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Can Neoclassical Economics Handle Complexity? The Fallacy of the Oil Spot Dynamic

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Summary:
This paper is essentially a rebuttal of the view that neoclassical economics can handle complexity. I have coined the locution 'oil spot dynamic' to denote the neoclassical ability to subsume each and every new perspective. The main part of the paper is devoted to showing why the oil spot dynamic cannot work with the complexity approach, which is seen as a coherent stand-alone research program that stems from the SFI Economics Program and manifests itself with different nuances.
The fallacy of the oil spot dynamic is relevant in this period, in which economists are beginning to realize that the Neoclassical Samuelsonian Paradigm no longer represents the common language of their profession. The spread of the complexity approach and the dissolving notion of 'mainstream' are here interpreted as indicative of a changing economics. A short foray into the features of the process of change completes my arguments by showing that the shift from one paradigm to another has many interrelated dimensions, and that there may be rigidities internalizing changes.

JEL CLASSIFICATION: B41 (Economic Methodology), B59 (Current Heterodox Approaches-Other)

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I. INTRODUCTION

The last two decades have witnessed the growing influence of complex system analyses on the physical, biological and social sciences. Economics has not remained indifferent to the power of nonlinear interactions to generate complex structures and an astonishing range of potential behaviors. Indeed, the possibility of explaining, in theoretical terms and by means of models, complex and sometimes erratic economic phenomena has sparked rapidly growing interest: the theoretical and analytical tools of complex systems analysis have been viewed by an increasing number of scholars as a promising route towards remedying important weaknesses in the traditional approach to the representation and understanding of economic facts.

The diffusion of the complexity approach is perceived by economists in different ways: it is considered either as an alternative approach to the Neoclassical/Samuelsonian Paradigm (NSP), one to which to resort when the former fails in its treatment of particular phenomena (Arrow, 1988; Blume and Durlauf, 2001; Blume and Durlauf, 2006; Kirman 2005, p. 18; Lesourne, 2002; Sargent, 1993; Krugman, 1996) or as an emerging paradigm (Beinhocker, 2006, ch. 1; Rosser, 2004 p. ix; Arthur, 1999; Markose, 2005, p. 159; Santa Fe Institute Bulletin 1988, 3, 2, p. 11).

Since the complexity approach and the neoclassical/Samuelsonian approach are grounded on sharply different micro-foundations and methodology, the way in which they are related within the discipline raises interesting interpretative issues.

A seminal body of literature frames the relationship between the two in the shared (Hahn, 1991) perception of ongoing change within economics and explains it mainly from a sociological viewpoint, either as a paradigm change à la Lakatosh (Colander et al., 2004), or as a shift toward a pluralism that may precede a new (now undetermined) orthodoxy (Davis, 2008). An opposing body of literature views complexity as successfully included in the NSP toolbox and argues that such a conjugation has no effect on the nature of the NSP theoretical corpus (Blume and Durlauf, 2006).

This paper participates in this debate by taking a different stance. While sociological analyses describe the effects of complexity by looking at the profession of economics and at its relationships with heterodox concepts (Colander et al., 2004), I will argue that NSP ontology and epistemology cannot deal with complex phenomena. This viewpoint is somehow taken for granted in sociological interpretations but seldom discussed in detail (Colander, 2000, Arthur, 2010).

I will also maintain, as a sub-thesis, that the attempt to subsume the complexity approach under the NSP is an instance of what I term the 'oil spot dynamic', an unintended attitude that to date has been functional to the survival of the NSP mainstream. As criticisms have been increasingly brought against the NSP core (violations of EUT axioms, inconsistency of the rationality postulate, unevenly distributed information, flaws in the REH, transaction costs), mainstream scholars have been able to stretch the notion of the NS paradigm so as to encompass them, thereby holding on to their intellectual and professional leadership.[2] I believe that this enlargement has taken place at the cost of gradually blurring the boundaries of the paradigm itself, so that, since the mid-1980s, we can speak of its dissolution and of the consequent fading away of a shared and demarcated notion of mainstream. Just as an oil spot loses depth as it grows in extension, so the NSP paradigm is losing its analytical and theoretical coherence as it covers more and more conflicting contributions.

Will the oil spot dynamic work with complexity? The discussion of the ontological and epistemological aspects of the two approaches will demonstrate that this cannot be accomplished without incurring substantial methodological contradictions: oil cannot mix with water. In addition, I hold that the complexity approach differs from other criticisms against the NSP core in that it does not challenge limited aspects or single assumptions but potentially constitutes a 'stand-alone' approach with a specific ontology, working concepts and methods.

Before starting the discussion, a few specifications are necessary. Historians of economic thought and economists have pointed out that the term 'neoclassical economics' is no longer appropriate to characterize the current state of economic theory (Blaug, 1999, 2003), and

[2] An example of an oil spot dynamic is the following statement : "Economic analysis must become more social and psychological in its treatment of the human actor, more institutional in its description of the exchange process, yet no less analytical in its model-building and no less dedicated to the construction of general equilibrium models" (Bowles and Gintis, 2000, p. 1412). In the same vein, also Bowles and Gintis (1993, p. 84-85) "Post-Walrasian approaches deploy the tools of constrained optimization. This continuity with traditional neoclassical economics has allowed the new models to be assimilated into the discipline with minor resistance".

they have stressed the risk of using such static categories to describe our discipline and our profession, which is instead a dynamic entity (Colander et al., 2004). Although I share this view, I strongly believe that in some cases, and this paper is one them, those categories are still useful if not necessary. The history of complexity theory since its early stages at SFI is inextricably bound up with the term 'neoclassical economics'[3] (I will deal with the features of both later in the paper), since the scholars involved in its development (e.g. Kenneth Arrow, Brian Arthur, David Lane, Lawrence Blume, Barkley Rosser, David Colander) have very often used it and have been very interested in determining the relative positions of the two domains. These two labels are part of the rhetoric and the mental models of the profession: I maintain that their use, not as static categories superimposed by the scientist but as elements of the analysis itself, is a key to understanding the issues covered.

II. FROM THE SANTA FE PERSPECTIVE TO THE COMPLEXITY APPROACH

The Santa Fe Institute (SFI) is a fruitful point of observation not only because the complexity approach has largely originated within its walls, but also because almost all of the approach's leading proponents (e.g. Rosser, Kirman, Epstein) have had connections with the institute. I will briefly survey the history of the SFI's Economics Program (1988-2003) in order to address two of the points on which my discussion is grounded: the relevant notion of neoclassical and complexity economics, and the changes that during that time span occurred in the perception of their relationship.

1. Neoclassical economics and the complexity approach: a brief history of a changeable relationship

In 1987, SFI organized a workshop in which economists and physicists tried to find a way to enrich economic theory.[4] K. Arrow, who chaired the meeting together with physicist Phil Anderson, described the neoclassical approach as the mainstream one and identified it with the general equilibrium theory (GET). The latter envisages firms and households as the only

[3] Historically, the term refers to Walrasian/Marshallian economics with Hicks' and Samuelson's developments. Because I am interested in contemporary events, I therefore refer to it as the neoclassical/Samuelsonian paradigm (NSP). For a recent account see Szenberg et al. (2006).

[4] The history of the complexity approach at the Santa Fe Institute for the Study of Complex Systems has been recounted in various works (Colander, 2003; Waldrop, 1992; Mitchell, 2009). I will therefore not dwell on the details of the subject. The issues covered this section are discussed at length in Fontana (2010).

relevant agents. Their behavior is described respectively by the production possibility set and by the attitude towards labor-time and preference over possible vectors of consumption and willingness to work; agents are endowed with rational expectations. Markets are complete for all commodities at any time. Agents make their optimizing decisions on the basis of correct predictions of future prices and of their own future decisions, with suitable generalizations when uncertainty is taken into account. Equilibrium is to be reached by tatônnement and the equilibrium dynamics of these models is captured by difference or differential equations (Arrow, 1988, p. 275-278).

Arrow's also stresses certain problems with the NS approach: "There was a generally held point of view, which indeed goes back to the origins of economics as a systematic discipline, that solutions that were not constant would tend to the constant solution or steady state. But more recent research [...] has demonstrated that there are solutions to the same equations with cycles and even with chaotic behavior. The multiplicity of solutions is itself an embarrassment, since it suggests that economic theory even if accurate, does not yield a unique pattern of dynamic behavior and hence its predictions are far from sharp" (1988, p. 278). And also: "The general perspective of mainstream (the so-called neoclassical) economic theory had certainly had some empirical success. [...] But it is clear that many empirical phenomena are not covered well by either the theoretical or the empirical analyses based on linear stochastic systems, sometimes not by either" (1988, p. 278). In light of these problems with the neoclassical theory, the collaboration among physics, biology and economics envisaged by the SFI founders was welcomed (1988, p. 280-281), with particular regard to chaotic dynamics and learning.

Arrow envisaged the complexity approach as consisting of two tracks, of which the NS approach was to remain the main one, and complexity tools were to be used only when the former failed.

The 1987 meeting led to the funding of the Economics Program, which was initially directed by W. Brian Arthur. During his term of office, the notion of economies as complex adaptive systems (CASs) developed into what came to be known as the Santa Fe Perspective.[5] According to this characterization, complex adaptive economies are characterized by dispersed interaction, no global controller, cross-cutting hierarchical organizations, continual adaptation, and out-of-equilibrium dynamics (Arthur et al., 1997, p. 3-4)[6]

[5] The term was coined by Arthur, Durlauf and Lane (1997, p. 3)

[6] This description is based on Holland's illustration of adaptive non-linear networks (ANNs) (Holland, 1988, p. 170).

These characteristics subsequently constituted the now generally endorsed definition of CASs. A more detailed description involves five essential features. First, complex systems are comprised of many morphologically diverse parts. Economies consist of a huge number of heterogeneous agents organized in a great variety of groups and institutional structures. These parts are morphologically diverse. Removal of one part induces the system to self-reorganize and gives rise to a series of changes made to compensate for the gap in the system.

Second, complex systems exhibit a variety of nonlinear dynamics. This is due to the fact that the components operate on different temporal and spatial scales. In turn, this implies that aggregate behavior cannot simply be derived from the sum of the behaviors of individual components. Even when a catalogue of the activities of most of the participating sub-components is available, an understanding of the effect of changes on the whole system is far from achieved.

Third, complex systems maintain themselves out of equilibrium. Indeed, the wide fluctuations to be observed in economic time series seem to indicate that economies tend to operate in a critical state, way out of balance, where minor disturbances may generate events (avalanches) of all dimensions. Such a state is what the literature on complexity refers to as self-organized criticality (Bak, 1997).

Fourth, complex systems respond adaptively to change, in ways that tend to increase their probability of persisting. Their interacting parts adapt by changing their behavior (sometimes in innovative ways) as conditions change and as experience accumulates. In turn, the environment of any adaptive element consists largely of other adaptive parts. Therefore, a portion of any individual's efforts at adaptation is spent adapting to other adaptive individuals.

Fifth, complex systems have irreversible histories. In nature, each individual organism is the unique result of the interaction between its genetic code and the environment; in social phenomena each event is the product of individual actions, within a given institutional setting, in precise circumstance of time and space (Brown, 1994; Kauffman, 1993; Holland, 1995; Gell-Mann, 1995).

In a letter to Martin Shubik on the spirit of his directorship, Arthur interpreted the Santa Fe Perspective as a shift from the neoclassical focus in a threefold way: "1. Because it [the complexity approach, hereafter CA] included heterogeneous agents (differing consumers, banks, firms) together creating the patterns they reacted to, models could not easily be "solved" analytically. The natural approach was agent-based modeling 2. Because agents in most models attempted to formulate decisions in a problem where other agents (who differed in unknown ways) were trying to do the same, ill-defined decision problems resulted. Decision making in this context could best be seen as inductive, not deductive. Hence we focused greatly on issues of cognition in the economy, making heavy use initially of John Holland's ideas 3. Because agents reacted to the patterns they co-created, by definition the problems we investigated started out of equilibrium (i.e. not at a static solution point). The appropriate research question in each problem was what patterns or outcomes would arise? Would the system find its way to a conventional equilibrium? Or would it find ever-new patterns, and produce perpetual novelty?" (Arthur, 2003, p.11). As to the respective positions of the CA and NSP, he stated that "Our objective in 1988 was not so much to reform economics as to catalyze certain changes that we saw as inevitable—in particular, the change from standard equilibrium economics to agent-based, out-of-equilibrium economics" In this context standard-equilibrium economics became a special case, and we often used it for a benchmark[7]. " (Arthur, 2003, p.11).

According to Arthur, the initial relation as posited by Arrow was now overturned: neoclassical economics, identified with the core concept of equilibrium was a 'special case' of a more general way of looking at economic phenomena, the CA. Rhetorically, criticisms of the NSP were now very explicit: "the equilibrium approach does not describe the mechanism whereby the state of the economy changes over time – nor indeed how an equilibrium comes into being. And the dynamic system approach generally fails to accommodate the distinction between agent – and aggregate – levels (except by obscuring it through the device of representative agents). Neither accounts for the emergence of new kinds of relevant state variables, much less new entities, new patterns, new structures" (Arthur et al., 1997, p. 3).

In the second half of the 1990s, especially under the directorship of Blume and Durlauf (1995-1998), this duality began to blur in both its declinations (Arrow's small add-on interpretation and Arthur general–to-special-case view): the oil spot dynamic was set in motion.

[7] The notion of NSP used by the scholars of the Santa Fe Perspective as a benchmark is expounded in the proceedings of the Economies as Complex Evolutionary Systems II meeting held in 1996. It revolves around two concepts: 'equilibrium,' in which "the problem of interest is to derive, from the rational choices of individual optimizers, aggregate-level "states of the economy" (prices in general equilibrium analysis, a set of strategy assignments in game theory with associated payoffs) that satisfy some aggregate level consistency condition (market-clearing, Nash equilibrium) and to examine the properties of these aggregate level states; and (2) 'dynamical systems', in which "the state of the economy is represented by a set of variables, and a system of difference equations or differential equations describes how these variables changes over time. The problem is to examine the resulting trajectories, mapped over the state space" " (Arthur et al., 1997, p. 3).

Its effects are evident in the proceedings (Blume and Durlauf 2006) of the 2001 workshop on The Economies as Complex Evolutionary Systems III. According to its editors, the volume demonstrates that the merger between economics and complexity science has matured (Blume and Durlauf, 2006, p. 1) and that there is no contrast between the two: "The models presented here do not represent any sort of rejection of neoclassical economics. One reason for this is related to the misunderstanding of many non-economists about the nature of economic theory; simply put the theory was able to absorb SFI-type advances without changing its fundamental nature. Put differently, economic theory has an immense number of strengths that have been complemented and thereby enriched by the SFI approach" (Blume and Durlauf, 2006, p. 2).
Blume and Durlauf maintain that there is now a wider notion of neoclassical economics that includes the CA without undergoing any major change. It follows that complexity scientists should be considered neoclassical. However, it is not clear how the two approaches have been reconciled in their views. In fact, it has been noted (Hanappi, 2007) that many of the papers contained in the 2006 volume 'subtly subvert' the traditional approach in many respects (e.g. communication as an infection process, learning from past subjective experience, scaling).

This is a nice example of the effects of the oil spot dynamic. The rhetorical move ('neoclassical economics was able to absorb SFI-type advances without changing its fundamental nature') is to claim that no fundamental change is taking place in the discipline, while, in substance, the notion of mainstream is enlarging to include complexity methods and concepts that subvert the traditional approach with the consequent dilution of internal cohesion.[8] In what follows I will concentrate on the ways in which the CA subverts the traditional approach. For this purpose, I must more closely specify the features of the current complexity approach, which has been pursued in economics along different lines that largely rely on particular aspects of the broader Santa Fe definition described above.

III. Nuances in the complexity approach

[8] The oil spot dynamic does not contradict the description by Colander, Holt and Rosser (2004) and Davis (2008) of the process of change. Rather, it adds to it by showing that mainstream openness to heterodoxy is conditional upon the possibility of including it in its reference paradigm.

Economists have developed the CA's features along three distinct but interrelated paths (Foster, 2005): the one that looks at complexity as an inherent property of the dynamical behavior of the system (or 'dynamic' complexity); the one that uses the term 'complexity' to refer to systems whose analysis requires computationally heavy procedures ('logical' or 'computational' complexity); and the one that understands complexity theory as the study of the connections in a system ('connective complexity') and explores its evolutionary properties.

1. Dynamic complexity

The most uncontroversial definition of dynamic complexity is essentially a mathematical one: an economic system is dynamically complex if its deterministic endogenous processes do not lead it asymptotically to a fixed point, a limit cycle, or an explosion (Day, 1994). Non-linearity is a necessary but not sufficient condition for complexity: complex dynamics are processes that involve non-periodic fluctuations and switches in regime or structural changes, such as those implied by bifurcations and transitions to chaos.

The latter are the object of two important branches in the theory of complex dynamics. Bifurcation theory is the study of the points in a system at which the qualitative behavior of the system changes – the critical thresholds that may trigger drastic change.[9] There exist several different mathematical definitions of chaos.[10] The common underlying concept, however, is the randomness or irregularity that arises in a deterministic system. The intuitive notion is that of a time evolution with sensitive dependence on initial conditions – that is, arbitrarily close initial conditions display independent evolution as time proceeds. The two

[9] Bifurcation theory makes it possible to study the behavior of a nonlinear system over time. Analysis of this kind is referred to as comparative dynamics. It enables one to see if a qualitative kind of behavior persists when the initial conditions are perturbed. It also provides insights into the type of change that can occur when some crucial parameters, instead of being assumed constant for analytical convenience, are allowed to vary. It allows one to study, for example, the conditions that can bring about irreversible or slowly reversible changes. It therefore also makes it possible to study the extent to which the behavior of a system could be influenced or controlled by policy. Chaotic dynamics are another important kind of complex behavior. The term 'chaos' in its present meaning was first used by Li and Yorke (1975). However, the significance of such behavior in the natural sciences had already been recognized by Lorenz (1963) in meteorology.

[10] For a formal definition see, for example, Devaney (1992). More accessible introductions are Lorenz (1963), Peak and Frame (1994), and Ruelle (1991) (in order of increasing reader-friendliness). A fascinating application of chaos theory to the study of biological systems and physiological rhythms can be found in Glass and Mackey (1988).

other basic properties are topological transitivity (indecomposability) and density of periodic points.

2. Computational Complexity

Computational complexity refers to the computational and cognitive skills of the decision maker. In deciphering the environment in order to make a decision, agents may face two kinds of computational complexity (Albin, 1998; Rosser, 2009). The first one concerns problems that are undecidable, so that no mind or computer can devise a computational procedure able to solve them in a finite time. A typical example of such a problem is self-reference. An agent has to form conjectures about the conjectures of the other agent(s), assuming that each decision maker tries to foresee what the others' conjecture would be and to adjust her own on that basis. This leads to a procedure that never settles on a solution. Undecidability is not overcome by perfect rationality[11] and foresight because they could lead to infinite regress[12]. The agent should resort to some other resources to settle on a solution. These could be procedural rationality (Simon, 1976), animal spirits (Keynes, 1936, ch. XII), or focal points (Schelling, 1960, p. 57). There are many examples of self-reference[13] in economic literature, but it is with the development of the complexity approach that they have become central to choice theory (Arthur, 1994).

The second type of computational complexity regards problems that are in theory decidable but for which the cost of an optimal solution can be so high as to deprive the optimal choice of any possible advantage for the decision maker (Albin, 1998, p. 46). Undecidability and computational costliness shed light on the controversy regarding the epistemological or ontological nature of complexity. McIntire (1998) posed the question of whether complexity is merely a revival of the old debate concerning indeterminism versus hidden variables. Undecidability suggests that there are limits to our knowledge that do not depend on us but on the nature of the problem; in these cases complexity is ontological. In the context of decidable problems, the presence of computational costs and limited cognitive skills suggests

[11] Actually, it may be worsened by it (Koppl and Rosser, 2002).

[12] This is a merely illustrative analysis of non decidability. For a more technical treatment see, for instance, Binmore (1987) and Albin (1988).

[13] Cournot's duopoly (1838), Morgenstern's Holmes- Moriarty problem (1928,1935), Keynes' beauty contest (1936, ch. XII), Hayek's arguments against prediction (1967a).

that there are limits on our side that prevent us from deciphering complexity; in these cases complexity is epistemological.

3. Connective Complexity

Connective complexity refers to the links existing among the elements forming a system. In the presence of connective complexity, it is the kind of relationship that connects the system's elements together that shapes their behavior, and are the changes in such relationships that cause the system to evolve. The distinctive feature of this kind of complexity is the emphasis on forces that act to maintain the order of the system and on countervailing forces that drive it towards disorder. The struggle between the two generates novel entities and relations, and leads to the disappearance of some (say, old or unfit) structures. It is this process of creative destruction that fosters selection and, thus, evolution (Foster and Metcalfe, 2001; Kauffman, 1988).

IV. Arguments against the oil spot dynamic: oil and water

1. Ontological arguments: The functioning of economies

General equilibrium models describe the market as a system of prices for commodities such that, if agents exchange at these prices, each agent will obtain a set of commodities that provides him/her with the maximum attainable utility or profit (given his/her initial endowment) and all markets (existing for all present and future commodities) will clear.[14] The state in which the market clears is the equilibrium. The attainment of equilibrium is explained by the presence of the auctioneer: agents listen to the prix crié au hazard and then trade at equilibrium price. The succession of equilibria in time determines the dynamic path of the economy.

The functioning of this kind of market mechanism requires identical fully-informed and faultlessly-rational agents, no institutional framework, logical time, no exchange out of equilibrium price and interaction mediated by the auctioneer.

The equilibrium price is achieved by assuming homogeneity of means (Olympian rationality and complete information) and ends (maximization of utility and profit) and linearity in interaction.

Is this ontology compatible with the functioning of economies as complex adaptive systems? Connective complexity theory stresses that observable macro-regularities and self-organization in CASs derive from the relationship that links the elements together.[15] Links are

[14] See Ingrao and Israel (1990) for a history of economic equilibrium.

dynamic – i.e. they change through innovation and adaptation - and each element is connected to some of the others by different links: that is to say, each agent is part of various institutional and organizational settings. Agents are heterogeneous in skills, experience and features. Their decision making is adaptive, i.e. guided by the observation and anticipation of other actors' behavior. Agents do not act in isolation as in the GET, nor are decisions simultaneous – each adaptation cascades in the system and produces further adaptation and so forth. The economy is in perpetual adaptation and change; equilibrium is not a natural tendency of the systems, which, as stressed by Arthur (2010), naturally operate out-of-equilibrium. Connections among elements are important since they determine the 'goodness' of a complex system. That is to say, a given system can be more or less beneficial for its elements depending on the configuration of the network of connections. For instance, a market can be more or less efficient depending on its rules of exchange, or an innovation can spread more or less rapidly depending on links among adopters.

Staggered adaptation and link dynamics imply the importance of historical time: the schedule of adaptation and the order of subsequent actions determines the system's dynamics.

Dynamic complexity theory has emphasized that all such features have strong implications in regard to the functioning of economic systems. Economies are non-linear systems that often exhibit chaotic behavior. Sensitivity to initial conditions implies unpredictability; the system exhibits path-dependence, and although in principle it should be possible to predict future dynamics as a function of time, this is in fact impossible because any error in specifying the initial condition, no matter how small, leads to an erroneous prediction at some future time. Indecomposability implies that it is not possible to derive implications on the behavior of the system's subcomponents by analyzing them separately. Furthermore, chaos gives a mathematical foundation to the irreversibility of historical time: a correct computation of the path of the system in the past is generally not possible since it would require absolute precision in determining the current position. In the presence of chaotic dynamics, however, time reversibility becomes impossible in theory. In fact, if we consider a unimodal map f, for example, the existence of a turning point makes f non-invertible because the inverse of f is set-valued: the inverse of f is no longer a function – it maps, not onto a point, but into a set of points. Functions that display chaotic dynamics can therefore only be integrated forward in time.[16]

[16] For a more thorough discussion of the implications of chaos for economic modeling see Gandolfo (1997, p. 528-532).

Agents in CASs are very different from those populating the GET economies. They are heterogeneous, adaptive, constrained by historical time in path-dependent environments which are continuously changing in unpredictable ways. In such contexts, the assumptions of complete knowledge and perfect rationality are not sufficient to guarantee an optimal individual conduct or an optimal global arrangement. In GET economies, cognition and behavior are reduced to the calculus of a flawless mind that chooses the best among many given options. In CASs, we may even ignore the studies on rationality that have shown that human computational skills are insufficient to support heavy computations and that complete knowledge is unattainable, since the functioning of the system makes those assumptions irrelevant. Even if agents were all endowed with homo oeconomicus genius, global optimization would still not be possible: even if they knew the entire set of future outcomes and their associated probabilities, the rest of the system (the configuration of links and other agents' actions) would never stop long enough to make such an ordering and the resulting choices stable and optimal.

This consideration makes it necessary to find different cognitive models and decision-making theories. In CAS agents are less cognitively gifted than their fellows in GET and face a much more complicated world. Holland (1995) and Arthur (1994) describe the decision-making process in complex contexts as 'inductive'. They refer to the representation of the problem to be solved and to decision-making as a progressive refinement of the definition of the relevant setting and of the available options, as perceived in the self-referential adaptation process. In the El Farol Bar problem,[17] Arthur (1994) demonstrates that, in a world of mutual adaptation and limited information, it is impossible to use deduction in order to formulate satisfactory decisions. This view recalls Simon's procedural rationality, which, I believe, can give a pretty good account of how agents make decisions in complex environments. H. Simon is more often

[17] In the El Farol bar problem illustrated by Arthur (1994), agents must foresee attendance at the bar by observing attendance in the previous weeks. The underlying idea is that if the bar is very crowded no one wants to enter and vice versa: a typical situation in which the payoffs of an action are higher the fewer the people that undertake it. A corresponding economic example is that of buying when everybody is selling and the price is falling. Agents form their expectations self-referentially: if they expect the bar to be crowded they will not show up, thereby invalidating the forecast, and vice versa. In self-referential situations, decision makers rely on induction: they try different routines and choose the best one in terms of performance. Since each choice alters the performance of the others, the ecology of routines changes over time.

remembered as the father of the concept of bounded rationality:[18] he pointed out that agents are unable to perform the required computation even in rather simple settings. However, bounded rationality is a weaker formulation of the rationality postulate and therefore does not apply to the indeterminate situations typical of CASs.

CASs raise a further challenge for the analysis of decision-making: in an ever-changing environment, it is almost impossible to foresee the outcome of decisions with a satisfactory degree of precision. This undermines the entire concept of rationality in terms of adequacy of actions to achieve given goals. In order to define the decision making process under such occurrences Simon introduced procedural rationality. Decision making under uncertainty in complex environments takes account of the agent's conceptualization of the problem to be solved and her ability to draw inferences based on the available information (Simon, 1969, 1976). The focus is on the skill in building an adequate representation of the problem and to adapt it in reaction to environmental responses with the aim of improving the performance of actions. Behavior can be deemed as rational if it derives from an appropriate deliberation. The decision maker designs alternatives on the basis of her own (partial) information and adopts the first strategy that is expected to satisfactorily (not optimally) solve her problem. Learning plays a crucial role in this decision-making process. Through learning, the information set is updated and new options are generated. The agents adapt to the environment and, by innovating, contribute to its change. The NSP view coincides with that of Lucas, who states 'in cases of uncertainty, economic reasoning will be of little value' (1981, p. 224). By contrast, procedural rationality offers a theoretical tool with which to extend economic reasoning into the domain of uncertainty.

In order for the oil spot dynamic to be successful, GET should incorporate the aspects that make economies into complex adaptive systems without incurring any major change.

In light of this description, the operation appears relegated to the rhetorical level. The functioning of the two economies cannot overlap: the GET economy relies on linearity, absence of hierarchies and links between entities, homogeneity of means, ends and skills, perfect rationality, logical time, symmetry in decision-making and acting and equilibrium, whereas CASs are characterized by non-linearity, tangled hierarchies, the importance of connections among components, heterogeneity, inductive reasoning, historical time, broken symmetry and out of equilibrium behavior.

[18] Bounded rationality is another interesting instance of the oil spot dynamic: it aroused much interest among economists, was rapidly adopted by heterodox economists and was eventually integrated in the mainstream

All these features taken individually appear profoundly different, if not contrasting. However, I believe that the impossibility of mixing the two descriptions of the economy is better understood when one acknowledges that all the elements necessary for their functioning are linked to each other in ways that make the GET or the CAS non-decomposable.

This amounts to saying that it is difficult to adhere to either definition by substituting one or more of its constituents. For instance, what if I substitute Olympian rationality with procedural rationality into a GET model? In spite of their god-like cognitive skills, agents will still have to deal with the self-referential nature of expectations and continuous adaptation, so there would be no settling on an equilibrium. It is probably pleonastic to stress that a GET economy without equilibrium is a contradiction in terms. Other attempts at performing such a substitution can be easily imagined as producing the same outcome: increasing returns, non-linearity, broken symmetry and so forth.

Even the relationship, from general to particular as posited – in different directions – by Arrow and Arthur is difficult to defend. GET and CAS do not lie at the extremes of a continuum; rather, they are systems that work according to different laws and it is not possible to switch from the one to the other by gradually weakening or strengthening some assumption.

For instance, procedural rationality is not a weaker notion of Olympian rationality; rather, it is an alternative representation of problem-solving activity. And again, adaptation does not represent an imperfect form of maximization; rather, it is an alternative behavioral description.

Finally, imperfect information is not a proxy for the differentiated knowledge that agents have in CAS. Agents that operate in CAS are heterogeneous in skills, features and experience. They interpret the world according to their previous history: even if they had the same information, there would still be differences in its interpretation, in that the process subjectively transforms pieces of information into personal knowledge.

Differences in the functioning of these systems naturally reverberates in the ways in which they disclose themselves to the scientist's understanding. I now turn to the epistemological side of the discussion.

2. Epistemological arguments

2.1 Connective complexity and reductionism

Sugden (1998) provides an interesting example in order to illustrate why CASs escape the reductionism typical of the NSP. He compares the NSP view of agents and their interaction to bricks. He observes that all bricks fall downwards when dropped from the top of a building. Once the brick's law of motion is known, 'we can form correct expectations about the behaviour of all bricks, but the regularity we observe is nothing but the common property itself'. In contrast, the complexity view implies that the macro regularities are generated by the properties of the links that connect the agents. Sugden exemplifies this case with the gradient of a scree slope which 'is a property that the rocks have in relation to one another'. It is therefore impossible to study the properties of complex systems by observing their elements in isolation. The overall dynamic of a CAS is emergence from bottom-up non-linear interaction, not a summation of identical behaviors.

This implies that economists have to renounce simplifications such as the 'representative agent' and, from a broader perspective, to think about the theoretical body of their discipline as a set of Chinese boxes in which maximizing agents and firms are aggregated to form coherently maximizing systems. As soon as this is acknowledged, then it can longer be assumed that it is possible to move from the micro to the macro level just by increasing the number of the entities observed without incurring a qualitative change of behavior.

The network of interconnections and their feedbacks renders each system unique in time. We therefore have many instances of economies as complex systems. We do not have 'a market' with a sole outcome – 'the equilibrium'; we instead encounter many markets with their path dependent, historically determined and most likely temporary states. What consequences does this view have for theorizing and modeling?

2.2 Economics as a mathematical science

In the early 1960s, mathematics[19] began to predominate over economic content. Economic propositions embedded in theorems and proofs had geometric precision and a general[20] and abstract applicability; they disregarded realism and derived their validity from correctness of logical deduction. As Debreu wrote: 'as a formal model of an economy acquires a mathematical life of its own, it becomes the object of an inexorable process in which rigor, generality, and simplicity are relentlessly pursued' (1986, p. 1265). From that point onward, theorizing and modeling were no longer sharply separated; it seemed that economists endeavored to reduce economies (ontology) to their favored mathematical modeling tools (epistemology).

It follows that the adoption of different mathematical views (such as those sketched in the subsection on dynamic complexity) does not only imply a change in the modeling tools, it also involves a change in the perception of observables.

Attempts to explore complex adaptive systems have brought about a necessary shift towards nonlinear mathematics Non-linear mathematics is less elegant and rigorous than linear mathematics. In fact, one reason for the widespread use of linear differential and difference equations in economics is that such equations are always solvable, whereas nonlinear models offer no such guarantee. Moreover, whereas linearity is unique, there exist countless possible nonlinear forms. In situations when we only know that a generic nonlinear functional relation exists with given qualitative properties (for example, conditions on the first order partial derivatives, such as their sign and given bounds), the feasible analysis is purely qualitative.[21] The choice of a specific nonlinear functional relationship, unless there are compelling theoretical or empirical reasons in favor of a certain form, can in fact be as arbitrary as linearity. In some cases, specific nonlinear functional forms may however serve the important purpose of showing that a certain dynamical behavior is possible. Their role may be simply to

[19] 'An axiomatized theory first selects its primitive concepts and represents each one of them by a mathematical object. […] Next assumptions on the objects representing the primitive concepts are specified, and consequences are mathematically derived from them. The economic interpretation of the theorems so obtained is the last step of the analysis. According to this schema, an axiomatized theory has a mathematical form that is completely separated from its economic content. If one removes the economic interpretation of the primitive concepts, of the assumptions, and of the conclusions of the model, its bare mathematical structure must still stand' (Debreu, 1986, p.1265)

[20] 'The pursuit of generality in a formalized theory is no less imperative than the pursuit of rigor' (Debreu, 1986, p. 1267).

[21] Indeed, in economic theory purely qualitative nonlinearity is often regarded as the true generalization of linear dynamics (Gandolfo, 1997).

highlight that a certain motion cannot be ruled out, with no claim that the model constructed is more general or more accurate than the corresponding linear model.

If we continue to think - in Debreu's vein - that mathematical forms dictate the rules of economic thinking, then non-linear mathematics involves a completely different view and, therefore, a different method, of which generality and abstraction cannot be the hallmarks and in which traditional techniques do not apply.

For instance, let us think in terms of connective complexity. On the traditional view, the net of links that shapes the economy is kept very simple owing to the hypotheses of complete information and perfect knowledge. These make it possible to assume that each element of the economy can 'contact' and 'evaluate' all the others elements at no cost, so that the network of connections is irrelevant to the functioning of the system (Foster, 2005). This is functional to the possibility of conducting an equilibrium analysis in mathematical form: '[interconnections] are akin to mathematical operators which must stay fixed if logical deductions concerning equilibrium outcomes are sought' (Foster, 2005, p. 884). This assumption does not hold in complex systems, which are subject to changes that alter the structure itself of the system, the existence, the position, the nature of the connections. It thus impairs the possibility of focusing on equilibria.

Moreover, the continuous variations that take place in connections often impede the use of optimization techniques. Optimization is practicable under the hypothesis that all possible outcomes of the process under analysis and the probability associated with each of them, are knowable. These conditions are not met in complex systems. Within complex systems, uncertainty is inescapable. Therefore, as shown above, optimization cannot be taken as a metaphor for individual or organizational decision-making and the conditions are lacking for its use as mere technique.

The epistemological contraposition is not limited to the 'kind' of mathematics used: taking the complexity perspective to its extreme consequences leads to criticisms to mathematics tout court – i.e. including chaos and bifurcations.

The large number of elements in a complex system and their heterogeneity prevent their grouping into a few broad categories (e.g. the consumer, the firm, the representative agent), so that their description would require mathematical systems made up of a great number of equations, thereby increasing the computational load and the difficulty of analytical treatment.

Under connective complexity, a complex system assumes a given configuration according to the properties of its elements and to the nature of the connections among them. The state of the system is subject to evolution and selection and therefore there are variations in topology and dynamics. In other words, it is important to consider not only the system's dynamics, but also how the dynamics themselves change over time. It follows that it is often impossible to freeze the behavior of the system in a model made of equations (no matter whether they are linear or not) since its dynamic is not fixed but endogenously variable (Packard, 1988).

When it comes to capturing innovation as a result of a process of adaptation and selection, because any kind of model expressed in the form of equations is inherently deterministic, it cannot generate 'new behavior' by the components of the system or new elements: in order to account for similar phenomena, the equations must be reformulated. Even the mathematics of complexity can at best express non-linear systems that cannot be adaptive.

It follows that the economics of complexity cannot be equation-based; rather, it must extend to computational models able to encompass the CASs hallmarks.

Agent-based models overcome the problems of equation-based models[22] because they enable the representation of numerous instances of heterogeneous agents that interact autonomously. In addition, by using learning algorithms (genetic algorithms, neural networks and classifier systems), they also introduce the adaptation-selection mechanism necessary to foster evolution and free the researcher from the need to assume maximizing behavior[23] in order to obtain meaningful solutions.

Instruments used to simulate problem-solving, adaptation and innovation are explicitly grounded on biological models and metaphors. For instance, the genetic algorithms (Holland, 1975) used to simulate learning and adaptation are modeled on the processes of biological evolution. A genetic algorithm manipulates a set of structures called 'population'. Each structure is assigned a value (fitness) based on the result of its interaction with the environment. Genetic algorithms operate on the population by replicating or making copies of individuals in proportion to their observed fitness, i.e. the fittest ones have a greater chance of being reproduced. The outcome is a population of individuals that adapt increasingly well to

[22] One could object that a simulation is indeed a computation; and that, because - according to the Church-Turing principle - for every computation there is an equivalent representation in terms of equations, simulations are nothing but mathematics (Epstein, 1999; Fontana, 2006). In principle, this is true. However, in practice when it comes to writing down and then solving such a model (possibly comprising hundreds of instances of different individuals and evolutionary algorithms), computational complexity arises.

the environment[24]. To be noted is that all these operations take place out of the researcher's control and independently of her degree of knowledge about the system under study. Economists engaged in this line of inquiry observe human living beings, their organizations and their institutions with the aim of uncovering the rules that guide their behavior and generate the phenomena of interest.

2.3 Generality, Explanation, Solution and Prediction

The science of complexity is deeply rooted in the notion of synchronic (at each moment in time entities of CAS are different and behave differently) and diachronic (CASs change over time and are different the one from the other) difference. This has a consequence that is very important for my reasoning: the NSP aims at finding general solutions, whereas CA is the science of particular explanations and solutions.[25]

The most lucid reflection on this topic is Joshua Epstein's illustration of 'generative science' (1999, 2006), a term that is often used as a synonym for complexity science (Arthur, 2010).

In generative science, explaining a phenomenon amounts to finding the micro rules and the configuration of links that are sufficient to make it emerge from decentralized autonomous interaction (Epstein, 1999, 42). That is to say, explaining a phenomenon amounts to generating it from the bottom up – a marked difference with respect to the mathematical treatment of mainstream economics.

Mainstream economics, in fact, holds that it has explained a phenomenon when a mathematical expression able to replicate the behavior of a system has been found. Faced with such a mathematical expression, a complexity theorist would speak of description, since there is no knowledge of the underlying mechanisms that generate it. If a given set of rules generates the macro regularity of interest, then it is a candidate explanation. If there is more than one candidate explanation, then further investigation is required.[26]

[24] Other learning algorithms such as classifier systems and neural networks work in a similar way.

[25] Even where the mathematical derivation of results is possible and takes – as it often does – the standard form of theorems and proofs, their purport is limited to the system being studied or to a strict range of its instances.

[26] In the 1990s, techniques able to explore the output of agent-based models were at their beginnings. The problem of distinguishing between specifications, comparing models, and testing their sensitivity predominated (Axelrod, 1997; Axtell and Epstein, 1994; Holland and Miller, 1991) because of the relatively scant experience in this field. Recently, the state of affairs has much improved (Phan and Amblard, 2007; Windrum et al., 2007)

The economist is seen as a kind of biologist that conducts experiments in her laboratory by observing a large number of instances in order to gain understanding of the phenomenon under study (Epstein, 1999, p. 51). It is the ability to observe and compare patterns, and not pure logical deduction, that leads to explanation.

The main instrument with which to conduct such experiments is an agent-based model, which has a 'solution' in a much weaker sense than in traditional mathematical modeling. Instead of a being 'specific element of a well designed function space' (Epstein, 1999, p. 52), it is an interval of elements or, in the case of computational models, a 'sample path of a stochastic process' (ibidem). The scope for 'precision' and 'rigor' is greatly reduced.

A further point concerns the role of prediction in economic science, which is crucial for the NSP, as shown in the influential work of Milton Friedman. He thought (1953, p. 7) that the 'ultimate goal of a positive science is the development of a 'theory' or 'hypothesis' that yields valid and meaningful (i.e., not truistic) predictions about the phenomena not yet observed'.

Given that complex systems are ontologically unpredictable, a science dealing with them cannot take prediction as its aim; nor can the goodness of a theory be judged according to its predictive power. However, unpredictability is not an obstacle to explanation: 'electrostatics explains lightning but does not predict their occurrence' (Epstein, 1999, p. 55).

The role of economic science is then to find a posteriori causal relationships that must be tested by being applied to facts to see whether they fit them (Lane, 2010). Economists cannot predict the future, but they have to identify patterns and, in the policy realm, find particular and contingent recipes grounded on historical comparisons.

If the NSP and the CA are ontologically and epistemologically irreconcilable, we have to make sense of the current state of our discipline. There is the historical fact that the CA is gaining increasing importance in economics and there is evidence that the oil spot move cannot work with the CA. It follows that economics is facing a tension that surfaces as a consequence of change.

The next two sections analyze, respectively, the CA as a stream of thought and claims that it is a candidate to become the next paradigm and the rigidities of the process of change that could induce a paradigm shift.

V. THE COMPLEXITY APPROACH AND THE PARADIGM SHIFT

The oil spot dynamic has been successful for nearly forty years. Its success has been due to the abstraction and to the axiomatization of economics performed by the NSP, which has allowed for extreme modularity.

By abstracting from phenomenal detail, the NSP has been able cumulatively to include both progress and criticism. By transforming economics into an axiomatized science, it has shifted the discipline to a self-referential plane of immanence.

In fact, by restricting its attention to mathematically provable facts, the NSP has built its ontology out of its epistemology: theories and models are no longer related to observables; they are subordinated to the existing mathematical options. Because the NSP epistemology dominates over theories about observables, ontology (e.g. do we really observe market equilibrium?) is no longer a strict constraint on what the NSP can cover as long as it is possible to use the appropriate mathematical/deductive language.

Since the CA is spreading and cannot possibly enter this scheme, we must conclude that economics is entering a period connoted by pluralism (or at least by dualism). Does the spread of the CA against the background of a fading neoclassical paradigm mark the dawn of the complexity era? Colander, Holt and Rosser (2004, 2010) answer in the affirmative by arguing that economics is opening up to a broad definition of the CA that includes, for instance, experimental and behavioral economics. In the same vein, Frank Hahn anticipates future developments in economics by sketching the main traits of the CA: 'not only will our successors have to be far less concerned with general laws than we have been, they will have to bring to the particular problems they will study particular histories and methods capable of dealing with the complexity of particular, such as computer simulation. Not for them […] the pleasure of theorems and proofs. Instead, the uncertain embrace of history, sociology and biology' (1991, p. 50). Sheri Markose, in the introductory paper to an issue of the Economic Journal devoted to Computability and evolutionary complexity: markets as complex adaptive systems, states that 'these principles mark a paradigm shift from earlier ways of viewing such phenomenon [the market]' (2005, p. 159), while, according to Barkley Rosser (2004, p. IX) 'awareness of the ubiquity of complexity is transforming the way that we think about economics'. Colander, Holt and Rosser (2010) use the distinction among dynamic, connective and computational complexities to provide a sort of map for research on complexity and to address the problem of defining what complexity is. In doing so they doubt that a unified science of complexity will ever exist. I subscribe to the idea that it is premature to interpret the success of the CA as a paradigm shift. However, as I have shown in this paper, the SFI's notion of CAS can encompass all three of the nuances in complexity research, so that we can treat the complexity approach as a coherent way of doing science. As shown in the previous sections, the CA has distinctive features that can make it a paradigm (Kuhn ,1962).

Historically, the complexity approach is a unique[27] experience in that it does not challenge a few aspects of the NSP as did, say, bounded rationality theory or experimental economics. Rather, it is a stand-alone approach with its own theories and methods. Strictly speaking, it cannot be interpreted as a critique against the NSP either; it is best thought of as an autonomous way to observe and know economies.

Whether or not the spread of the CA will usher in the complexity era is not entirely a matter of the properties of the approach itself; it also heavily depends on the features of the process of change within the discipline.

VI. THE CHANGE IN ECONOMIC SCIENCE AND THE COMPLEXITY APPROACH

Economics is undergoing a process of transformation triggered by the birth of many different streams of thought that make important departures from the NSP. The change can be seen from different points of view that help shed light on the complicated relationship between the complexity approach and neoclassical thought.

There is a factual datum: the CA is spreading within the discipline. It does not appear to behave like a typical academic fad characterized by a rapid increase in the number of published papers followed by a collapse within a few years. It is difficult to establish a starting point or a clear divide between complexity theory and earlier fields such as cybernetics,

[27] There have been previous alternative views, such as Hayek's catallaxy (1978, 1967b) which have anticipated many of the CAS themes (Vriend, 2002), but they have all been discarded on the grounds that there were no suitable methods with which to explore them. By contrast, advances in non-linear mathematics and in simulation techniques make the CA capable of thoroughly exploring the implications of its underpinnings.

catastrophe theory and chaos theory, but one can safely argue that economic analyses based on a complex systems approach began to appear in leading economic journals in the 1980s and have been increasingly present throughout the 1990s and 2000s: which is too long a time span to dismiss them as a mere intellectual bubble. The mainstream neoclassical approach must therefore deal with this diffusion. The oil spot move is a natural reaction for those that occupy leading intellectual and academic positions. Minimizing differences and including dissenting views, or in another rhetorical formulation, using advances in the new approach to fix the drawbacks of the mainstream approach, is a highly effective strategy with which to reap the benefits of being mainstream (Colander et al., 2004). The oil spot move ensures the continuity of leadership and the smoothness of change by substituting one concept after another while maintaining the framework as intact as possible. The succession of various oil spot moves generates the oil spot dynamic, which is successful until the oil spot dissolves or until water is met on the expansion path.

I believe that neoclassical economic is very close to both of these limit points. Inclusion of game theory, evolutionary game theory, experimental economics, bounded rationality, transaction costs and so forth has rarefied the internal cohesion of the neoclassical research agenda and the encounter with the complexity approach poses a serious challenge to the feasibility of the oil spot move. As envisaged by many authors (Colander et al., 2004; Davis, 2008; Hahn, 1991), the change is likely to accelerate and to produce a shift in the concept of mainstream.

What the next mainstream will be depends on the various dimensions of change. The first one is mainly a pre-requisite for change to come about: if economics is to change, there must be approaches that diverge from the current mainstream. The analysis of the differences between the NSP and the CA comprises an objective level, which I have tried to describe, that makes the oil spot dynamic fallacious on the substantive plane. There is no third way between adhering to the neoclassical view of economic phenomena and embracing the complexity approach. There are compelling ontological and epistemological reasons for maintaining that the two research programs have almost nothing in common and mostly contrasting tenets.

This implies a logical dimension of change. A research is nothing but a procedure: a problem of interest is analyzed by means of suitable methods and methodologies. The goodness of the research resides primarily in the ability to adhere to the correct procedure, which must be internally (made up of assumptions and methods that are compatible) and externally (appropriate for the phenomenon under study) consistent. The oil spot dynamic intended to include complexity is likely to produce internally and externally inconsistent research.

Change also has a narrative scope, which involves the way in which economists tell themselves stories about their discipline. To say that economics is changing is nothing more than a truism unless economists make sense of it, interpret it and try to fit it into their vision of the discipline. Neoclassical economics is not only a paradigm, it is a mental model deeply rooted in the economic profession. Mental models and the relative visions of the world change very slowly: the dissolution of the neoclassical orthodoxy is apparent when one looks at the current contents of economics, but much less evident in economists' descriptions of their work. This consideration leads to clearer interpretation of the rhetorical oil spot move (Blume and Durlauf, 2006, Bowles and Gintis, 2000), which from this perspective, mainly consists in a reassuring move: the familiar cognitive model is still usable and novelties can be considered as adjoining. On the other hand, those who conduct heterodox research seek to spread their ideas by emphasizing their path-breaking nature. This narrative dimension follows its own route, which may be independent from its objective nature.

The ongoing shift from the NSP to a new mainstream has – until the encounter with the CA - resembled a Lakatosian change in which the movement is gradual: an 'old' concept is replaced by a 'new' one until the change is complete (Colander et al., 2004). On the grounds of their irreconcilability, I believe that the complexity approach will accelerate change in the NSP and will impress a Kuhnian perspective on it.

VII. CONCLUDING REMARKS

The paper is essentially a rebuttal of the view that neoclassical economics can deal with complexity. I have coined the locution 'oil spot dynamic' to denote the neoclassical attempt to subsume each and every new perspective. The main part of the paper has been devoted to showing why the oil spot dynamic cannot work with the complexity approach, which is seen as a coherent stand-alone research program that stems from the SFI Economics Program and manifests itself with different nuances.

The fallacy of the oil spot dynamic is relevant in this period, in which economists are beginning to realize that the Neoclassical Samuelsonian Paradigm no longer represents the common language of their profession. The spread of the complexity approach and the dissolving notion of mainstream have been interpreted as signs of a change in economics. A short foray into the features of the process of change has completed my arguments showing that the shift from one paradigm to another has many interrelated dimensions and that there may be rigidities which internalize changes that have already taken place and which are evident to those who have not been long exposed to the mainstream education.

Economics is now a discipline in search of a new paradigm. The next issues to cover, which I now leave for future work, are whether the complexity approach will complete its process of coming together and will became a – possibly – dominant paradigm.

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