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Rethinking Economic Methodology: Complexity, Agent-based models (ABMs) and Individuals

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Abstract: This paper argues that the comprehension of the individual remains central to the study of Economics, especially in terms of the recent complexity theory and Agent-based models (ABMs) method. The main claim here is that it is possible to understand the ABMs, which refers to the relation between complexity and economics, as a new and promising method in what concerns human interaction. Furthermore, we defend the thesis that the methodological innovation proposed by ABMs also requires a modification in the way one should conceive the "individual". In other words, we indicate as the next step for this methodological discussion the theoretical development of an ontological concept of "complex agent" which deals with micro-macro relationships to replace the atomistic (representative) rational agent adopted by neoclassical/Walrasian economic models.

Key-words: Complexity economics; Agent-based models; Economic methodology, Individuals.

Resumo: Este artigo defende que a compreensão de indivíduo permanece central ao estudo da Economia, especialmente na teoria da complexidade recente e do método dos modelos baseados em agente (ABMs). O argumento central está fundamentado na possibilidade de entender os modelos baseados em agente, no que se refere a relação entre complexidade e Economia, como um novo e promissor método que considera a interação humana. Além disso, defendemos a tese de que a inovação metodológica proposta pelo ABMs requer também uma modificação na forma que é concebido o "indivíduo". Em outras palavras, indicamos como o próximo passo para esta discussão metodológica o desenvolvimento teórico de uma concepção ontológica de "agente complexo" que trata com a relação micro-macro para substituir o agente racional maximizador atomístico (agente representativo) adotado nos modelos neoclássicos/walrasianos.

Palavras-chave: Economia da complexidade; Modelos baseados em agente; Metodologia econômica; Indivíduos.

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Introduction

Economics, especially in its neoclassical/Walrasian branch, has focused its analysis on the individual behavior. Mainstream economics is an axiomatic theory, being the individual the starting point of the explanations derived from the method it adopts. For Pessali (2015), by means of the axiomatic method, the conclusions are derived from assumptions taken as true, irrespective of how far they are reasonable. This method was the basis for the further development of neoclassical Economics in the first half of the 20th century. As it is well known, this school of thought was responsible for minting the periphrasis of economic man (as a rational agent), being rationality an attribute of the agent that is taken as the touchstone for his abstract representation. Indeed, the assumption of rationality – that agents, i.e. consumers/firms/governments, given their means or

strategies, always seek their own best interests trying to maximize their expected utility – underlies most of economic theory, being utility maximization in the core of mainstream economic theory.

For Gallegati; Kirman (2012) the research program launched by the neoclassical school announces that macroeconomics should be grounded on micro-foundations and this means that economic phenomena at a macroscopic level should be explained as being based on the choices made by independent individual decision markers. This approach is constructed on three pillars: the precepts of the rational choice-theoretic tradition[1], the equilibrium concept of Walrasian analysis[2] and the reductionist approach of classical physics[3]. Gallegati; Kirman (2012) argue that the first two are logically defective and empirically unfounded, but the third one leaves open the road to a different approach that of complexity. Standard economic theory is an axiomatic discipline and the advocates of this view argue that such an abstraction is necessary once the real world is complicated: rather than compromising the epistemic knowledge, and this, of course, is true for any modeling approach. But, for Rappaport (1996 in Kirman, 2012, p.10) *this argument does not invalidate the criticism of unrealistic assumptions.*

In the past fifty years a vast number of empirical evidence has been accumulated suggesting that real agents systematically deviate from the version of substantive rationality. In this list, we can identify situations in which agents: (i) do not always try to maximize their utilities, (ii) choose courses of action based on mistaken estimates of probability, (iii) behave as if they believed in contradictions, (iv) do not act as they know they should or (v) do not do what they know they should. (Sutherland, 1992, Tversky; Kahneman, 1971, Thaler; Sunstein, 2009). Although the first evidences of this supposed irrationalism have been observed in experiments of cognitive psychology, they greatly contributed to the development of the research program on behavioral economics. This field that considers the observed deviations in the behavior of real agents adopted Herbert Simon's concept of bounded rationality[4] as one of its central assumptions. In other words: taking the substantive rationality assumed by neoclassical economics as the parameter of evaluation for rational human action, a great amount of empirical evidence has been accumulated showing that individuals act irrationally in a wide variety of circumstances.

Davis (2011b) argues that behavioral economics critiques of standard rationality demonstrated the importance of methodological reasoning in economics. Kahneman and Tversky and Simon´s emphasis on the observed psychological characteristics of decisions-makers derive from the methodological view shared by most scientists that our fundamental assumptions need to be the product of our empirical investigations of the world rather than logically determined. For this reason, Davis (2011b, p. 18) *suggest, thus, that enlarging this critique to make methodology of economics central to economics would make the rationality-individuality connection more central to economics*.

But it is important to differentiate the old behavioral economics (Simon) and the new behavioral economics (Kahneman). Simon understood the idea of bounded rationality somewhat differently from how it was understood by Kahneman and his prospect theory. Davis (2011b) emphasizes that Kahneman explains boundedness in terms of characteristics of the decision-maker,

[1] See Simon (1955) for a presentation of some general features of rational choice.

[2] Kirman (2010) emphasizes that theoretical economics, especially in the 20th century was directed by Walras´influence, but it is important to note that this was not so much the result of his own results but the refletion of his vision (Kirman, 2010, p.3).

[3] Drakapoulos (1994a) argues that the methodology of the new physics, which has also influenced modern philosophy of science, is quite different from classical physics, and this has serious implications for the scientific ideal that many economists have in their minds. See also Drakopoulos (1994b). Luperi (2017) discusses how mathematics and physics have influenced the constitution of economics, culminating in the adoption of general equilibrium as metatheory and the generalization of the hypotetical-deductive method.

[4] See Simon (1978) for a discussion of how to characterize bounded rationality.

and this is something Simon also addressed when emphasized the decision-makers´ cognitive and computational abilities. However, Simon (1956) thought that bounded rationality was understood to be bounded not just in virtue of the nature of decision-makers´ cognitive abilities but also in virtue of how those abilities functioned in the different kinds of decision environments in which they were exercised. It is important to note that *Simon rejected the subjectivist utility function representation of individual which abstracts from the environment of choice, whereas Kahneman and Tversky saw it as their task to modify that representation to produce a more psychologically realistic account of human behavior* (Davis, 2011b, p. 8). Moreover,

> Simon later captured the difference between his view and theirs in his adaptation of Marshall´s famous (supply and demand) scissors metaphor: human rational behavior…is shaped by scissors whose two blades are the structure of task environments and the computational capabilities of the actor (Simon 1990, p.7 *apud* Davis, 2011, p. 8).

The neoclassical economics takes as given its axioms, especially the rationality principle. If the observed human action does not fit on the axiomatic specifications, the recalcitrant behavior is delegated to an exogenous dimension. The proponents of the dominant view in economics divide the social world between domains of behavior that adhere to the rule of rationality and other realms that should be ruled by different laws, defining economics as the study of the former one. This vision has been questioned for several reasons, among which there is one claiming that it does not seem very scientific. Insofar as the rational agent (also called Representative Agent - RA[5]) is implausible in real terms, mainstream economics does not have the purpose of confronting it with reality and does not care to understand, study, and take into account what other sciences have to offer in terms of human reasoning and behavior (Pessali, 2015).

For Gallegati; Kirman (2012, p. 7) it is essential to differentiate the nature of atoms and agents, which means going beyond the confines of the methodology proposed in statistical physics and the passage to the economics of complexity. It is important to recover Simon´s (1962) emphasis on the fact that in most systems in nature it is to some degree arbitrary as to where we cease the partitioning, and what subsystems we accept as elementary. Simon *argues that physics makes much use of the concept of elementary particle although particles have a disconcerting tendency not to remain elementary very long. Only a couple of generations ago, the atoms themselves were elementary particles; today, to the nuclear physics they are complex systems* (Simon, 1962, p. 468). In this way, Gallegati; Kirman (2012) quote Foley (1994) and Aoki (1996) and their contribution *to the possibility of dealing with the issue of heterogeneous and interacting agents analytically and thus to micro-found aggregate behavior without recurring to the heroic but scientifically unacceptable hypothesis of a representative agent* (Gallegati; Kirman, 2012, p. 7).

To solve the problem of the lack of realism concerning reasoning and human behavior in economic traditional theories, many authors have proposed that economics analysis could not focus on the individual. Gode and Sunder (1993) and Mirowski (2007), for instance, detach that analyses could depart from the individual and goes to models of markets with zero intelligence agents (ZI) or the study of "markomata", respectively. Gode and Sunder (1993) use computational agents with ZI (lacking capacity for learning, memory, intelligence, rationality and which do not seek to maximize profit) as representation of human agents, to simulate the operations on the market. The main question to be answered by the authors concerns the influence of the agents' intelligence on the market, that is, the question if there is a difference between the results of the market if one supposes ZI agents and if one supposes the regular rational agent concept. They concluded that the allocative efficiency of the market is more dependent on the actual structure of the market than on the intelligence and on the agents´ motivation.

[5] Cf. Hartley, 1996 and Gallegati; Kirman, 2012 and Hands, 2016, for instance.

Mirowski (2007), by his turn, proposes an alternative program to think the market as an algorithm, the "markomata", which incorporates the computational economics. For the author, markets evolve under the individuals and not the other way around. While Hands (2016) discusses the rescue of the representative agent in economic theory, emphasizing that there is a broad set of economic research that suggests that rationality is more a feature of several types of institutions – particularly the market – rather than an attribute of individual agents. These studies show that it is possible to maintain mathematical tools to optimize the final result, without involving the concept of rational agent individually. Yet in modern macroeconomic models, which still claim to be Walrasian, individuals do not interact at all, since they are subsumed into a representative individual (Kirman, 2010).

Hands (2016) quotes Becker (1962) and his defense of the market's rationality as a substitute of the individual rationality. He also highlights the research of Gode and Sunder (1993, 1997) on traders of zero intelligence (ZI). As Becker, they suggest that economists could reasonably ignore the psychological research and move from the individual rationality to the market rationality. In this light f thought, Hands (2016) argues that the marriage of economics with computers conducted to an unexpected discovery: there is no internal contradiction in suboptimal behavior of individuals yielding aggregate-level outcomes derivable from assuming individual optimization. But, *Individual behavior and aggregate outcomes are related but distinct phenomena* (Sunder, 2006, p. 322-323 *apud* Hands, 2016, p. 13).

The importance of experimental economics, especially the research of Vernon Smith and the research program related to experimental market economics is also particularly worth mentioning. Besides, Hands (2006) argues that Smith shared the Nobel Prize in Economics in 2002 with Kahneman, but his research is quite different from the research program of behavioral economics. Smith´s analysis contributes to emphasize the rationality of the market framework more than the individual rationality. Although these are only a few of the many possible examples of the relevant literature concerning the agents' rationality problem, the underlying message is the same; *the problems of individualistic rational choice theory are red herrings, since markets should be the main focus and the rationality of agents is not necessary for the rationality of markets* (Hands, 2016: 14).

Davis (2003), by his turn, argues that without the recognition of the centrality of the concept of "individual" to social theories, it is impossible to comprehend the historical evolution of political systems in terms of freedom, human rights, development of knowledge and science. Nevertheless, there are very good reasons to believe that the concept of individual used in the economic theory may be inadequate; the traditional conception of the individual does not explain what is the individual, only provides an abstract design that uses the term "individual" to represent the individuals as atoms, unique people, collections of people, countries, machines or any notion that it is possible to assign the role to maximize (Davis, 1992; 2003; 2011a).

Having this scenario in mind, one of the paper's main claims is that the comprehension of the individual remains central to the study of Economics, especially in terms of the recent complexity theory and agent-based models (ABMs) method. Our argument is that ABM method could be understood as an innovation in economic methodology in what refers to human interaction, which leads us to defend the thesis that the methodological innovation proposed by ABMs also requires a modification in the way we should conceive the "individual". The paper is divided into the following sections: 1. Complexity and Economics; 2. ABMs and individuals, and 3. ABMs and the innovation in economic methodology. As final remarks, we suggest that as a possible next step for this discussion the theoretical development of an ontological concept of "complex agent" (complex individual) in order to replace the atomistic (representative) concept of "rational agent" adopted by neoclassical/Walrasian economics.

1. Complexity and Economics

The precise definition of complexity in economics is still open to debate[6]. Nevertheless, there is a set of main ideas that underline the different approaches to the complexity within Economics. Complexity is an alternative theoretic framework within economic science based upon complexity theory and nonlinear models. Approximately, Economics is viewed as an open system composed by heterogeneous agents with bounded rationality. The interaction of these individuals gives rise to networks, and to a macro level non-equilibrium state to the economy, which evolve due to its internal dynamics.

For Farmer (2012, p. 4), complex systems theory develops concepts, methods and tools that surpass specific application and disciplines. It also pursues to apply this approach to problems that are well beyond the traditional scope of physics, such as adaptive systems, like those encountered in biology and social science. While manifestations of complex systems are different in every field, there are commonalities. It is possible, for example, *to show that models of adaptive systems including neural networks, classifier systems, autocatalytic networks, immune networks, and evolutionary game theory can all be mapped into a common mathematical framework* (Farmer, 2012, p.4).[7]

Common to all these referred views, there is the understanding that the object of study of complexity are the *complex systems*, which are composed by many different parts that interact with each other, and in so doing, they influence their own individual environment. The combined system-level behavior originates from the interactions of the parts that are influenced by the overall state of the system (Bruno, Faggini, Piarziali, 2016, p. 31).

> By a complex system I mean one made up of a large number of parts that interact in a nonsimple way. In such systems, the whole is more than the sum of the parts, not in an ultimate, metaphysical sense, but in important pragmatic sense that, given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole (Simon, 1962, p. 468)

Bruno, Faggini and Parziali (2016) highlight that the methods applied in complexity studies are different from those used by traditional science. They include: agent-based modelling, cellular automata, catastrophe theory, complex adaptive systems, data mining, dynamical systems theory (otherwise known as chaos theory), fractal geometry, genetic algorithms, neural networking (otherwise known as distributed artificial intelligence), power law, scale-free networks, self-organized criticality, synergetic. Complexity economics is based on the proposition that the economic system is not necessarily in equilibrium because economic agents constantly change their actions and strategies in reaction to the result they mutually create. This outcome further changes the result, which requires it to adjust again. *Agents live in a world where their beliefs and strategies are constantly being "tested" for survival within an outcome or "ecology", that both these beliefs and strategies have created* (Arthur, 2013 *apud* Bruno, Faggini, Parziali, 2016: 6).

Arthur (2010), argues that in the last twenty years this different way of doing Economics has been developed under different names: complexity economics, agent-based computational modeling, generative economics and Santa Fe economics, each of them with its own style. The important fact is that of all these is that after two centuries of studying equilibria, economists are starting to investigate the economy out of equilibrium. The economy, when out of equilibrium, reveals itself as not deterministic, not predictable and not mechanic; but as process-dependent, organic and evolving. The traditional approach comprehends behavior in the economy as in an equilibrium steady state; that is, people in the economy face well described problems and their action are based on the use of deductive reasoning. Complexity framework, on the other hand, understands the economy as always

[6] Among many other possible definitions of the term, see, for example: Vicsek (2002); Farmer (2012); Rosser (1999).
[7] For a general review of complex systems: Newman (2003), (2011); Mitchell (2006); Kirman (2010).

in process and changing; that is, people try to understand the situations they face using whatever reasoning they have at hand, and together (by interactions) create outcomes they must individually react again. The resulting economy is not a well-ordered machine, but a complex evolving system (Arthur, 2010).

In many important aspects, Economics considered as a *complex phenomenon* can be seen as a mirror inversion of neoclassical theory. The figure bellow describes the dichotomies between both paradigms. There are five pairs of contrasts between the conceptions of neoclassical economics and the complexity approach.

Figure 1: Dichotomies between Neoclassical and Complex Economics

	Neoclassical Economics	**Complexity Economics**
Agents	Substantive rationality	Bounded rationality
Emergency	All macro properties can be derived from its micro properties (the hole is nothing but the sum of its parts).	Macroeconomic patterns are emergent properties of micro-level interactions and behaviors.
Networks	Agents do not interact at all.	Agents participate in sophisticated overlapping networks.
Dynamics	Thermodynamically closed, static, and linear	Thermodynamically open, dynamic, nonlinear
Evolution	There is no mechanism for creating novelty or growth in complexity.	An evolutionary process of differentiation, selection, and amplification provides the system with novelty.

Source: Elaborated by the authors.

According to Neoclassical economics, agents are perfectly rational, have perfect information and no costs to optimize. On the other hand, the complex approach claims that the agent's capacity to optimize is limited by many possible costs: limited time, limited available information and/or limited cognition mean to compute or to process information in order to maximize the expected utility, that is, individual have bounded rationality.

The Walrasian/neoclassical economy has no macro properties that cannot be derived from its micro properties. In the complex economy, otherwise, macroeconomic patterns are *emergent* properties of micro-level interactions and behaviors. In such cases, one cannot analytically derive the properties of the macro system from those of its component parts, although one can apply novel mathematical techniques to model the behavior of the emergent properties.

Moreover, *emergence* is considered a crucial feature of a complex system. The notion of emergence refers to the fact that the system´s global behavior is not only complex but arises from collective actions based on simple components, and that the mapping from individual actions to

collective behavior is not simple (namely, the individual actions). The complexity of the system´s global behavior is characterized in terms of the patterns it forms, of the information processing that it accomplishes, and of the degree in which this pattern formation and information processing are adaptive for the system; that is, the degree in which it increases its success in some evolutionary or competitive context. In characterizing behavior, complex-systems scientists use tools from different disciplines, including nonlinear dynamics, information theory, computation theory, behavioral psychology, and evolutionary biology (Mitchell, 2006, p. 1196).

In Neoclassical economics, agents do not interact at all. Rather, each agent faces an impersonal price structure. In the complex economics, agents participate in sophisticated overlapping networks that allow them to compensate the limited information they incur and the considerable information costs they will incur.

The neoclassical/Walrasian approach is thermodynamically closed, static, and linear in the sense that economics can be modeled by means of algebraic geometry. Complex economics modeling, on the other hand, is thermodynamically open, dynamic, nonlinear, and generally represents a system far from equilibrium. Finally, according to the neoclassical/Walrasian economics, there is no mechanism for creating novelty or growth in complexity. According to complex economics, on the contrary, the evolutionary process of differentiation, selection, and amplification provides the system with novelty and is responsible for the growth in order and complexity.

Cardoso; Lima (2008), following Foley (2003),[8] detaches that once it is considered the possibility of non-linearity in the behavior of agents, the results of complexity appears in social and economic theory. If the complex interactions have a role in the evolution of social reality, then its abstraction means a high price paid by the social and economic theories in terms of miscomprehension of social/economic phenomena. For the neoclassical epistemology, the rational actor does not need to take into account the reactions of other actors in all their complexity, once price equilibrium in the market already presents all the important information needed to utility maximization.

Common to all studies on complexity is the idea that systems have multiple elements that adapt or react to patterns that are created by them. The complex systems share many interesting characteristics as non-linearity and the following common properties: diverse potential solutions, the achieved result is not predictable, the system tends to be prisoner in this result, it is not necessarily the most efficient and it is path dependent (Cardoso; Lima, 2008, p. 363). For these authors, the complexity approach intends to consider the characteristics of economic system which are not explained in a satisfactory way by mainstream economics, specifying agents and their rules of behavior and trying to explain, by means of simulations, the *emergent* properties raised by the interaction of the agents.

> The Complexity theory seeks explanations of how the economy works that have empirical validity. To accept human behavior, imperfect institutions, and the complex interactions and dynamics of the economy as they really are rather than what an idealized model says they should be. Not more aggregate reduced to the analysis of a single, representative, individual, ignoring by construction any form of heterogeneity and interaction, but the aggregate emerging from the local interactions of agents. The economy considered as a complex system emphasizes the based-agent bottom-up approach to model the economic systems made by interconnected layers populated by more and more complicated agents (Bruno, Faggini and Parziali, 2016:36).

[8] Foley´s (2003) central argument is that the classical political economists, not just Marx but also Adam Smith and Malthus with Ricardo, developed ideas that are well suited to representation and understanding using the methods of modern complexity economics, such as themes of dynamic out-of-equilibrium self-organization in systems with boundedly rational agents, in contrast to the requirements for full Walrasian general equilibrium that he studied early in his career.

The first point that is important to the argument defended on this paper is the difference between complex systems and complex adaptive systems, especially about the concept of agents used by the former and the later type of analysis, like is argued by Davis (2013). Complex adaptive systems theory *a la* Simon (1962) is not only different from complex systems theory in that the overall system´s self-organization is explained by means of the subsystems´ self-organization, but specially in the view that these subsystems are composed by agents with the most elementary sort being made up of basic agents (Davis, 2013, p. 234).

The second point relates to the difference between complex adaptive systems (and consequently agent based complexity) and general system theory, a holistic approach developed in he half of 20th century by the Austrian biologist Ludwig von Bertalanffy[9]. According to general system theory, phenomena that appear to have simple causes, such as unemployment, actually have a variety of complex causes – complex in the sense that the causes are interrelated, nonlinear, and difficult to determine. Complex adaptive approach, on the other hand, looks for simple rules that can support complexity (Galegatti; Kirman, 2012, p. 8).

As we have pointed out above on the discussion about complexity and Economics that there are different methods of analysis and seems to prevail a consensus on a different notion of basic agents (individuals) that differs from the representative agent. The paper focuses its attention on the agent-based models (ABMs) *a la* Kirman as one of the diverse methods within the discussion of complexity in Economics. Our main reasons are the two followings: first, this method can present an interesting innovation in economic methodology in what refers to human interaction and secondly it presupposes a concept of individual different from the representative rational agent used by neoclassical/Walrasian economics to model the micro-macro relationships.

2. Agent-based models (ABMs) and the individuals

In the beginning of 21st century, the first researches based on the ABM came to light. They proposed economics to derive inferences from formalizations using computational math, seeking to analyze Economy as a complex system based on its micro-foundations, which is based on the interactions between heterogeneous agents under asymmetric information (Gaffard; Napoletano, 2012). More narrowly defined, this approach is called "Agent based complexity" (Gallegati; Kirman, 2012).

For Kirman, economists entered the 20th century developing models based on the physics of the 19th century and maybe in the 21st century we could move to a model based on the physics of the twentieth century. Agent-based models are one alternative to traditional models in the sense that they consider the Economy as a complex adaptive self-organizing system consisting of purposeful but not optimizing individuals, with local and limited knowledge. *Like colonies of social insects, these agents exhibit complex aggregate behavior that cannot be represented as that of one of the individuals of whom the system is composed*. (Kirman, 2014, p. 3).

Arthur (2005) argues that the standard neoclassical economics asks whether actions, strategies and expectations of agents are in equilibrium (consistent with) the result or pattern that these aggregate behaviors create. The computational economics based on agents allows us to ask others questions: how actions, strategies or expectations of economic agents react to patterns that they create. Besides, it allows one to ask how the economy is out of balance, when it is not in *steady state*.[10]

[9] Cf. Bertalanffy (1968).

[10] There is a long history of agent-based models in Economics, for example: Schelling (1971) and the model of spatial segregation, Nelson & Winter (1974; 2002) and the technological change, Axelrod (1984) and the emergence of cooperation, Silverberg; Lehnert (1993); Dosi, Fagiolo, Roventini (2010) and Savioti, Pyka (2013) and economic growth.

Pyka and Fagiolo (2005) accentuate the importance of the multidisciplinary character of the proposed agent-based models. The prospect of the Economy as a complex system is based on Biology, Physics, Sociology, Computing, and Psychology. It is a counterpoint established in relation to traditional static and balanced models, which indicates the monitoring of the progress of the Economy in relation to the advancement of other sciences, something not verified by mainstream models. In general terms, ABMs deal with the study of socio-economic systems that can be conceptualized by means of a set of micro-macro relationship. It is important to note that the micro level typically contains heterogeneous basic entities what implies that the decomposition does not help to explain the phenomena under study (firms, consumers, workers).

> Repeated interactions among these entities over time induce ceaselessly changing microeconomic patterns (production and consumption level). These micro patterns, once aggregated over the relevant set of micro entities, generate a macro dynamics for the aggregate variable of interest (GNP). The goal of ABMs is to properly describe such complicated systems and to analyze their properties. More precisely, agent-based formalizations depict decentralized economies as complex systems and try to infer their aggregate properties – in a bottom-up perspective – from interactions and behaviors of micro entities (PYKA; FAGIOLO, 2005: 3-4).

Napoletano, Gaffard and Babutsidze (2012: 2) emphasize that ABMs characterize economic processes as dynamic systems of heterogeneous agents and that this approach is opposite to the standard one[11], once assumptions like heterogeneity, bounded rationality of agents and market disequilibrium are considered. The authors argue that *this feature makes these models a promising research tool for understanding the situations and problems emerged with the recent crisis*.[12]

One can point out at least two advantages of the application of an agent-based model. The first one is its capacity to show how collective phenomena came about and how the interactions of autonomous and heterogeneous agents lead to these complex phenomena. The other is that the ABMs are used to get a profound understanding of the inherent forces that drive a system. Also, agent based modelers use their models as computational laboratories to explore diverse institutional arrangements, varies potential paths of development as to help and guide firms, policy makers in their particular context (PIKA; FAGIOLO, 2005 p. 8-9).[13] Besides, agent based modeling is not just an intellectual exercise, since *policy-makers can thus simulate an artificial economy under different policy scenarios and quantitatively explore their consequences* (Farmer; Foley, 2009: p. 25).[14]

Beyond the various labels under which different classes of ABMs have become known among economists scholars, Pyka and Fagiolo (2005) state that all of them share a common set of assumptions that reflect their underlying modeling philosophy. These assumptions are: bottom-up philosophy; evolving complex system approach; heterogeneity; bounded rationality; true dynamics; direct (endogenous) interactions; endogenous and persistent novelty; select-based market mechanisms, as figure 2 shows:

[11] For explanation on increasing dissatisfaction with mainstream models and standard macroeconomic models, see Pyka; Fagiolo (2005, p. 4-7) and Napoletano; Gaffard; Babutsidze (2012, p. 2-5).
[12] This same argument is presented by Davis (2013) and the emergence of agent-based modeling.
[13] For a discussion of examples using the ABM methodology, see Napoletano; Gaffard; Babutsidze (2012).
[14] Napoletano; Gaffard; Babutsidze (2012, p. 7-8) discusses some critiques on ABMs.

Figure 2: Contrasts between the neoclassical modeling and the ABM approach

	Neoclassical Modeling	ABM approach
Philosophy	Top-down	Bottom-up
System approach	Simple (Closed) System Statics No presupposed novelty	Complex evolving (Open) System True Dynamics Endogenous and persistent novelty
Agents	Homogeneous Substantive Rationality Indirect Interactions	Heterogeneous Bounded Rationality Direct Interactions

Source: Pyka; Fagiolo (2005).

The *bottom-up* perspective means that aggregate properties must be viewed as the outcome of micro dynamics involving basic entities. The ABM methodology presupposes autonomous and heterogeneous agents, which are guided by simple behavioral rules. Moreover, they are supposed to have local interaction and to change (thought adaptation) both the rules which constrains their choices and their network itself. This assumption is completely different from the top-down nature of neoclassical/Walrasian micro-macro models, in which the bottom level is compressed into the behavior of a representative rational individual[15].

According to the ABM assumption, agents live in *complex systems evolving* through time, that is, systems in which aggregate properties *emerge* out of repeated interactions among simple entities, while neoclassical modelling presupposes consistency requirements carried through by rationality and equilibrium assumptions made by the modeler[16]. Agents are assumed to be *heterogeneous* in almost all their characteristics and they are assumed to behave as *bounded rational* entities with adaptive expectations once they live in a complex environment. ABM, as a consequence of adaptive expectations, is defined by a true, non-reversible, dynamics. The direct interactions reflect that the decisions undertaken today by any agent directly depends on past choices made by subgroups of others agents in the population. These interaction structures may endogenously change over time, as agents can strategically decide whom to interact with based on expected payoffs. Endogenous and persistent novelty occurs because socioeconomic systems are non-stationary (Pyka; Fagiolo, 2005).

For Davis (2013) there are several strategies of thinking complexity in economics and it is important to distinguish complex system and complex adaptive systems; the latter understood in terms of agent-based models or computational Economy based on Kiman´s (2011) agents. Davis (2013)

[15] For a discussion of representative individual, see Hands (2016). Kirman (1992) provides examples in which the representative agent does not represent the individuals in the economy so that the reduction of a group of heterogeneous is not just an analytical convenience. On the contrary, it is unjustified and leads to conclusions which are usually misleading and often wrong.

[16] The most important example of emergent behavior in economics is Adam Smith's metaphor of the invisible hand: how the self-interested actions of real agents in the economy combine to produce socially optimal outcomes. One of the strengths of agent-based modelling is that this invisible hand is made visible and its workings may be examined. This is in contrast to some other model approaches in which the actions of many individuals are assumed to lead to a particular outcome, often using a single representative agent. This simplification is valid in some cases but not all combinations of behaviors can be represented by the actions of a single agent (example of the fallacy of composition) (Turrel, 2016, p. 178).

discusses the relevance of thinking about complexity to the economy, taking into account whether the agent-based models provide an adequate description of agency in economic systems understood as complex.[17] Kirman (2011), by his turn, points out that among his main ideas, one is the dissatisfaction with *homo economicus* in which regards to what exactly we understand to be the identity of an economic agent. Kirman; Teschl (2004) has tried to clarify the nature of the rational agent identity, as he experiences, engages and interacts with others. The influences of the groups to which the agents belong to and its impact on those groups are at the heart of the sort of problems generated in analyzing the evolution of an economic system. For Kirman (2010) the structure of interaction between people matters to Economics; the idea of an anonymous market in which people interact through the price system is totally unrealistic.

Related to micro-macro relationship, Kirman (2011) argues that it is enough to open any macroeconomic book and we will found out a microeconomic study of the simplest case, which presupposes a single representative agent. In no other discipline we could find the assumption that the behavior of hole is the same as the behavior of a typical part of it. For all these reasons, rather than persist with models based on the idea that the Economy behaves like a rational individual, according to him we should build models of the Economy as a complex system of interacting agents. This confirms the argument that the fundamental underpinnings of most modern economic work and indeed of quantitative work are the general equilibrium models. *The problem seems to be embodied in what is an essential feature of a centuries-long tradition in economics, that of treating individuals as acting independently of each other* (Kirman, 1989, p. 137).

The agent-based models use simulation tools to analyze economic dynamic and heterogeneous scenarios. In defense of this proposal for modeling, following Kirman we can argue that the traditional models are unable to represent reality, given they simplify too much. Computational models, due to their great ability to work with data, allow us to categorize different patterns of behavior in individuals and create dynamic scenarios. Kirman (1993) observed the interaction in the ant model and argues that the most important feature of the process suggested is that there is a perpetual change. Many models are developed with the specific intention of finding a steady state to which an economy or market will finally converge for defining a static equilibrium. Financial markets are often thought of as being characterized by periodic switches of the collective mood of investors. Such switches in the ant model are, unlike those in many models, not driven by exogenous shocks. In conclusion then, is seems, paradoxically, that this model has perhaps more to teach us about the way in which economic agents act than about the normal behavior of ants (Kirman, 1993, p. 154).

The individual in terms of ABM is characterized like heterogeneous in almost of his characteristics, has the behavior guided by bounded rationality and is in constant interaction with others to whom he/she can or cannot identify and form groups in different and complex scenarios. The ABMs models presents a different view of individual (heterogeneous, bounded rational and interactive) living in different and diverse, changing and complex scenarios, but this different individual is also an agent, that is, this new conception of individual provides a description of what would be individuals in the evolutionary and complex environments. In this light of thought, it is possible to emphasize that, besides its many contributions, one of the problems that the AMBs could solve is how to best select the appropriate behaviors for these agents. *There are not always obvious criteria for choosing which behaviors are the most realistic* (Turrel, 2016, p. 173)[18].

[17] In this sense, Davis contradicts the vision of Mirowsky (2007, 2010) of complex systems because the agents do not play a significant role, rather functioning as placeholders for kinds of factors whose changing population frequencies we may wish to track for reasons independent of our understanding of the complexity of those systems (Davis, 2013, p. 231).

[18] Turrel (2016) uses 'agent-based model' to refer to any model in which the interactions and behaviors of a large number of heterogeneous agents are simulated, manually or by a computer.

3. Agent-based models (ABMs) and the innovation in economic methodology

In the pertinent literature, it has been widely held that agent-based modeling (ABM) is a new and different method of investigation compared to the one employed in standard economics. The most important consequence is that this new method makes it possible to reconstruct economics on a sounder basis. Davis (2017) quotes Hands (2001) arguing that economic methodology has historically undergone and continues to undergo evolution and change. We do not reason about the grounds for believing our theories in the same way today as we did in the past. The unchanging standard view is also contrary to what some proponents of ABM claim, namely, that their methods involve a new type of economic methodology (e.g., Epstein, 1999, 2006).

Davis (2017) defends this latter view, and argues that economics, its methods, and economic methodology all gradually change together. He argues that the adoption of new method of ABM also advances economic methodology and our understanding of the nature of explanation in economics, thus justifying the view that this method makes it possible to reconstruct economics on a sounder basis. For this author, the agent-based modeling has promoted innovations in method in terms of simulation techniques and involves also an innovation in economic methodology. He also links this alternative view of economics and economic methodology to a social science model of economics and contrasts this with standard economics' natural science model of economics. With this proposal in mind, Davis (2017) presents three methodological differences between standard (neoclassical) economics and ABM economics in terms of economic methodology, methodological approach and science model (Figure 3).

Figure 3: Methodological differences between standard economics and ABM economics

	Neoclassical economics	**ABM economics**
Methodology	Unchanging, closed and natural	Evolving, open and social
Methodological Approach	Natural science	Social science
Science Model	Linear causation	Circular (or downward) causation

Source: Davis (2017).

Davis (2017) argues that, for standard economics, the economic methodology is unchanging, closed and natural; for ABM economics it is evolving, open and social. Standard economics accept a natural science model of economics – the idea that the object of investigation of economics is unchanging just as the laws of nature are unchanging in the natural sciences. ABM economics, on the other hand, assumes a social science model of economics, according to which economics is an object of investigation that gradually change together with the evolution of the world it investigates.

As it is well known, the proposal of a natural science model of economics is the dominant position in economics (Davis, 2017). The authors who defend this position often point to such things as the law of demand or the principle of comparative advantage as evidences that the principles or laws in economics are unchangeable. On the other hand, supporters of the social science model of economics often point out Veblen's concept of *cumulative causation*. The concept of cumulative (or circular) causation is to be understood in terms of the interactions between the effects science is

assumed to have on the world and the effects the world is assumed to have on science – a two-way causal relationship that implies that the content of economics and the world gradually change together (Davis, 2017).

Indeed, according to Gallegati; Kirman (2012, p. 15), ABM method is characterized by two main tenets: it presupposes the existence of a multitude of objects ("agents", also called "individuals") that interacts not only with each other, but also with their environment. Besides, the objects are heterogeneous and autonomous, in the sense that there is no "top down" control over their behavior. It is also worth highlighting that "agents are allowed to have *local interaction* and to change their *individual rules* (through adaptation) as well as the network which drives their interactions". While interacting, emergent properties and behavior begin to arise in the individual level (circular causation), establishing a macro foundation of micro behavior. That means: the agents learn from their experiences and react to institutional changes and to the behavior of other individuals. The rationality is not given *a priori*, but rather the result of dynamic and uncertain social constructs. Summing up, according to the ABM, the underlying assumptions on individual behavior can be weakened in comparison to the assumptions of utility maximization adopted by standard economics. In this sense, as we have pointed out in sections 1 and 2, from the methodological perspective, the ABM approach and its emphasis on the complex theory view, is in direct opposition to the axiomatic approach of neoclassical economics.

Given its tenets, the ABM approach can thus be taken as a methodological innovation in economics, and the paper follows with the question concerning the relevance of discussing a more adequate concept of "individual". More specifically, we are concerned with the possibility to conceive a concept of complex individual who interacts with other individuals in complex environments, taking into account the positive feedbacks of his actions – i.e. the cumulative causation – as well as the emergent properties involved.

Because economics is an applied social science, it has the tradition of considering the individual as a central element, but without considering what is an individual, where it is inserted and who is the individual (Kirman; Teschl, 2004). For Kirman (1992), the representative individual of the general equilibrium model will persist as long as the economists focus on a structure of anonymous individual maximization. Also, he emphasizes that only if we are prepared to develop a paradigm in which individuals function in a limited subset of the Economy, are diverse both in their characteristics and the activities that they pursue, and interact directly with each other, will economics escape from the influence of the representative agent. However, the fact that behavior at the macroeconomic level shows regularities does not mean that it is appropriate to understand the Economy as a maximizing representative individual (Kirman, 1992, p. 134).

The agent-based model, as a methodological alternative to traditional neoclassical modeling, has a different perspective in relation to the individual: it is opposed to the model of economic agent rationally representative, *homo economicus.* It is understood that, from a new vision of individual, it is possible to find answers to other central problems in the Economy, as the source of the imbalances, for example. The individual is heterogeneous and therefore interactions in the microeconomic framework affect the macroeconomic scenario, negating the idea of balance and stability. Gaffard and Napoletano (2012) indicate that the heterogeneity between agents occurs not only at the individual level or in microeconomic groups; production processes are also heterogeneous and dynamic. The use of ABMs allows the understanding of which factors are related to structural changes that arise from the productive dynamics in strategic sectors.

For Davis (2006) the dual design – individuals and forms of interaction – is challenged in many complex, computational evolutionary explanations for economic events that assume that the individual agent and his forms of interaction are heterogeneous. In fact, for some the stimulus for this

different conception of individual is the perception that traditional concept is declining. Davis (2006) cites Kirman (1997) and his emphasis on the collapse of the theory of axiomatic general equilibrium, particularly associated with the results of Sonnenschein-Mantel-Debreu for the traditional view of individual and argues for a new approach to the individual as central to new forms of economic theory. Davis (2013) noted that some authors explain complexity in terms of computational complexity or use strategies of econophysics.[19] However, in his view the perspective of evolutionary biology associated with the idea of emergent phenomenon is more promising because these views emphasize the agency that is a central concept in the economy[20].

Besides the ABM models to be considered as a methodological innovation, there is still the need to develop a new approach to the individual, i.e the concept of heterogeneous and autonomous agent itself is still missing. A more detailed discussion on *who* is this heterogeneous individual with bounded rationality that interacts in diverse and complex scenarios is required. A possible notion of complex individual required by ABM models would mean a methodological and ontological improvement in economic theory in which regards to *human* interactions in Economics.

Perhaps a return to Simon's bounded rationality in what refers to his scissor metaphor and his emphasis on adaptive systems and Veblen and his instinct, habit conception of individual and circular causation's proposal would be interesting starting points to conceive a concept of complex individual[21]. This is one of the challenges of this methodological innovation provided by ABM models and could be thought also as a process of rethinking and reconstructing the economic methodology.

Final Remarks

The ABMs represent a new way of thinking and understanding economic questions and can be understood as a different methodology and also as an innovative method based upon the analyses of complex adaptive systems with many autonomous and heterogeneous interacting agents in diverse, evolutionary and complex scenarios. These interactions lead to empirical regularities (*emergent properties*), which are considered a main tenet of the complexity approach. It also proposes a bottom-up analysis, which can offer different answers to old and unsolved questions in which regard the agents´ behavior as well as to the aggregate behavior and to the relationship between them.

The question that remains is whether this new form of thinking in Economics based on complexity theory that means an approximation to social science model requires a concept of individual that is also complex. On the other hand, if it is the case that complexity theory applied to Economics works with complex scenarios without theorizing a complexity inherent to different and heterogeneous individuals (agents) that interact in diverse and complex contexts, is it possible to affirm that this new models consider the aspect of individual´s identity (agency) in these different kinds of *human* interactions?

[19] See Mantegna and Stanley (2000).

[20] Foster (2004) highlights the importance of complex adaptive systems because of their relevance to the understanding of the economic system, but not in the sense of the biological aspect of it.

[21] For Rosser Jr; Rosser (2017), Veblen not only called for economics to be an *evolutionary science* (1898), but introduced certain ideas that have since then proven to be important in understanding the nature of complexity in economics, particularly that of *cumulative causation*, often thought to have been introduced later by either Allyn Young (1928) or Gunnar Myrdal (1957), with the latter making the term widely known among economists, and Nicholas Kaldor (1972) drawing out its negative implications for equilibrium economics. Among the various forms of complexity that are relevant to economics, cumulative causation is most obviously tied to *dynamic complexity*, which leads to increasing returns, multiple equilibria, and a variety of bifurcations in economic dynamical systems. However, it can be seen to be connected also to *computational complexity*, as well as *hierarchical complexity* due to Simon (1962). (ROSSER Jr.;ROSSER, 2017).

In our view, based on the pertinent literature here presented, the answer to the first question is “yes” and the answer for the second is “no”. It is important to leave behind the concept of representative agent in order to take into account the contributions of ABM models, as a methodological innovation in Economics, as suggested by Kirman and his emphasis on individual´s identity and the relevance of human interaction and the fact that agents learn from their experiences and react to institutional changes and the behavior of other individuals. Therefore, we indicate as the next step for this methodological discussion the theoretical development of an ontological debate on “complex agent” which deals with micro-macro relationships.

There seems to be a consensus on the importance to take into account the role of agency in these new method based on agents. In the relevant literature, it seems to be an agreement that these models based on agents could be an interesting way to replace the atomistic (representative) rational agent adopted by neoclassical/Walrasian economic models. But, the challenge of this new method is how to understand the agent, that is, *who* is this agent that is heterogeneous and has bounded rationality. Simon´s ideas on adaptive complex system and Veblen´s thoughts concerning human behavior (a conception of evolutionary habit of the agent) and cumulative causation can be considered as two promising starting points for an ontological initiative in order to solve the challenge of ABMs in which concerns rethinking the economic methodology and how to consider *human* behavior in the most diverse *human* interactions in Economics.

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