Pluralism(s) in economics: lessons from complexity and innovation.

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Pluralism(s) in economics: lessons from complexity and innovation. A review paper

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Abstract My analysis focuses on two main observations. First, many competing schools of thoughts are currently present in economics with no predominant paradigm. We are experiencing an era of pluralism (Davis J Econ Methodol 14(3):275–290, 2007, Camb J Econ 32:249–366, 2008; Colander 2000; Colander et al. J Polit Econ 16(4):485–499, 2004). The term 'pluralism' is extremely interesting since, as I will show, it has different dimensions to it. These offer insights into interpreting the tangled universe of the economics. Second, there is a progressive intertwining of innovation economics with complexity economics, which I argue provides an instance of the above-described shift toward pluralism.

Keywords Innovation and invention · Processes and incentives · Economic methodology

JEL Classifications O30 · B41

1 Introduction

In the aftermath of the crisis faced by the economic orthodoxy, there is turmoil in the field of economics. On the one hand, neoclassical theory no longer knits the economists into a cohesive community. On the other hand, their confidence in supposedly new methods such as stochastic dynamic equilibrium models has been betrayed by the poor performance of the models in times of crisis (Colander et al. 2008). The recent publication of three volumes, *The Nature of Technology* by Arthur (2009), *Complexity Perspectives in Innovation and Social Change* by Lane et al. (2009b), and the *Handbook on the Economic Complexity of Technological Change* by Antonelli (2011) gives me the opportunity to dwell on some of the emerging patterns in the field of economics.

I am indebted to R. Bronk for the conversations we had on the theme of pluralism in economic models. He directed my attention to the issue and his papers (2011a, b) inspired in me the ideas developed in this work. The usual disclaimer applies.

2 Pluralism(s) in economics

The presence of research programs (on evolutionary game theory, neuroeconomics, complexity agent-based economics, and experimental economics) that make considerable departures from the neoclassical tradition can be taken as evidence of a shift toward pluralism (Davis 2008: 349–50). Some of these streams, such as experimental and information economics, have stemmed from neoclassical theory by showing that some of its core assumptions are systematically violated and therefore its predictions are wrong. Others, such as complexity, agent-based theory and evolutionary economics, have emerged from different micro foundations and methods. This perspective is important if one wants to investigate, as Davis (2008) does, whether a new orthodoxy will emerge out of the competition among these different streams of work. I will label this as *straightforward pluralism*. It implies the contemporary presence of diverse theories that cover the same economic phenomenon. This kind of pluralism is of no particular interest to me for the purpose of this paper. It exists merely as a necessary condition for the existence of other – non-mutually exclusive – epiphanies of pluralism, namely, what I refer to as *horizontal* and *vertical* pluralism and *interdisciplinarity*.

Horizontal Pluralism exists when methods available in different research of programs are used to explore the facets of the phenomenon of interest. This has been brought to the fore recently (Bronk 2011a, b) as a way to overcome epistemological uncertainty. It relies on two strongly related hypotheses. First, there is no direct access to facts: the model we use to 'read' reality filters our perception. Second, models are—by definition—simplified and incomplete representations of reality Diamond (2011). Using only one kind model sentences the researcher to peer always at the same aspect of the phenomenon under study. By contrast, using different models helps in escaping from the limits intrinsic to our investigative capabilities.

Vertical pluralism is present when past theories are not discarded but taken as the basis for new ones and thereby extended (Marchionatti 2002; Foley 2003). It is a little more specific than simple cumulative learning. It means that 'new' theories are recognized as continuations and ameliorations of the 'old' ones. A major part of innovation economics, for instance, takes Schumpeter[1] as its *musa* and the principle of creative destruction as its *explanandum*. In a broader context, vertical pluralism raises the question of what to do with outmoded theories. Once it is incontestably proved that the Olympian rationality does not apply to human decision-making, and that the requisite of optimality is empirically irrelevant, what should we do with the 'rest' of the neoclassical postulates, say, with marginalism? Should we drop them or try including them into newer economic theories?

[1]As Diamond (2004: 366) points out, Mansfield credits Schumpeter with founding the field (1995, I, p. ix). Rosenberg (1982: 106) says: "[...] the study of technological innovation […] still consists of a series of footnotes upon Schumpeter. Griliches (2000: 45) includes Schumpeter in the list of the early economists who recognized the importance of technological innovation.

Interdisciplinarity[2] economic theory can be pluralist in that the interaction between different skills and backgrounds leads to conceiving of theories and exchanging of methods (as in complexity economics, econophysics and neuroeconomics) with an effect analogous to horizontal pluralism (i.e. multi–disciplinary views of the same phenomenon).

In agreement with Davis (2007, 2008), I maintain that, in the last decade, there has been a shift towards straightforward pluralism (rather than towards a dominating paradigm). In addition, I propose that economics is showing an increasing degree of pluralism intended in the other meanings. This is particularly evident in the ongoing merging of complexity and innovation economics.

I believe that innovation and complexity economics are particularly sensitive to pluralism because they deal with what is yet to be created, that is, with novelties. Under this circumstance, pluralism becomes almost a necessitary choice a glimpse into human creativity requires the widest span of tools and perspectives.

3 Complexity and innovation economics

There seems to exist a natural attraction between complexity and innovation economics. Lately, a number of thinkers in complexity have focused on innovation (e.g., Arthur 2009; Lane et al. 2009b), while scholars dealing with technological change have taken complexity economics as the frame for their research (e.g., Foster 2005; Antonelli 2008, 2011). While the former have taken innovation as a natural prosecution of their enquiries, it is only recently that innovation economics has explicitly recognized the overlapping of the fields. I will trace the progress in the development of their merging mainly through the analysis of the work by Arthur, by Lane et al and by Antonelli in the three volumes mentioned earlier, which, in my opinion, reflect the different stages in the union as well as different perspectives on pluralism.

As a starting point, I refer to a note that Arthur sent to me along with his 2009 volume. It said, “Complexity is not really discussed here, but it is everywhere present.” I continue with the following statement by Antonelli on his work: “This Handbook presents a systematic attempt to show how building upon the achievements of complexity theory, a substantial contribution to the economics of innovation can be implemented” (2011:3).[3] Before delving into the discussion, however, I examine the plausible reasons for the ‘attraction’ between the two streams of thought.

[2]Interdisciplinarity is different from multi–disciplinarity. The latter takes place when a particular subject is analysed separately by various disciplines.

[3]I am aware that the literature on the economics of innovation is much wider than what is mentioned here. I will focus on these books since they all propose a wider theoretical apparatus than the earlier, more evolutionary, approach to innovation that has characterized the first attempt at dealing with innovation through complexity (e.g., Foster and Metcalfe 2001; Metcalfe and Foster 2004). For further discussion, see Section 6.

3.1 Natural attraction

The proximity of the two domains is evident when looking at their definitions. According to Antonelli, the economics of innovation studies "the determinants and the effects of the generation of new technological and organization knowledge, the introduction of innovation in product, process, organization, mix of inputs and markets, their selection and eventual diffusion. Innovation takes place when it consists in actions that are able to engender an increase in the value of the output, adjusted for its qualitative content, that exceed their costs" (2011: 6).

In turn, complexity sees economies as "systems comprising large numbers of elements the properties of which are modifiable as a result of environmental interaction [...] Complex adaptive systems process information, and can modify their internal organization in response to such information. In general, complex adaptive systems are highly nonlinear and are organized on many spatial and temporal scales." (Cowan and Feldman 1986: 11). This definition, as Holland (1988: 117–118) puts it, implies the following features:

1. The overall direction of the economy is determined by the interaction of many dispersed units acting in parallel. The action of any given unit depends upon the state and actions of a limited number of other units.
2. There are rarely any global controls on interactions. Instead, controls are provided by mechanisms of competition and coordination between units mediated by standard operating procedures, assigned roles, and shifting associations.
3. The economy has many levels of organization and interaction. Units at any given level [...] typically serve as "building blocks" for constructing units at the next higher level. The overall organization is more than hierarchical, with many sorts of tangling interactions (associations, channels of communication) across levels.
4. The building blocks are recombined and revised continually as the systems accumulate experiences – the system adapts.
5. The arena in which the economy operates is typified by many niches that can be exploited by particular adaptations; there is no universal super-competitor that can fill all niches [...].
6. Niches are continually created by new technologies and the very act of filling a niche provides new niches [...]. Perpetual novelty results.
7. Because the niches are various, and new niches are continually created, the economies operate far from an optimum (or global attractor) [...]

The two approaches share the same foundational proposition: economies change through novelty generated from within them. Moreover, innovation—*rectius*: the knowledge that leads to and stems from innovation – is not like manna from heaven. Rather, it is largely private, heterogeneous, and localized. For both the acknowledgement of the endogenous and local nature of novelties calls for new methods than can account for the dynamic network of interactions that characterize the economies (Foster 2005; Holland 1988) and their out-of-equilibrium behavior.

The natural attraction, however, has to be put to the test taking into account the different backgrounds involved in the merging. Scholars dealing with complexity (economics) are generally not from a traditional economic background and therefore the methods that they have applied (e.g., spin glasses, power laws, and agent-based simulation) are different from those used by 'pure' economists, whereas researchers in innovation have a background in traditional economics, and therefore resort to a more familiar toolbox.

A further difficulty is represented by the fact that economists show no particular attitude towards interdisciplinarity. As Siegers (1992: 541) notes, they have a penchant instead for "multidisciplinary [. . .] imperialism à *la* Becker." By contrast, interdisciplinarity has been a crucial theme for the sciences of complexity. The talk by Gell-Mann (1987) at the foundational workshop of the Santa Fe Institute for the Study of Complex Systems (SFI), significantly entitled 'Emerging Synthesis in Science" went as follows:

> It is usually said that ours is an age of specialization, and that is true. But there is a striking phenomenon of convergence in science and scholarship that has been taking place, especially in the forty years since the Second World War, and at an accelerated pace during the last decade. New subjects, highly interdisciplinary in traditional terms, are emerging and represent in many cases the frontier of research. These interdisciplinary subjects do not link together the whole of one traditional discipline with another; particular subfields are joined together to make a new subject.

To cite another instance, we may note that the editors of *Complexity Perspectives in Innovation and Social Change*, who all have been part of the SFI community, are a statistician, an archaeologist, an urban geographer, and a physicist. W.B. Arthur himself is an economist, but has his initial training as an engineer and demographer.

Antonelli's *Handbook on the Economic Complexity of Technological Change* seems to contradict Siegers' view. In fact, in spite of his being a 'pure' economist, Antonelli's volume is one in which the interdisciplinary view is thoroughly accounted for. A number of papers are dedicated to defining the boundaries of the "economic complexity of technological change". For instance, Lane (2011) explores the nature of a theory on innovation grounded in complexity and calls for the use of agent-based simulations side by side with mathematical models; Bloch and Metcalfe (2011) review the theories of the firm in order to include the complexity tools; and, Krafft and Quatraro (2011) define the production of knowledge as the outcome of a process of recombination of existing information in novel ways by explicitly referring to Kauffman's theory of self–organizing autocatalytic sets (Kauffman 1993).

Kauffman, a theoretical biologist, observes that economics has no theory to explain the increasing complexity of the web of creation and transformation of products that constitutes the economy (1988: 125). By adopting the autocatalytic set hypothesis – the basic idea of which is to start from an initial set of "molecules", some of them acting as catalysts, attracting new elements that, in turn, can grow more complex and reproduce – it is possible to generate endogenously dynamics that can be interpreted as analogous to economic phenomena that escape traditional modelling (e.g., endogenous innovation, waves of innovation, new uses of already existing artefacts). This view is different from the notion of Darwinian evolution that has been adopted in economics. There is no pretence of climbing a fitness landscape: agents, organizations and technology do not steadily proceed toward a global optimum. Rather, they are linked to one another and their interactions create (and also prohibit) pathways for their future development (Fontana 2010b).

Kauffman's autocatalytic sets also provide an explanation to the ever-increasing space of innovation. As Beinhocker provocatively puts it: "if traditional economies of scale were all there were to the economic growth story, then we would simply be making stone tools more cheaply today than we did 2 million years ago. But if we think of human organizations as a kind of […] network (admittedly with far more states than on and off), then we can see that as organizations grow in size, the space for possible innovations unfolds exponentially" (Beinhocker 2006: 150).

Consistent with these premises, the contributors to the volume edited by Antonelli adopt network analysis. See Ormerod et al. (2011)[4] and Cantner and Graf (2011). Its application to the economics of innovation is a substantial contribution to complexity theory. The latter has suffered from the lack of a normative dimension, which accounts for its failure to provide policy prescriptions.[5] Network analysis has shown that it is possible to discern between 'good' (i.e. beneficial to innovation) and 'bad' complex systems, and to intervene to modify their features. See Saviotti (2011).

In addition to having the same foundation, what is also common to both complexity and innovation with respect to their theoretical base is the contribution of J.A. Schumpeter.

4 Vertical pluralism: Schumpeter and the "from within" perspective

While it is commonly acknowledged that J.A. Schumpeter is the intellectual father of innovation economics, it is less known that he has inspired the work of many complexity economists (e.g., Arthur 2009: 199; Ginzburg 2009: 131; Villani et al. 2009).

As Antonelli (2011: 11) notes, Schumpeter (1947: 149–50) provides the definition of the main concepts used in both domains. Schumpeter distinguishes between adaptation ("whenever an economy […] adapts itself to a change in its data in the way traditional theory describes, whenever, that is […] an industry reacts to a protective duty by the expansion within its existing practice, we may speak of development as an adaptive response") and innovation. The latter is unpredictable ("something that is outside the range of the existing practice […] that can practically never be understood ex-ante it is to say that it cannot be predicted by applying the ordinary rules of inference from the pre-existing facts"), it causes discontinuity in the economies

[4]Antonelli also uses agent-based modelling. see Antonelli and Ferraris 2011.

[5]An interesting exception is the book edited by Dolphin and Nash (2012) that is entirely dedicated to applying complexity methods to economic policy.

("it creates situations for which there is no bridge to those situations that might have emerged in its absence") and it is localized ("it depends on the quality of the personnel available in a society").

Schumpeter also explains the effects of the introduction of innovation and, more generally, the functioning of a complex adaptive system: "new goods, the new methods of production or transportation, the new markets, the new forms of industrial organization" induce a process of mutation that "incessantly revolutionizes the economic structure *from within*[italics mine], incessantly destroying the old incessantly creating a new one" (Schumpeter 1942: 83–85).[6]

The innovation process described by Arthur (2009:178–179) is in fact an enriched, algorithmic representation of the Schumpeterian view:

> 1. The novel technology [made out of combination between pre-existing technologies] enters the active collection as a novel element. It becomes a new node in the active collection. 2. The novel element becomes available to replace existing technologies […]. 3. The novel element sets up further "needs" or opportunity niches for supporting technologies and organizational arrangements. 4. If old displaced technologies fade from the collective, their ancillary needs are dropped. The opportunity niches they provide disappear with them, and the elements that in turn fill these may become inactive. 5. The novel element becomes available as a potential component in further technologies […]. 6. The economy – the pattern of goods and services produced and consumed readjust to these steps. Costs and prices (and therefore incentives for novel technologies) change accordingly.

The same holds for Lane et al. (2009a: 38–39):

> 1. New artefact types are designed to achieve some particular attribution of functionality. 2. Organizational transformations are constructed to proliferate the use of tokens of the new type. 3. Novel patterns of human interaction emerge around these artefacts in use. 4. New attributions of functionality are generated – by participants or observers – to describe what the participants in these interactions are obtaining or might obtain from them. 5. New artefacts are conceived and designed to instantiate the new attributed functionality.

With some specific traits, Antonelli also proposes a similar framework:

> […] ii. The reaction of firms can be either adaptive or creative. […] The levels of knowledge externalities and the quality of the generative relations that takes place in the context into which firm are localized, determine the actual chances that the reaction of firms leads to the actual introduction of innovation. iii. […] Innovation emerges as the result of the fertile interaction between the knowledge characteristics of the context and the competence of individuals. iv. The introduction of innovation changes the structure of the economic system

[6] Schumpeter and the complexity view on economics share the belief that endogenous innovation makes the economies behave 'out-of-equilibrium' or, in Schumpeter's (1939) words, in 'disequilibrium'.

> […]. Occasionally, loops of systemic positive feedbacks between structural and technological change lead to the emergence of organized complexity that feeds innovation cascades and Schumpeterian gales of innovations.

Building upon the legacy of the late Schumpeter, Antonelli stresses the crucial role of the system into which firms are embedded as the sorting device that makes innovation actually possible. Firms do not plan to innovate. Innovation is the possible outcome of two intertwined factors: i) unexpected events that change the conditions of both product and factor markets and ii) the amount of knowledge externalities available in the system. The chances that firms choose the creative reaction to unexpected events and its outcome in terms of actual introduction of innovations depend upon the amount of knowledge externalities, whether it is sufficient to support their innovative efforts. The introduction of innovations however affects the structure of the system and the amount of knowledge externalities. Knowledge externalities are endogenous. The effects are not necessarily and always positive. The introduction of an innovation may reduce the amount of knowledge externalities. The loop between the changes in the system and the individual conduct is framed as a recursive non-ergodic dynamics where small events, along the process, may alter, both in a positive and in a negative way, its rate and direction.

Arthur, Lane and Antonelli rely on the Schumpeterian legacy in order to emphasize a particular feature of the innovative process. Innovation not only takes place "from within" but also can be autopoietic and self-organizing (Arthur 2009: 189), bootstrapping (Lane et al. 2009b: 13 and self-sustaining (Antonelli 2011: 33). These labels are almost synonymous with the fact that innovation creates itself out of itself. This consideration recalls Kauffman's ideas showing the benefits of interdisciplinary research. The theory of autocatalytic sets, operationalized through network analysis, enables the economists to explore the implications of the Schumpeterian theory of innovation.

The "*from within*"/autopoietic perspective on innovation makes it distinct from the more traditional approaches that take innovation as a shock that hits the system from the outside. This is to say that traditional (general) equilibrium analyses[7] do not apply to an economy in a perpetually adaptive and innovative state (Fontana 2010a). This reverberates on the methods that scholars can use for their research.

In the traditional view, the network constituted by the links among agents is complete under the hypotheses of complete information and perfect knowledge. These allow us to assume that all nodes of the economic system can communicate with all the other nodes without any friction or cost, such that the network underlying the economic activities does not affect the functioning of the system (Fontana 2010a). The reasons that lie behind such controversial assumptions are strictly technical: they allow for equilibrium analyses in a straightforward mathematical form: '[interconnections] are akin to mathematical operators which must stay fixed if logical

[7] It is worth noting that Antonelli (2011: 10) is the only one, among the three volumes, referring to Marshall's partial equilibrium analysis.

deductions concerning equilibrium outcomes are sought' (Foster 2005: 884). Unfortunately, this condition is not met in complex systems where changes can alter the structure of the system and economies are out-of-equilibrium systems.

Moreover, the changes in connections that derive from asynchronous adaption and innovation often prevent the use of optimization techniques. Optimization is feasible when all the possible outcomes of a choice—together with the probability of their occurrence—can be listed and ranked. Knightian uncertainty and the unpredictability that characterize complex systems ban this possibility. Under such circumstances, optimization is not a faithful portrait of human or organizational behavior and cannot be applied as a mere technique (Fontana 2010a).

The contraposition between traditional economics and complexity economics can result in a criticism of the use of mathematics *tout court.* First, complex systems are composed of a high number of heterogeneous entities, and so an analytical description would require models consisting of a large number of equations. Cognitive bounds and computational load suggest avoiding this route. Second, innovation modifies both the system and its properties rendering the deterministic nature of equations inadequate for its representation (Packard 1988). These considerations lead to the discussion of which method is more suitable for the study of innovation.

5 Horizontal pluralism: the danger of monoculture and the multifaceted complexity

The epistemological difficulties with the traditional mathematical approach to economics are aggravated if one considers that modelling consists in simplifying reality.

On the one hand, when using a kind single model, as economics has done for quite a long time, the risk of ignoring or underrating what could be important aspects of reality becomes very high (Bronk 2011a). This can harm the quality of research, when the neglected aspects actually contribute to determining the occurrence of the phenomenon and, above all, can hamper the correct diagnosis of a given economic juncture and the subsequent policy response. The failure of the stochastic dynamic general equilibrium models in detecting the early signals of the 2008 financial crisis,[8] I believe, is a good example.

On the other hand, complexity economics is very ambitious in its scope, since it maintains that the number of elements that affect economic performance is much wider than what is included in traditional theories. In complex systems, what matters is the topology of interaction (i.e. the presence of tangled hierarchies, clusters and hubs), history (i.e. small events can lock the system in (in) efficient states), institutions (i.e. private and public rules define the set of possible actions and the correlated incentives), and heterogeneity (i.e. diversity of agents is a source of non-linear combination of individual action). The possibility of encompassing all these aspects in a

[8] See Kirman (2011).

single intelligible model is beyond the capacity of currently available cognitive and computational resources.

The way out from this impasse is therefore multi-modelling (Bronk 2011b). Innovation complexity economics has embarked on this much earlier than other parts of the field. This can be seen in Antonelli's volume where traditional methods of investigation (e.g., Stephan 2011; Freitas et al. 2011; Dutrénit and Teubal 2011) are combined with complexity tools (e.g., Latham and Le Bas 2011; Saviotti 2011).

Moreover, the principle of multi-modelling is explicitly stated in Lane et al. (2009b: 6):

> Mathematical and computational models help us to understand how social systems can share some features of their structure and evolution with other complex systems, as reflected for instance in structural power laws or scaling laws, whereas the parameters that are involved in these models take specific values which may imply a quite different qualitative evolutionary behavior from natural or living systems. Because of that, we chose to develop not only analytical models of social change, but more flexible models that are no longer analytical but computational, including multi-agent models. These models allow the handling of both invariant features, including entities and rules whose properties represent stylised facts from observed empirical evolution, and creative aspects of social organisation when the nature of agents or artefacts is transformed through dynamic interactive processes.

6 On pluralisms and differences

The merging between complexity and innovation can be considered a good example of pluralism in economics. However, on a closer inspection we can see that the development of a unified approach has yet to be accomplished.

Starting from the definition of innovation, we find relevant differences. Antonelli states that "technological and organizational changes are defined as innovations only if and when the two overlapping features of novelty and increased efficiency coincide" (2011: 7) since TFP indicators can capture the "full bundle of the economic effects of the introduction and diffusion of an innovation" (*ibidem*)[9] and therefore takes a firm/sector perspective, whereas complexity scholars are more interested in innovation at the system level. This is particularly evident in Arthur's work that considers innovation simply as "novelty in technology" (2009: 89) and in Lane et al. (2009a: 68) and Lane (2011: 46) that distinguish between two different kinds of invention activities: those that are intended to deliver an existing functionality "better-faster-cheaper" and those that are designed to deliver *new* kinds of functionality.

The two views appear to be reconcilable at first sight, but problems immediately arise if the analysis shifts from the individual firm to the system level. For instance,

[9]This is discussed in depth in Antonelli (2003) and (2008).

the attempt at finding out whether innovation has positive effects on the growth of the economies encounters difficulties from Antonelli's point of view. Maione (2003: 10–13) states that the theoretical perspective which credits productivity as the driving mechanism of growth rests on a mistaken transposition to the economic system of a thesis that may (sometimes) be valid for an individual firm. According to him, a reduction in the unit cost and price does not automatically lead to the growth of the economy. First, the fall in price cannot prevent a possible shift in collective taste toward other goods (e.g., tablets vs. laptop computers). In the meantime, saving on costs can cause a contraction of sales of the supply firms. The main problem with this perspective is that it conceives genuine innovation, i.e. "the discovery of new products and processes [. . .] only as an auxiliary element of productivity" (Maione 2003: 10). The complexity view (Ginzburg 2009; Arthur 2009) instead, explains growth in terms of network: product and process innovation may spread to other sectors of production and marketing. In this perspective, "the increase in productivity (which, by the way, in the case of product innovation, escapes rigorous definition) is, if anything, an element that is auxiliary and subordinate to the innovation, not the other way round" (Ginzburg 2009: 132).

From another viewpoint, we could say that Antonelli conforms to the view that links innovation to TFP and which is therefore profit driven. Instead, complexity scholars link innovation to the demand for new functionalities. According to Arthur (2009), innovation takes place only if there are needs that foster it. This is not the same as a demand for new goods that, in the case of radical innovations, could be difficult to envisage. Rather, innovation emerges when firms spot a niche, "a technological and economic space that can be profitably occupied." (Arthur 2009: 174) In turn, niches derive from human needs and from the need of technologies themselves (such as new processors for the pc, technologies to reduce the pollution created by other technologies and so on).[10]

However, Antonelli's argument provides complexity economics with a powerful instrument to base its argument in favor of an 'out of equilibrium economics' (Arthur 2006; Arthur et al. 1997: 3–4) thereby strengthening its approach. A typical theme of complexity economics is that of the 'walk on a rubber surface': each step that an individual takes warps the environment and requires adaptation by the other individuals. Economies are animated by actions that are continuously undertaken by various entities and, therefore, adaptation never dovetails to a static equilibrium.[11] In addition, complex systems generate perpetual novelty.

In stating that novelty, in order to be considered an innovation, has to be matched with an increase in TFP, Antonelli delivers a deathblow to the Arrowian, post Walrasian models that have been opposed by complexity economists since the early 1990s. If an innovation[12] induces an increase in TFP, then the marginal product of

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[10]Lane et al. 2009b have similar ideas.

[11]Another argument is that of the presence of increasing returns that disrupts competitive equilibrium (Arthur 1989).

[12]Innovation here is not random, but rather is the product of a purposeful activity. I'll return briefly to this point.

innovation must exceed its marginal cost. Hence, the market is not, and cannot be in equilibrium. Furthermore, Antonelli makes it clear that the endogenous nature of innovation deprives the notion of future prices of any logical relevance and calls for a new – post Arrowian – theoretical apparatus[13] that, I believe, is the target of much complexity theorizing (Fontana 2010b).

Another discrepancy arises in the interpretation of individual behavior. In illustrating the mutual benefits that can derive from the merging of the two approaches, Antonelli stresses that complexity often misses "the basic feature of economics that consists in the analysis of the role of the intentional, rent seeking conduct in the interpretation of the behaviour of agents. Agents are portrayed as automata that are not able to implement the pursuit of their interest" (Antonelli 2011: 3). In this statement Antonelli refers to a very narrow interpretation of complexity economics that does not reflect its actual scope. As early as in the foundational workshop of the Economics Program at the SFI, in which the issue at stake was the birth of a physics-based economics, the economists and physicists remarked that the difference between human decision makers and the particles of physical/biological systems is that the former are intentional and able to anticipate the consequences of their action (Anderson 1988: 269). In complexity economics, agents are boundedly rational and therefore non-maximizers but rent seekers (Kauffman 1988: 126). Confusion might arise because, in agent-based modelling, the entities can be deterministic or hardwired to play a given strategy independently of the context (e.g., zero-intelligence players). These models aim at showing that some typical economic assumptions such as complete information or Olympian rationality are neither necessary nor sufficient to achieve, say, an optimal result. It has never reflected a general systemic attitude to neglect the kernel of economic analysis.

I could subscribe to another interpretation of Antonelli's statement, according to which we could complain that complexity treats innovation as a "passive" behavior, a creative reaction to adaptive pressure, whereas R&D entails a strategic activity that aims at innovating in order to prevail in the market.

I have no doubt that collaboration among the researchers engaged in the field of innovation and complexity economics could be fruitful. This opinion is invigorated by the fact that the three volumes (Antonelli 2011: 8; Lane et al. 2009b: 4, and Arthur 2009: 183–185) share the same view on evolution. Innovation can be described as a recombination of knowledge with variations but, differently from what happens in biological systems as "human societies are inherently responsible for their own innovation [it] is a self-monitored, directed (intentional) modality of social change" (Lane et al. 2009b: 4).

The notion of evolutionism is probably the catalyst around which the Complexity Innovation view is coalescing.[14] On the one hand, both complexity and innovation

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[13]In accordance with *vertical pluralism*, Antonelli claims that we should rely on Marshall's analysis in order to build it.

[14]Schumpeter believed that biological metaphors were of no use to economic analysis and, therefore, the evolutionary penchant of complexity innovation theory could seem in contrast with his views. However, Foster (2000) shows that it is possible to reconcile the two views through the notion of self-organized complexity.

economics support Nelson and Winter (1982) in rejecting the view that the market would be able to select the fittest entity (Alchian 1950) or design (Abernathy and Utterback 1978). On the other hand, both complexity and innovation economics deepen and widen the previous attempts at linking evolutionary and complexity economics (e.g., Foster and Metcalfe 2001; Metcalfe and Foster 2004).

The three volumes downplay the mechanism of selection and focus on the exploration of the process by which novelties are generated. As already expounded, according to Arthur (Arthur 2009: 167), the collective of technologies is self-created, that is to say, it derives from what already exists. There is no magic, just recombination of building blocks: as if the already existing technologies were like the DNA, the mutations and recombination of which create novelties. Here, innovation is intentional and does not have to be small, which is different from the viewpoint of (neo) Darwinists (such as Maynard Smith and Dawkins) who assume non-purposeful, small, random mutations. Lane et al. (2009a) provide an interesting case study on the history of dog breeding. In the mid-19th-century in England, dogs were selected according to their ability in performing given tasks (such as pointing, retrieving, herding), but later other features concerning their coat, height and so forth were added as further criteria of selection which are not naturally involved in being a dog. This story tells us that humans do decide to innovate but also, through interaction, establish some artificial criterion of selection. The concept can be easily transferred to technological innovation. Entities engage in technology recombination in order to obtain new artefacts and functionalities the selection of which is largely determined by the self-generated needs of the systems. Antonelli completes the picture: firms, the particular kind of entity which is mostly responsible for innovation, innovate in obeisance to the rent-seeking mantra (possibly through an increase in TFP).

The latter is particularly important for the purpose of this paper: complexity economics stems from the attempt at rebuilding the field on the ground of different premises and aims. Its representatives, often from disciplines other than economics, have easily renounced the theoretical apparatus developed earlier. Instead, the complexity innovation stream seems to have moved a step beyond the *pars destruens*, to match finally the core of economic propositions (such as rent seeking behavior) with more revolutionary theories and tools. The reconciling of a new branch of economics with its ancestors wards off the risk highlighted by Schumpeter (2006: 115): “Owing to the resistance that an existing scientific structure offers, major changes in outlook and methods, at first retarded, then come about by way of revolution rather than of transformation and elements of the old structure that might be permanently valuable or at least have not yet had time to yield their full harvest of result are likely to be lost in the process”. The evolutionary theory that is emerging from this stream of work is a precious instance of vertical pluralism, where old and new theories recombine to innovate.

The same consideration applies to straightforward pluralism. The theories that cohabit and compete after the dissolution of neoclassical theories can be considered as material for recombination in a Schumpeterian perspective (1934: 66). From this viewpoint, scholars engaging in the merging of complexity and innovation economics are not mere managers but entrepreneurs (ibidem: 82).

The recombination of complexity and innovation economics yields benefits for both disciplines. The more traditional, extolled innovation economics stands to profit from the powerful ideas and methodology nurtured by complexity economics. The novel, bold complexity theory can be rooted and guided by the experience accumulated in innovation theory. In particular, in Antonelli's volume, there are hints of complexity theory moving towards policy analyses, a branch so far mainly ignored.

Paraphrasing Rosser (2008: 800), I can say that the author and the editors of the three volumes deserve applause. If these volumes are the inception of the merge between innovation and complexity economics, then they are worthy and substantial inceptions.

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