their configuration and how this responds to innovation and shocks. Such systems are constituted by interconnections across multiple scales between diverse and heterogeneous agents. Many of them display spatial behaviour that bears crucially on their robustness and adaptability. Moreover, local co-evolutionary effects within such systems typically

produce innovation and novelty (Metcalfe et al, 2005; Markose, 2005). Indeed, it has recently been argued that complex systems are preternaturally 'spatial' (Thrift, 1999). O'Sullivan et al (2006), for example, argue that spatial variability is central to complexity, as where elements are located relative to other elements is critical to their behaviour (Manson and O'Sullivan, 2006). As Bullock and Cliff (2004) have argued, however, the role that spatiality plays in underpinning complex adaptive behaviour is poorly understood. While many of the leading accounts of complexity and complexity economics discuss system movements in 'state-spaces' and their adaptive walks on 'fitness landscapes', they say little about geographic space and its relation to the adaptive behaviour of individuals and businesses.

If there is a spatial metaphor essential to complexity economics then it is the 'network'. Complexity approaches represent 'the economy' as made up of innumerable flows and connections, and they are predicated on the notion of incomplete and selective networks. The starting point is that everything is not connected to everything else so that the 'force field' metaphor underlying neoclassical economics is inappropriate (Potts, 2000). Instead, the bounded rationality and imperfect knowledge of economic agents mean that we should address imperfect and incomplete networks that are irreducibly broken and partial, and in this sense they are spatially distributed, with a bias towards some degree of localisation. Complexity thinking tends to start with the assumption that components interact most strongly with their nearest neighbours, and in some physical systems this means a form of distance decay. The idea of complex territorial economies is then most aptly applied where interactions between agents are geographically localised. But, of course, where distance is as much or more 'relational' rather than spatial, 'localised' interactions do not always translate into spatial proximity. As Cilliers (2005) has argued, we can not always assume that socio-economic subsystems are spatially contiguous. Parts of socio-economic systems may exist in totally different spatial locations and systems may interpenetrate each other and so be part of different systems simultaneously. Localised interactions can then simply mean interaction with selected other components. Ultimately, it is plausible to argue that spatial entities such as regions and cities become self-organising complex systems when they are strongly interactive and the interdependencies between agents are 'global' in the sense of operating throughout the trading system (Batten, 2001). For example, Batten (ibid) argues that Medieval Europe in the Carolingian era was a weakly interactive system in which villages and groups of villages were autarkic and self contained. However, as long distance trade and the geographical circulation of goods and merchants intensified, this weakly interactive economy was transformed into a highly-interactive one, and the European economy self-organized. Does this mean, however, that all modern economies are self-organizing? What are the critical transitions and thresholds in different types of interaction and circulation that define whether a region or city is strongly rather than weakly interactive?

A defining feature of a complex system is that it is composed of interacting subsystems and hierarchical levels, and on this basis we might argue that the national economy can be divided into smaller territorial subsystems such as regions, cities and localities. Batty et al (2004), for example, claim that cities are the quintessential example of complexity. But if complex systems define their own scales and can shift scales unpredictably, then can we assume a certain geographical scale can always be defined as a complex system? The boundaries of complex systems are never pre-given but are a matter of framing, which is partly about the purpose of study and research strategy, and partly about the constraints arising from the operations of the system itself (Cilliers, 2005). Dividing a complex system into territorial sub-systems is bound to be at the cost of analytically fragmenting and simplifying its complexity, but it can be justified if the constituent flows and connections are producing some forms of identifiable boundary and system integrity. Clearly, identifying spatial economic subsystems does not imply that they are closed. Rather the boundaries of complex systems are neither fully open nor fully closed. Moreover, Cilliers (2001) also argues that when components are richly interconnected, there is only a short route to the outside of the system. There is no safe inside, the system boundary is folded in so that in a richly interconnected system we are never far away from the boundary. Boundaries are functional constitutive components that do not separate but connect systems with their environment. Sub-systems can be identified within complex systems if the sub-system becomes responsible for maintaining its own configuration, and it can then be said to show 'organizational closure'. In this state the organisation is determined purely internally even though the subsystem (a region or city, say) exchanges energy and matter (that is, flows of goods, services, knowledge, capital, money and people) with its environment (other regions and cities). The interactions between these subsystems (regions, cities, clusters, etc) may also determine systems at a higher hierarchical (and spatial) level so that a 'boxes within boxes' architecture emerges.

The subsequent question is whether we can justifiably argue that spatial entities such as regional economies and clusters are economic sub-systems that show emergent properties. Do they emerge from unplanned and unintentional localised interactions between agents and display relatively ordered paths of change? What is not clear here is whether such units (clusters, cities, regions) show 'organisational closure' such that they retain their organisational identities and configuration despite fluctuations and perturbations in their external environments. Is it feasible that regions, clusters and cities develop key internal interactions that provide them with some organisational 'attractor' and continuity in the face of environmental changes? Given that market-based economic systems are always importing knowledge and information then there is no simple distinction between internal organisation and flows, and the metaphor of organisational closure may imply too great a level of coherence, stability and endogeneity. Furthermore, what has not been explained so far is how we might identify such organisational maintenance in regional and local

economies. What exactly are the key organisational connections, flows and interactions that define this condition and are they flows of money, value, people or ideas?¹⁵ A further question is whether we can apply the idea of emergent properties to economic places. According to O'Sullivan et al (2006) "the novelty of complexity lies in a sustained attempt to grapple with the 'bottom up emergence of aggregate behaviour on the one hand, and the top down impact of emergent structures on the behaviour of constituent elements on the other" (p.614). In this view, emergent characteristics exercise 'downward causation' and influence the localised interactions between agents (Gilbert, 2002, refers to this as 'second order' emergence). There is now, of course, much evidence that there are forms of positive feedback in regional and cluster development so that initial advantages and firm location decisions may initiate path dependent, self-reinforcing trajectories, and indeed Krugman (1996) argues that such feedbacks and spillovers are good examples of emergent effects.

However, there are also difficulties in applying the notion of emergence to economic landscapes, largely because of the key role of knowledge. One of the conditions of emergence is that local agents are unaware of the emergent effects of their actions and relations (Manson and O'Sullivan, 2006). Complex emergent effects are generated by relatively simple behavioural rules and interactions between agents. Clearly this does not apply in the same way in Foster's (op cit) 'fourth order' complex systems where action is to a far greater degree reflexive, intentional and subject to continuous monitoring and cooperative behaviour. As Sawyer argues, because of the character of human symbolic communication, processes of emergence in social systems are different from those in natural and biological systems. "In social systems the components (individuals) contain representations of the emergent macropatterns, unlike in any other complex system" (2005, page 26). Thus, for example, to describe industrial clusters as emergent phenomena may obscure some of the ways in which the knowledge and expectations that maintain their success are not simply localised interactions but are also public, collective and interpretive. Economic knowledge may itself be continuously emergent, arising from exchanges of information (Potts, 2000; Ramlogan and Metcalfe, 2006). But if that knowledge then acts as the basis for further change and economic growth, then the idea of simple sequence of localised interactions generating emergent effects would seem too simplistic.

5. Self-Organisation in Economic Landscapes

As we have noted above, a key set of issues in complexity economics revolves around the notion of self-organisation. While some complexity economists use the notions of self-organisation and self-transformation fairly loosely, others hardly use the concepts at all (see, for example, Beinhocker, 2006). Recall that self-organisation describes the way in which systems order themselves without central direction or

¹⁵ Schnabl et al (1999) argue that input-output matrices reveal that the Queensland economy has become more interconnected and co-ordinated over time through market relations and has followed a coherent self-organising developmental path. Yet this surely reveals only one aspect of co-ordination.

external control such that they acquire and maintain structure and arrange selected parts to promote (and reproduce) a specific function. In this latter respect, the idea of self-organisation is closely related to the notion of autopoiesis, which refers to the dynamics of a non-equilibrium system that produces the components which in turn continue to maintain the organised structure that gives rise to these components. At one level, these twin concepts would seem highly applicable to the economic landscape. Cities or clusters, for example, would appear to be good examples of self-organised, autopoietic systems: as localised economies, they comprise sets of components (firms, institutions, infrastructures, people, etc) that generate outcomes (decisions, relations, daily behaviours, profits, incomes, knowledge, and the like) that serve to reproduce the components that make up the city or cluster. The emergence of positive localised externalities or agglomeration economies might thus be interpreted in autopoietic terms, since they feed back to help reproduce and maintain the economic components (firms, workers, institutions) whose spatial juxtaposition and interrelationships create those very externalities. In this way, as organised (and dissipative) autopoietic systems, cities, clusters and particular types of regional economy can remain stable for long periods of time despite people, goods, knowledge, and money continually flowing into and out of them.

Yet there are also clearly problems using a self-organisation metaphor in economic geography. First, there is the question of how valid it is to think of the economy of a city, or cluster, or region in autopoietic terms. City and regional economies are not internally coherent structures: certain components can be added or removed without necessarily influencing the organisational stability of the city or region as a whole; many firms may have few if any links with other local firms; and different parts of the city's or region's economy may function in different ways, and be linked to the external environment (external markets) in different ways. In other words, self-organisation in the economic landscape may not necessarily of itself equate with autopoietic dynamics.

Second, the basic assumption of distributed and dispersed control among system components is clearly not applicable to many types of economic organisation such as cities or regions. In fact, complexity economics says little about the power inequalities that exist in all economic landscapes and strongly shape the selection of institutional and organisational configurations. This has major implications, of course, as the assumption that the connections and configurations that exist in economies have been selected for their 'fitness' by market processes and for their ability to maximise flows of value, can yield a remarkably uncritical view. In fact connections and linkages in the economy are likely to be selected according to several different criteria simultaneously, including the vested interests of more powerful groups and their ability to channel and control these flows.

Third, self organisation is problematic as it is hard to identify mainly endogenous dynamics when the boundaries of economic systems – such as regions

and cities - are so hard to identify¹⁶. Metcalfe, for example, argues that the economy self-transforms when economic agents become dissatisfied or concerned about their returns so that they search for new ways of doing things and combine knowledge in new ways to produce new value flows. But it makes little sense to insist that these new bits of knowledge and problem solutions are mainly internal to the economy as human learning is far too tangled and unbounded for this. Furthermore, while markets may show forms of self-regulation and co-ordination, it is clear that there are numerous institutional and political preconditions which allow these co-ordinating effects to occur.¹⁷

Fourth, there are further questions about the relationships between self-organisation, connectivity and order in the economic landscape. Complexity theorists see self-organisation as a critical balance between order and chaos, and according to Potts (2000), in the economic sphere the degree of connectedness is key to understanding the nature of this balance. An ordered system is defined as one with a low level of connectivity. In such a system a change at any one point or in any one component has limited impact on the rest of the system, which as a whole, remains virtually unchanged: low connectedness implies a high degree of order and a high degree of stability of the system. In a system with a high degree of connectedness, a change at any point in the system impacts on many other elements so that change is propagated across the system as a whole. In the extreme case, where every element is connected with every other, the system would be wholly unstable, in effect chaotic. Complex systems are somewhere in the middle: “order is associated with low connectivity, chaos with high connectivity, and complexity forms a narrow window of low-to-intermediate connectivity between order and chaos” (Potts, 2000, p. 90). According to Potts, the economy, as a complex system, is in dynamic balance between order and chaos, and is

Neither ordered not chaotic but both, in a balance between information, pattern and coordination being usefully locked into a system (as preferences, technology, institutions) and the continued experimentation and search for new patterns and the maintenance of flexibility within the system so that these may then be adapted (ibid, p.90).

What does this imply for the economic landscape, for the geographies of the economy? Most economic geographers would agree that there is a high degree of stability and order to the spatial structure of the economy: cities do not appear or disappear overnight; patterns of industrial location and agglomeration do not change from one day to the next; regional specialisations do not develop or decline spontaneously. Yet this stability and order is hardly the result of low levels of connectivity, either within or between cities and regions. Indeed, adherents of the

¹⁶ This is indeed a general criticism that can be levelled at the idea of autopoiesis when applied to social systems (see Mingers, 2002).

¹⁷ The formation of institutions can also be the result of co-evolution or self-organisation, and are thus not exogenous to the system under study. They might be assumed as exogenous in the short run, but themselves become endogenous in the longer term, as they change and transform as the economy itself evolves (see Martin and Sunley, 2006)

new ‘relational turn’ in economic geography would probably argue that it is primarily in terms of multifarious relational (connectivity) networks that the geographies of the economy should be understood. Yet again, equating order, stability and lock-in with low levels of connectivity would seem to run counter to those accounts that explain regional lock-in in terms of excessive interrelatedness – the ‘weakness of strong ties’ argument (for an extended discussion of regional lock-in, see Martin and Sunley, 2006).¹⁸ In short, the relationships between self-organisation, connectivity and order would seem to require extensive elaboration in an economic-geographic context.

And, fifth, so too does the relationship between self organisation and adaptation (Essletzbichler and Rigby, 2007, in this journal issue). According to Hodgson and Knudsen (2004a) self-organisation alone cannot provide the basis for an evolutionary economic theory as it tells us nothing about selection: “Self organization alone cannot explain the adaptation and differential survival of self-organized systems” (ibid, page 16). In their view an exclusive focus on self-organization at the expense of selection does not explain how systems are adapted to their environments. They conclude therefore that selection acts on self-organized systems once they have emerged. But whether the emergence of connections and interlinkages in economic systems (self-organization) can be clearly distinguished from their subsequent selection is debateable. The contexts for the generation of variety and its selection in economic organizations are often combined and inseparable (Loasby, 2001). As we have already seen, other complexity economists appear to suggest that some complex systems have properties that make them robust and adaptable. They argue that self-organised systems move to a poised state, called the ‘edge of chaos’, where they balance between no order and too much order (Potts, 2000). In this critical state, complex systems have a dynamic efficiency that allows them to meet evolutionary and competitive pressures, whereas excessively ordered as well as chaotic, unstable systems are both eliminated. Self organised systems have a high degree of resilience and robustness as they are marked by distributed and dispersed, rather than centralised, control, as well as by strong positive and negative feedback loops, and by a high level of redundant variety (Heylighen, 1999). It is not surprising then that this vision of complex systems has been used in a normative fashion and has been used to explain the resilience and adaptability of complex industrial clusters (Lindsay, 2005).

At the same time, however, complexity economics also suggests that once co-evolutionary complexity, in terms of a system’s internal and external co-evolutionary linkages, passes a certain threshold, the system may become unresponsive to environmental pressures. Foster (1997), for example, points out that all dissipative systems have a tendency to degrade through time and the renewal of their links

¹⁸ Potts expressly links ‘lock-in’ to low connectivity (ordered) systems:

In the ordered regime, the particular configuration of connections locked into (descriptive of preferences, technology, institutions) may or may not be optimal in the sense that other combinations may be better, but the system has no internal mechanism to change to these states (ibid, p.90).

depends on the continual import of information, energy and resources. He also argues that complex systems tend to become more specialised as their order, integration and 'knowledge' increase. As their coherence increases, they specialise on adapting to particular environmental niches and if these niches suffer from resource depletion or the entry of new competitors, then even complex systems may disintegrate and start the process of self-organization anew. Thus complex linkages and connections that constitute complex economic systems may over time prove to be too specialised. In the case of 'complexity catastrophes', too many interdependencies act to trap a system within a basin in a fitness landscape so that environmental selection can not operate. McKelvey (1999) applies this thinking to firms and Beinhocker (2006) also argues that hierarchical systems in organisations are often more efficient and adaptable because they can make and implement decisions more rapidly.¹⁹ Once again however, whether this can be applied to the evolution of urban and regional economies is unclear. How can we judge when their connectivity has exceeded a beneficial value and started to move towards a complexity catastrophe? What would an excess of external connectivity mean in this case? Under this logic also, the increasing complexity of many production networks and regional economies might imply that we will witness more 'complexity catastrophes' in future, although this will depend, of course, on whether any such effect is offset by other trends in innovation and the evolution of knowledge.

6. Complexity and Regional Economic Evolution

An issue of particular interest in the present context, given the above discussion and our comments in the Introduction, is whether and how far complexity economics represents an advance on other types of evolutionary economics, and evolutionary economic geography, that draw insights by using Darwinian and other natural evolutionary analogies and metaphors. While some complexity economists argue that their approach is macroscopic and supersedes a microscopic, generalized Darwinianism (Foster, 1997), as we have already noted, most argue that complexity economics can synthesise complexity with evolutionary approaches based on natural selection. At the same time complexity economics tends to claim that it no longer has to rely on restrictive natural analogies and metaphors. Instead it aims to tell stories about its own subject matter (Wakeley, 2002). Beinhocker (2006), for example, argues that his approach is based on a universal evolutionary algorithm so that he does not have to rely on natural analogies. However, natural metaphors continue to be permeate complexity economics and are used when convenient. Beinhocker (2006) later identifies general laws of evolutionary systems that subsume the biological:

¹⁹ Later and perhaps inconsistently, however, Beinhocker swallows a reductionist version of Putnam and argues that economies with more connections in the form of social capital have more trust and grow more quickly.

The claim of the modern algorithmic view of evolution is that evolutionary systems are a universal class with universal laws. We can then ask whether the economy is part of that class and subject to those laws. If the answer is yes, then the economic and biological worlds are both members of that universal class. They may be very different in their implementations of the algorithm, and thus asking what a parent and an offspring are in economics makes no sense. Nonetheless, the two worlds are still subject to the same general laws of evolutionary systems, thus explaining the strong (pardon the metaphor) family resemblance (p. 217).

Indeed, he relies heavily on finding a business equivalent to DNA which can be differentiated, selected and replicated. But do we need to search for this if socio-economic evolution is fundamentally different from natural evolution? Moreover, he also uses evolutionary psychology to explain what he means by wealth as 'fit order'. Goods and products that push peoples' 'pleasure buttons' are those that satisfy the needs and instincts derived from our long evolutionary history. Thus, his explanation proves reliant on drawing out the implications of natural evolution.

Furthermore, other complexity economists are more willing to use direct natural evolutionary analogies. For instance, one of the most interesting aspects of self-organisation identified in the complexity literature is the 'Red Queen' (or competitive co-evolution) effect in which two competing species become locked into an intensive and adaptive race, equivalent to running in order to stand still. There have been several applications of this idea in complexity economics (for example, Robson, 2005; Markose, 2005). Thus it has been argued that this effect may explain the dynamics of innovation in high-technology and financial sectors as it forces competitors to continuously introduce new variety. It is not hard to envisage a spatially-defined version of Red Queen effects in which firms in clusters are driven to innovate more by the pressure of close competitors (Porter, 1998). The synthesis of evolutionary ideas with complexity means that recent versions of complexity economics still appear to be vulnerable to criticisms of evolutionary approaches. One of these is that they still portray human agents as mainly adapting to their environments rather than actively making these environments. There seems to be little in complexity economics on the ways in which powerful firms transform their economic environments through buying out competitors, switching investments into new sectors and locations, introducing major innovations in processes or products, or remaking markets through the effects of mass advertising.

Notwithstanding this continued use of natural metaphor, the main difference between complexity economics and neo-Darwinian views of economic evolution appears to rest on the relative importance of system self-transformation relative to selection.²⁰ The key point here is that some complexity accounts argue that selection can not operate on complex economies. This is either because there is too much innovation and mutation happening simultaneously or because interdependencies between system components mean that the fitness landscape is flat and that these co-

²⁰ Foster (1997) also appears to argue that a complexity view focuses on selection via changes in system boundary conditions rather than by microscopic dynamics.

evolutionary pockets become trapped in suboptimal fitness (McKelvey, 1999; Kaufmann, 1993). In these conditions environmental pressures will not work even if they are strong. This surely implies that our analysis of the evolution of an economic landscape should look at both types of change and should not always assume that selection is operative. As yet, we do not know enough about the prevalence and integration of these two types of change, or how we can establish their relative importance in specific cases of regional and local economic evolution.

Complexity economics has undoubtedly proved a fruitful source of ideas, but to what extent does it also provide the basis of a coherent ontological conception of regional economic evolution that could be developed by economic geographers? Such a theory would have to be based on the premise that regional economic evolution is driven by advances in knowledge and that knowledge consists of rules or connections between ideas. The geography of knowledge is crucial to understanding the rate of macro-economic growth as economic changes are the outcome of the relative balance between forces producing innovation, new knowledge and new variety, and forces leading to the disappearance of this variety through selection and the ageing of knowledge (Ramlogan and Metcalfe, 2006). This process is uneven across sectors and spaces: “Growth does not occur without the continual emergence of innovation and the persistent changes in the relative importance of products, methods of production, firms, industries, regions and whole economies, that adaptation to innovation implies, and these changes in structure are a consequence and a cause of the growth of knowledge” (ibid, page 29). Dopfer and Potts (2004a) argue for a form of evolutionary realism which explains knowledge as evolutionary dynamics among systems of generic economic rules. The *micro* level of analysis refers to individuals’ carrying of rules and actualization of these rules, while the *macro* level is the population or deep structure of meso-rules that defines how rules co-ordinate with each other and fit together (Dopfer et al, 2004). At the *meso* level generic rules undergo phases of origination, diffusion and adaptation, and retention and replication.²¹ The emergence of a new rule disrupts the coordinated structure and produces a period of de-coordination in actualizations. As the new rule moves through diffusion and retention phases re-coordination occurs as a new division of labour, possibly involving regional and industrial organization, stabilises. Dopfer et al (2004) argue that rules and their actualizations form ‘meso units’ which are the dynamical building blocks of an economic system. “Work on industrial districts, regional knowledge clusters, learning regions, inter-firm organisation, national innovation systems, networks with weak or strong ties, or technical support communities all falls under the heading of meso economics from the evolutionary

²¹ Beinhocker (2006) also argues that there are co-evolutionary dynamics which simultaneously shape social technologies, physical technologies and business plans. Such plans are carried by businesses which act as replicators. These plans are built from amalgamations of modules which themselves are combinations of atomistic physical and social technologies. He defines modules as “a component of a business plan that has provided in the past, or could provide in the future, a basis for differential selection between businesses in a competitive environment” (p. 283). Is this a rehearsal of, or an advance on, Nelson and Winter’s neo-Darwinian evolutionism?

perspective” (ibid, p. 268).²² In this view an analysis of regional economic change depends on understanding how generic rules, that are composed of knowledge connections, emerge and are actualized and institutionalised in particular regions. While this view has considerable potential, the precise meaning and content of such rules seems to require much further clarification and illustration.

This emerging theoretical approach certainly has important implications for economic geography. First, it implies that there strong reasons to re-examine and further develop the network perspectives deployed in parts of geography (for example, Castells, 2000; Taylor, 2003). It raises the question whether the evolution of networks and connections can be analysed in terms of changes in underlying generative rules. Second, it suggests that the chreodic evolution of knowledge is the main reason why regional economies and local economies show forms of path dependence (see Loasby, 2001). Beinhocker (2006) proposes that human decision making is guided mainly by inductive reasoning, so that condition-action (If-Then) rules used in the past will be applied in uncertain environments and experienced mental models become resistant to change. This, he contends, explains the inertia and elimination of established businesses. In this view, the roots of path dependence in industrial clusters and regional economies lie in human decision-making. At the same time, inertia is never inevitable because of the diverse ways in which knowledge can change. As Ramlogan and Metcalfe (2006) argue, innovation arises in combinatorial knowledge and that this has no rest points but constantly undergoes chreodic change “It can undergo subtle changes as information percolates across networks of relationships or it can undergo sweeping changes that take understanding into entirely new dimensions. To this degree understanding is unstable”(ibid, p. 130). The origins of regional path creation may well lie in this instability.

Third, this knowledge-based perspective also implies that the most effective complex systems are those that balance inertia and innovation. It is argued that if all the knowledge and beliefs in an organization are changing rapidly and simultaneously then it proves impossible to exploit innovations. Complex organizations that have an intermediate mixture of inertia and innovativeness appear to have higher fitness (Hodsgon and Knudsen, 2006b). In Ramlogan and Metcalfe’s words “If beliefs are too fluid, order will descend into chaos; if beliefs are too rigid then order descends into lifeless equilibrium” (2006, p. 118). The degree to which this also applies to regional and local economies is an important research question. Are the most successful economies those which show the highest rates of innovation, and

²² In an interesting paper, Mehier and Brette (2005) seek to use Dopfer’s *micro-meso-macro* ontology to formulate some hypotheses concerning the life cycle of clusters. They argue that Dopfer’s ontology equates to Veblen’s institutional framework, whereby micro relates to individual habits of action and thought, meso to institutions and ‘institutional logics’, and macro to the ‘cultural complex’ of society. They go on to suggest that a cluster can be considered to be a spatial institutionalisation of an agglomeration rule, and hence amenable to analysis in terms of Dopfer’s idea meso trajectories (origination, diffusion and retention of a novel rule in an economic system).

highest rates of global and local search, or is it those which are able to apply new innovations within relatively stable knowledge structures?

Fourth, the complexity paradigm also highlights some important challenges for contemporary economic geography relating to the importance of markets and personal knowledge. In similar fashion to many cultural economic geographers, complexity economists have recognised that knowledge exchange and connections fundamentally depend on institutions and patterns of institutionalization. Institutional rules store and communicate information and embody socially shared beliefs and understandings (Ramlogan and Metcalfe, 2006). However, in contrast to much recent economic geography, the complexity paradigm argues that markets play an essential and central role in co-ordinating knowledge and driving the evolution of knowledge. They are a central and distributed form of innovation system in modern capitalism. The growth of knowledge and markets are mutually reinforcing processes as markets do not simply match but continually reshape supply and demand. Selection processes are essentially market based as they distinguish reliable from less reliable knowledge connections and are a means of destroying some connections in favour of others. Markets also contain a great variability of types of linkage and many fluxes of connections, some of which are stabilised. In Potts' words "the market process is an experiment in knowledge: the creation of unforeseen compounds out of ephemeral elements that become obvious only after the event" (2001, p. 422). This view implies that economic geography's recent focus on 'untraded interdependencies', whilst certainly valuable, is missing or downplaying the most important cause and condition of the evolution of economic knowledge, namely markets. It surely implies that we should devote more attention to markets in regional and local economies both as experimental spaces and as mechanisms shaping production.

Finally, the paradigm implies that restless regional and local economies with dynamic rates of knowledge evolution will bring together two things. First they will have high knowledge heterogeneity as a result of having individuals with specialised and idiosyncratic knowledge which can be actualized as non-average behaviour. Second, such economies require high rates of information flow as these are necessary for the emergence and sustainability of social understanding. According to Metcalfe and Ramlogan (2005) shared social understanding in turn allows the growth of new idiosyncratic and specialised knowledge through the exchange and combination of information and also allows personal knowledge to be tested and put to use. Another implied challenge for economic geography then is not only to understand how institutional contexts shape collective understandings, but also to give much greater attention to the growth of personal knowledge and beliefs about economic action as these act as basic engines of economic change.

7. Some Conclusions: Fragments of a Research Agenda?

Our aim in this discursive paper has been to begin to explore the scope and limits of ‘complexity thinking’ in evolutionary economic geography. It is clear that there are several key issues that require close attention in any research agenda aimed at constructing a complexity-based evolutionary approach to the subject. Essletzbichtler and Rigby (2007, in this journal issue) argue that economic geographers need to move beyond applying evolutionary ideas and concepts in an ad hoc manner, and develop a more general theory of economic evolution. In our view, complexity economics does not, as yet, provide the basis of such a theory, since there is no well defined or universally accepted complexity theory as such that economic geographers can simply turn to and apply to their own set of empirical issues and concerns. Rather, what exists is a series of generic notions about the characteristics and behaviour of complex systems, and most of these notions have their origin in the study of physical, chemical and biological systems. These do indeed provide some interesting potential concepts and ideas for thinking about socio-economic systems, and about the economic landscape and its evolution. Thus the notions of self-organisation, emergence and adaptation resonate closely with questions about how the spatial structure of an economy emerges and changes; about how regional and urban economies rise and fall in relative prosperity; about why some regional and urban economies appear more adaptable than others over time to shifts in technology, markets, policy regimes and the like; about why certain industries and technologies develop in particular geographical areas but not others; and about how the various spatial networks of economic relationships and flows form and evolve. In this sense we believe complexity thinking could make a valuable contribution to the construction of an evolutionary economic geography. But as in the case of the use of neo-Darwinian metaphors and ideas, the abduction of complexity ideas into economic geography is not at all straightforward.

One of the basic issues, we would argue, is ontological. The approach taken thus far in thinking about the economic landscape as a complex system has been what Perona would call ‘theoretic, and what we would label ‘scientific ontological’ or even methodological; that is to say, it has been based on the use of formal models of complex systems drawn from the natural sciences to make claims about the nature and dynamics of (abstract) economic landscapes, as exemplified by the work of Arthur, Krugman and others. The problem with this approach is that the initiating premises, assumptions and processes are restricted to the content of the specific scientific models used, and these may not be adequate or realistic in relation to actually occurring, as opposed to hypothetical abstract and model-generated, economic landscapes. In such approaches, the characteristics of the economic landscape are thus those of the model, rather than those that actually exist.

Our argument here is we need to look beyond the increasingly dominant modelling paradigms associated with complexity, including the functional development of appropriate computational architectures (such as multi-agent models and dynamical systems models), to a more philosophically-inclined social-ontological

approach. What precisely does it mean to talk of the economic landscape as a complex system? In what sense is the economic landscape a meaningful complex system to which the concepts of complexity thinking can be meaningfully applied? What does connectivity mean and how do we distinguish partial from strong connections? These are difficult questions. To be analytically useful, complexity is not something that just bolts on to or can be blended with an existing conceptual/theoretical framework to add a 'complexity perspective' or 'evolutionary perspective'. Nor is it sufficient to invoke the terminology and concepts of complexity science without thinking through what these concepts are being applied to, and what they mean in an economic-geographical context.

We take the view that if 'the economy' is indeed a complex system, its complexity arises in large part precisely because it is spatially distributed and spatially embedded. But this then behoves us to specify how this spatiality relates to complexity, both theoretically and empirically. We might adopt the terminology of Dopfer and Potts (2004b) and say that geography contributes to complexity because it increases the modularity, hierarchic depth and openness of the economy. The economy is modular because it is made up of a very large number of functional (sub)systems that are connected to (and interact with) one another (households, firms, institutions, states, and so on). The complexity of the economy is also due to its hierarchic depth. That is, each (sub)system is itself complex in its own way, and simultaneously both made up of, and a component of, other systems: every part is a whole and every whole is a part. The economy is open in the sense that these systems interact via innumerable networks of connections and associations, and these connections can change. But exactly how does geographic space influence the modularity, hierarchic depth and openness of the economy?

From a complexity perspective, the spatial structure and organisation of the economy – the presence of features such as industrial districts, business clusters, cities, regional agglomerations, networks and the like – are to be understood as emergent properties of an economy, the unplanned meso-outcomes of the individual actions and behaviours of numerous individual economic agents (households, firms, institutions of various kinds, governments). Are such emergent spatial structures and features merely outcomes? Or they themselves complex (sub)systems? Or are they just part of the 'environment' within which households, firms and other economic agents exist and function? Economic geographers have spent considerable effort demonstrating that spatial structures such as clusters, regional high-tech agglomerations, cities and the like are the source of a host of externalities and spillovers that influence, shape and regulate the behaviour of individual agents located within them (and indeed beyond). In this sense, such spatial-economic structures are not only examples of 'first-order' emergence (unintended spatial outcomes of myriads of micro-actions) but also of 'second-order' emergence (whereby these same meso-level spatial structures and arrangements – in conjunction with macro-level processes - feed back to influence micro-level behaviours and actions). Explicating

these spatially emergent and spatially embedded systems of ‘upward and downward causation’ (Hodgson, 2004), and their multi-scalar operation and manifestation, would seem to us to be a critical task for a complexity-based evolutionary economic geography research agenda.

Likewise, how geographic-economic space both shapes and is shaped by the growth and transformation of knowledge are key ingredients of any complexity-based evolutionary economic geography. As we have seen, the most influential complexity economists argue that it is knowledge and its adaptation that makes the economy a complex system. But we know that the spatial localisation and agglomeration of economic agents is itself a major stimulus to the creation and circulation of knowledge: clusters, industrial districts and cities are quintessentially ‘knowledge communities’ (Loasby, 1998; Maskell, 2001; Pinch, et al, 2003). In this sense, the creation of new knowledge – the engine of economic growth – is a spatially emergent effect, which then becomes part of the properties of economic agents (see Plummer and Sheppard, 2006). New knowledge (and innovation) typically emerges on a small scale in local contexts. But some of this new knowledge has the capacity to stimulate widespread adoption and large-scale transformations of the economic landscape. Conceptualising the role of geographic space in stimulating and conditioning the emergence, diffusion and adoption of economic novelty is to our mind a fundamental research task confronting evolutionary economic geographers. A complexity approach necessarily focuses attention on the co-evolution of knowledge and the economic landscape.

These are but some of the fragments of what is obviously a much larger research agenda. Whether and how far complexity thinking can help inform the construction of an evolutionary economic geography is as yet an open question. And as we have argued, complexity economics is itself underdeveloped. Yet, a complexity approach does seem to resonate with some of the central concerns of evolutionary economic geography. We know that the economic landscape is a highly complicated system, but it is also complex, in the specific sense of the term developed in this paper: it is an open, highly interconnected, self-organising, emergent and adaptive system. The task is to construct an ontologically defensible framework based on this conception.

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