Duality of knowledge, singularity of method

The case of econophysics and J.S. Mill's notion of emergence

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Abstract

Purpose – How a micro-founded discipline such as economics could deal with the increasing global economic reality? This question has been asked frequently since the last economic crisis that appeared in 2008. In this challenging context, some commentators have turned their attention to a new area of knowledge coming from physics: econophysics which mainly focuses on a macro-analysis of economic systems. By showing that concepts used by econophysicists are consistent with an existing economic knowledge (developed by J.S. Mill), the purpose of this paper is to claim that an interdisciplinary perspective is possible between these two communities.

Design/methodology/approach – The authors propose a historical and conceptual analysis of the key concept of emergence to emphasize the potential bridge between econophysics and economics.

Findings – Six methodological arguments will be developed in order to show the existence of conceptual bridges as a necessary condition for the elaboration of a common language between economists and econophysics which would not be superfluous, in this challenging context, to clarify the growing complexity of economic phenomena.

Originality/value – Although the economics and econophysics study same the complex economic phenomena, very few collaborations exist between them. This paper paves a conceptual/methodological path for more collaboration between the two fields.

Keywords Methodology, Complexity, Econophysics, J.S. Mill

Paper type Research paper

1. Introduction

How a micro-founded discipline such as economics could deal with the increasing global economic reality? This question has been asked frequently since the last economic crisis that appeared in 2008. Numerous observers (Rickles, 2008; Schinckus, 2009) questioned the economic knowledge and its way of dealing with complex global issues. In this challenging context, some commentators (Rosser, 2010; Colander *et al.*, 2008; Jovanovic and Schinckus, 2013) have turned their attention to a new area of knowledge coming from physics: econophysics, which is a new hybrid discipline that emerged in the 1990s. This new field provides a specific way of thinking economic systems by using models coming from

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statistical physics. The direct contributions of econophysics to economic knowledge are still inconclusive and controversial (see Schinckus, 2010a, b) because this field is still in its infancy and two decades is not enough for developing a coherent unified framework. However, although these debates, an agreement emerged in the literature (Colander *et al.*, 2008; Chakraborti *et al.*, 2011a, b; Schinckus, 2011) on the contributing points which appear to be the way of modeling complexity and a potential enlargement of uncertainty. On that point, Colander *et al.* (2008), for example, wrote that by founding all economic macro phenomena on the rational representative agent, economists implicitly set the macro level equal to the micro level. These authors added that the consequence is that all macro-concepts such as "market," "systemic risk" or "financial crisis" are misunderstood in economic theory because these notions are founded on an inappropriate complexity. Because this aspect of complexity is at the heart of econophysics, this field can contribute to a better understanding of complex economic systems. In the same vein, Schinckus (2009) emphasized that econophysics can also enlarge the notion of uncertainty in economics by proposing collection of operational instruments for uncertainty situations.

Although the term "econophysics" is the combination of "economics" and "physics," the dialogue between economists and physicists appears to be difficult in the literature: economists consider that econophysicists develop a meaningless knowledge while econophysicists present economics as a priorist "tapestry of belief" (McCauley, 2004). Moreover these lack of dialogue is enhanced by controversial writings of econophysicists who often tend to exaggerate their contribution to economics and finance by claiming they deal with new concepts (such as invariance or emergence[1]) or stable Levy processes[2]. In this perspective, econophysics is sometimes presented as an autonomous emerging field (Gingras and Schinckus, 2012) with its own annual conferences[3] and its own academic education and PhD[4].

Despite these debates, some collaborations between economists and econophysicists exist: Farmer and Foley (2009) or Farmer and Lux (2008), for example, who published a special issue of the *Journal of Economic Dynamic and Control* dedicated to the "application of physics to economics and finance" whose objective was to favor collaboration between economists and econophysicisits, as Farmer and Lux (2008, p. 6) wrote it:

> We hope that this selection of papers offers an impression of the scope and breadth of the growing literature in the interface between economics/finance and physics, that it will help readers to get acquainted with these new approaches and that it will stimulate further collaborations between scientists of both disciplines.

In addition to these collaborations, some economists have provided a disciplinary reflection on econophysics (Keen, 2003; Rosser, 2008, 2010), while other authors (Drakopoulos and Katselidis, 2013; Jovanovic and Schinckus, 2013) tried to enhance common methodological points between the two fields in order to favor the development of an integrative collaboration enhancing a better modeling of complexity and uncertainty as evoked above. However, as Jovanovic and Schinckus (2013) wrote it, an integrative collaboration[5] between these two disciplines requires the elaboration of a common language in order to favor the transfer of meaning in the dialogue. We must admit that the development of this in-between language seems today difficult since both, economists and econophysicists claim that their knowledge has nothing to do with the another field. By showing that some conceptual aspects (such as emergence or complexity for example) of econophysics are consistent with the perspective developed by J.S. Mill to study economic phenomena, this paper emphasizes a methodological argument sustaining that a possible dialogue between econophysicists and economists[6] can emerge. That kind of dialogue would not be superfluous, in this challenging context for economic knowledge, to understand the growing complexity of economic systems. In terms of history of economic thought, this paper also stresses the contemporary relevance of the Millian framework which provides conceptual tools to better understand the development of a new field dealing with economic complexity.

The paper is structured into three parts. The first part will present econophysics and the kind of complexity we can find in this field. The second part will introduce the major dimensions of Mill's methodology about complexity and emergence. Finally, in the last part, we will identify common methodological points between econophysics and Mill's methodology.

2. Between physics and economics

2.1 The development of econophysics

Physics has always been a source of inspiration for economists[7]. However, the development of econophysics appears to be a bit different than usual historical links between economics and physics. Its practitioners are not economists taking their inspiration from the work of physicists to develop their discipline, as has been seen repeatedly in the history of economics[8]. This time, it is physicists that are going beyond the boundaries of their discipline, using their methods to study various problems thrown up by social sciences. Econophysicists do not claim that they are attempting to integrate physics concepts into economics as it exists today, but rather that they are seeking to ignore, even to deny economics and its foundations.

This movement out of physics was initiated in the 1970s, when certain physicists began to publish articles devoted to the study of social phenomena. While some authors extended what is called "catastrophe theory[9]" to social sciences, others created a new field labeled "sociophysics[10]."

In the 1990s, physicists turned their attention to economics, and particularly financial economics[11], giving rise to econophysics. Although the movement's official birth announcement came in a 1996 article by Stanley *et al.* (1996), who defined econophysics as a quantitative analysis of economic systems using ideas, models, conceptual and computational methods of physics. Although this definition seemed to gain ground as a compromise, and is found in a number of books and articles (Wang *et al.*, 2004; Rickles, 2007; Lux and Rosser, 2009; Rosser, 2008), an analysis of the themes studied by econophysics shows that research conducted in this field can be decomposed into two categories of works: "statistical econophysics" and "agent-econophysics" that we briefly present in the following section.

2.2 Two approaches in econophysics

The distinction between these two sub-fields has been suggested by Chakraborti *et al.* (2011a, b) and detailed by Schinckus (2013a). This distinction refers to the kind of physical methodology physicists extend to economics. Simply said, agents-based econophysics deals with microscopic models applied to heterogeneous agents while statistical econophysics rather focuses on macroscopic models describing phenomena through statistical macro patterns. Agent-based approach is not a strictly physics-emergent methodology since it appeared in the 1990s as a new tool for empirical research in a lot of fields such as economics (Axtell, 1999), voting behaviors (Lindgren and Nordahl, 1994), military tactics (Ilachinski, 1997), organizational behaviors (Prietula *et al.*, 1998), epidemics (Epstein and Axtell, 1996) and traffic congestion patterns (Nagel and Rasmussen, 1994). Basically, agent-based models can be looked on as an interdisciplinary approach (Epstein, 2006) dealing with so many fields that it is not possible to number them here[12]. The rest of this paper will only deal with statistical econophysics for two reasons: on the one hand, statistical econophysics holds a large part of the literature dedicated to econophysics and on the other hand, we will show how this computational approach is consistent with the methodology proposed by Mill to study economic phenomena.

Statistical econophysics comes from statistical physics and it is often associated to what we call "stylized facts" in the economic literature, and which refer to "empirical facts that arose in statistical studies of financial (or economic) time series and that seem to be persistent across various time periods, places, markets, assets, etc." (Chakraborti *et al.*, 2010, p. 994). For statistical econophysics, economic systems are composed of multiple components (non-adaptive agents) interacting in such a way as to generate the macro properties for systems (Rickles, 2008, p. 4). These macro properties can be characterized in terms of statistical regularities[13]. In opposition to economics or agent-based econophysics, statistical econophysics considers that only the macro level of the system can be observed and analyzed. Economic systems therefore consist of a large number of components (agents, traders, speculators, etc.) whose interactions generate observable macro properties that all components obey. Within this perspective, there is no modeling of the rational or/and individual behavior[14] and the main objective is to describe the past economic data through models whose ability to describe is implicitly associated with the explanatory dimension of the models (Schinckus, 2013b).

2.3 Econophysics and complexity

Describing socioeconomic system as complex systems suggesting the unavoidable result of bringing together numerous components in a non-simple manner is a methodological perspective shared by statistical and agent-based econophysicists. Both consider economic systems as an obvious candidate for the complexity treatment because these systems are composed by multiple components (agents) interacting in such a way as to generate the macro properties for economic systems and sub-systems (Rickles, 2008, p. 4).

Rosser (2003, 2006, 2008), Colander *et al.* (2008) and Mirowski (2012) provided a very interesting discussion about the interdisciplinary dimension of complexity and its influences on economics. Although complexity is a slippery concept, there exists a specialized literature dedicated to "complexity science" in which a lot of different conceptualizations are proposed: hierarchical complexity (Simon, 1962), algorithmic complexity (Chaitin, 1987), stochastic complexity (Rissanen, 1989), dynamic complexity (Day, 1994), computational complexity (Albin and Foley, 1998; Velupillai, 2000), etc. As reported by Horgan (1997, p. 305), Llyod has identified more than 45 definitions of complexity. However, whatever the complexity may be, a complex system might roughly be characterized as follows:

> By complex system I mean one made up of a large number of parts that interact in a non-simple way. In such systems, the whole is more than the sum of its parts, not in an ultimate, metaphysical sense, but in the important pragmatic sense that, given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer properties of the whole (Simon, 1981, p. 4).

By considering economic systems as macroscopic complex systems with an internal microscopic structure consisting of many interacting particles, econophysics is presented as field based on a dynamic complexity (Rosser, 2005, 2006). Schinckus (2013b) showed that this perspective must be detailed since econophysics can be associated with two different kinds of complexities referring to the two kinds of econophysics we presented in the previous section: the agent-based econophysics (whose aim is to reproduce past data) and statistical econophysics (whose objective is to describe past data). While the first is based on what we call a "small tent complexity," the second is rather founded on a more hierarchical complexity. This section aims to present a distinction between these two complexities by giving more details on the hierarchical complexity since it deals with statistical econophysics that we will associate with the Millian perspective of emergence and complexity.

2.3.1 Small tent complexity: from micro-interactions to emergence. Small tent complexity describes situations where a huge number of micro-interactions generate emergent properties. Although this definition is large, Arthur *et al.* (1997) identified six joint characteristics related to this specific complexity: dispersed interaction among locally interacting heterogeneous agents, no global controller who could exploit opportunities resulting from these dispersed interactions, cross-cutting hierarchical organization with tangled interactions, continual learning and adaptation of agents, novelty and mutations of the system and out-of-equilibrium dynamics.

Based on this categorization, Rosser (2008, p. 19) and Lux and Rosser (2009, p. 35) wrote that this "complexity can be seen to be very compatible with what is implied by many econophysics models." In line with these works, Schinckus (2013b) showed that agent-based econophysics deal with this "small tent complexity" defined by Arthur *et al.* (1997). Although we had to mention it here, this complexity and the kind of econophysics it implies (agent-based econophysics), we will not deal with it in this paper[15] which rather focuses on complexity related to statistical econophysics.

2.3.2 Hierarchical complexity: from regularities to emergence. Hierarchical complexity describes the functioning of a system composed by multiple levels of inter-related sub-systems[16] (Simon, 1962, 1996). Like the notion of complexity, the concept of hierarchy refers to several meanings discussed in a prolific literature (Lane, 2006) whose more famous works have been written by Simon (1962, 1996), Anderson (1972) and Holland (1999). This section presents major definitions of hierarchical complexity by beginning with the Simon's works completed by Anderson (1972) and Holland (1999). This evolution in the way of thinking complexity is necessary for understanding the complexity used in statistical econophysics (but also the one used in Millian perspective of complexity).

According to Simon (1962), hierarchy is a key concept in complexity since he defined "hierarchic system as one composed of multiple levels of inter-related sub-systems." In other words, distinctly operating sub-systems are combined to form a higher order operating system. By claiming that hierarchic systems have some common properties independent of their specific content, Simon (1996, p. 184) explained that self-organization and hierarchy are deeply interlinked[17]. In this perspective, the sub-systems interact with one another on an input-output basis meaning that their dynamics can change without impacting the system in its whole if they are able to produce the same outputs from different inputs. Although Simon developed a very coherent framework, the specialized literature emphasized the two main limitations to his definition of hierarchical complexity: on the one hand, it appears as a static structure (Holland, 1999) and on the other hand, it does not explain clearly the apparition of new levels (Anderson, 1972; Holland, 1999).

About this last point, Anderson (1972) provided a theoretical framework connecting complexity, hierarchy and emergence. According to Anderson (1972), emergence is the explaining phenomenon of hierarchy in complex systems. This author referred to the notion of scale in order to describe the organization of existing entities at each level of the system. A stimulated complex system creates interactions between entities and then new kinds of properties arise implying a new level of complexity based on what Anderson (1972, p. 393) called the "theory of broken symmetry." More precisely, these new properties change the system which needs not have all the symmetries of the laws that govern its constituents (Lane, 2006). By proposing this theory of broken symmetry, Anderson offered a specific law describing the phenomenon of emergence[18]. In this perspective, he wanted to explain the apparition of new levels. According to Simon, "the structure explains how complex systems works" (Lane, 2006) while Anderson rather presented the mechanism of emergence (characterized by the theory of broken symmetry) as the explanation of hierarchical complexity.

Holland (1999) continued the Anderson's idea since he provided "a setting in which emergence may be defined" (Lane, 2006, p. 91). For Holland, complexity is still a matter of structure but the apparition of new levels must be characterized through an emergence process.

More precisely, emergent properties result from complex relations implied by emergence that creates persistent regularities. A persistent pattern is a phenomenological regularity emerging from complex interactions of the system's components (Holland, 1999). Holland also used the term of "macrolaw" to describe an emergent regularity that makes no reference to the mechanisms and connection structure between individual elements of the system in which it arises[19]. The idea of persistence is important for Holland who emphasized this notion in his final chapter when he summarized in eight points his conclusion about emergence. He wrote (point 3) that "emergent phenomena are, typically, persistent patterns with changing components" and that "persistent patterns often satisfy macrolaws" (point 6). By associating emergence with a persistence (which structured the hierarchical organization of the system), Holland implicitly generated debates about the meaning of persistence which appears, in his book, like an "observed regularity" or a kind of "invariance[20]." Because statistical econophysics considered that regularities observed in complex systems are emerging patterns, Schinckus (2013b) explained that this approach of econophysics can directly be associated with hierarchical complexity enhanced by Holland (1999).

3. Mill and emergence

This section aims to present the Millian concept of emergence by focusing on what Mill called "heteropathic causation." The discussion proposed in this section will allow us to better understand the conceptual links existing between the Millian perspective of complexity and econophysics.

3.1 Classical emergentism

Emergence is a notorious philosophical concept that arises a lot of philosophical discussions (Kauffman, 1993; Hodgson, 1998; Jean; 1997). Often defined as the claim according to which "things can be greater than the sum of their parts," emergence can take various forms[21] depending on the kind of relation between entities (or properties) of a system. For Goldstein (1999, p. 50), emergence can be roughly defined as "the arising of novel structures, patterns and properties during the process of self-organization in complex system" (Corning, 2002). For Epstein and Axtell (1996), emergence refers to stable macroscopic patterns arising from local interaction of agents." Cunningham (2001, p. 62) reminds that emergence is an old idea that has been reemployed in the 1990s with the development of "complexity science" in which we observe a "re-emergence of emergence."

The idea of emergence dates back to the old British Emergenstism described by Alexander (1920) and Morgan (1923), Broad (1925) and of course, Mill (1843/1973). In the reductionist framework dominating science between the 1930s and the 1960s, emergentists proposed an opposite way of thinking since they claim that emergence referred to the properties of the whole which, on the one hand, cannot be deduced from the properties of the parts; and on the other hand, is not reducible to the laws governing these parts. In this perspective, emergence appeared as a macroscopic phenomenon with no micro-foundations. Epstein (2006, p. 32) emphasized that emergentists favored an "absolute unexplainability" and an "anti-scientific" meaning of emergence while Gregersen (2006) described the deistic and religious dimension of this definition. In the 1940s, Hempel and Oppenheim (1948, p. 568) explained that "this version of emergence is objectionable not only because it involves and perpetuates certain logical confusions but also because not unlike the ideas of neovitalism, it encourages an attitude of resignation which is stifling to scientific research[22]."

3.2 Mill and the concept of emergence

British Emergentists[23] of the late-nineteenth and early-twentieth centuries were the first to work on the notion of emergence and to provide a specific definition of this term[24].

The common question was to know whether macro properties of a system were reducible to its components or not. Mill (1843/1973), Alexander (1920), Morgan (1923) and Broad (1925) developed then some epistemological frameworks in response to this question of reducibility. In this paper, we focus especially on the Mill's stance by emphasizing why Millian emergence is close to the notion of emergence used in statistical econophysics evoked in the previous section.

The first definition of emergence[25] appears in the *System of Logic* written by J.S Mill (1843/1973, Book 3, Chapter 6, §1):

> All organized bodies are composed of parts, similar to those composing inorganic nature, and which have even themselves existed in an inorganic state; but the phenomena of life, which result from the juxtaposition of those parts in a certain manner, bear no analogy to any of the effects which would be produced by the action of the component substances considered as mere physical agents. To whatever degree we might imagine our knowledge of the properties of the several ingredients of a living body to be extended and perfected, it is certain that no mere summing up of the separate actions of those elements will ever amount to the action of the living body itself.

Mill extended his claim to inorganic systems and proposed a more general definition of emergence based on a non-reducibility of the macro level but also on a reject of what he called the "Composition of Causes." "I shall give the name of Composition of Causes to the principle which is exemplified in all cases in which the joint effect of several causes is identical with the sum of their separate effects" (Mill, 1843/1973, p. 370).

According to Mill, emergent properties are not subject to this law (Jean, 1997, p. 4). The distinction between emergent and non-emergent properties corresponds then to a distinction regarding two different ways in which conjoint causes can produce an effect: non-emergent properties are effects that can be viewed as a mere sum of the effects of each of the causal conjuncts while emergent properties are effects that are not a sum of the effects of each causal conjunct.

The Millian emergence is close to what Goldstein (1999, p. 50) calls "strong emergence" and Stephan (1999, p. 69) calls "diachronic emergence." This kind of emergence describes new properties arising in systems as a result of the interactions at an elemental level and these emergent properties are not reducible to the properties of components of the system. The main characteristics of a diachronic emergence are then novelty (new properties at a macro level) and irreducibility of the macro result. This way of conceptualizing the notion of emergence must be defined in contrast to a "synchronic emergence" that simply refers to a system within reducibility is conceivable[26].

Mill was the first to give a definition to the "compositional emergence" (Deacon, 2006, p. 122) that corresponds to a macro phenomenon that coming from non-simple interactions between lower level entities. This kind of emergence corresponds to an endogenous phenomenon that deterministically generates erratically dynamic results at higher levels of the system (Rosser, 2006, p. 1). Properties of the system are then fully defined by internal properties of its proprietary entity's components even if the first cannot be reduced to the sum of the latter (Cunnigham, 2001, p. 68). In this case, Mill explained that the system must necessary be studied through a macro perspective.

According to Mill, the chemical causation observed in the case of water is an example of "strong emergence" (called "compositional emergence"): "for example, two gaseous substances, hydrogen and oxygen, on being brought together, throw off their peculiar properties, and produce the substance called water)" (Mill, 1843/1973, p. 440), in other words, "the laws of the original agents cease entirely, and a phenomenon makes its appearance, which, with reference to those laws, is quite heterogeneous" (Mill, 1843/1973, p. 440). Water is then considered as a new fact that "may be subjected to experimental inquiry, like any other phenomenon; and the elements which are said to compose it may be considered as the mere agents of its production; the conditions on which it depends, the facts which make up its cause" (Mill, 1843/1973, p. 440):

> So, if we decompose water by means of iron filings, we produce two effects, rust and hydrogen: now rust is already known by experiments upon the component substances, to be an effect of the union of iron and oxygen: the iron we ourselves supplied, but the oxygen must have been produced from the water. The result therefore is that *t* water has disappeared, and hydrogen and oxygen have appeared in its stead: or in other words, the original laws of these gaseous agents, which had been suspended by the superinduction of the new laws called the properties of water, have again started into existence, and the causes of water are found among its effects (Mill, 1843/1973, p. 441).

According to Mill, emergence is still a matter of causality but it is a particular causality that he called heteropathic. Therefore, Millian emergence is a causal phenomenon based on a specific causality between lower and higher levels of the system. This point is important because despite emergists agreed on the fact that emergence is a macro result, these authors did not share the same explanation about link between micro and macro levels. According to Broad (1925), for example, Millian emergence is not a causal phenomenon as emphasized by O'Connor and Wong (2006):

> Mill's dynamical account of emergence differs from the synchronic, noncausal covariational account of the relationship of emergent features to the conditions that give rise to them that Broad was to espouse in *Mind and Its Place in Nature* (1925). Mill's account is thus an important precursor to the atypical dynamical account of emergence in the literature today (O'Connor and Wong, 2006, p. 23).

Among British emergentists[27], Mill implicitly used a compositional, dynamic and causal emergence in which the link between lower and higher levels can be characterized by a heteropathic causality that Mill defined as a breach of the principle of Composition of Causes:

> Though there are laws which, like those of chemistry and physiology, owe their existence to a breach of the principle of Composition of Causes, it does not follow that these peculiar, or as they might be termed, *heteropathic laws*, are not capable of composition with one another (Mill, 1843/1973, p. 375).

Heteropathic causality corresponds to a class of phenomena where the joint action of multiple causes is not the sum of effect of the causes acting individually[28]. Mill defined heteropathic causality in contrast to a homopathic causality (O'Connor and Wong, 2006) where the total effect of several causes acting in concert is identical to what would have been the sum of the effects of each of the causes acting alone. According to Mill, homopathic cause would be a mechanical causality which is in line with the principle of Composition of Causes while heteropatic causality would refer rather to a more chemical causality characterized by a violation of this principle[29].

Bedau (1997), Clayton and Davies (2006) and Francescotti (2007) explained that the notion of emergence[30] refers implicitly to a downward causation that can be found in the Millian framework (Stephan, 2002; Hendry, 2006). More precisely, Jean (1997) defined the heteropathic causality as downward causation:

> If we find a cause between the level n [or micro-level] and $n+1$ or [macro-level], there is no emergence because the latter is reducible to the first. In order to have emergence, a downward causality between $n+1$ and n must be found Jean (1997, p. 330).

Heteropathic causality is a top-down causation in which the macro result of the system restricts the micro levels' configuration. Downward causation takes place with higher level contexts influencing the outcome of lower level functioning. The components are then restricted once emergence properties appeared. The process of downward causality is the following: each microscopic state is undetermined but a macro property emerges and then the macro level of the system can be described through a statistical regularity which, in return, will restrict the micro levels configurations (i.e. we can deduce information about the micro levels only when macro properties are observed). A simple example is the brain interactions: the brain can control its atoms and molecules rather than the opposite (Clayton and Davies, 2006). Once having emerged from lower level, macro-process determines their components[31]. We can also mention an example from the economic theory of Mill which emphasized the influence of civilized society that changes the security of person and property.

4. Econophysics and the Millian perspective

As mentioned in the introduction, economists and econophysicists do not really dialogue preferring rather to adopt what anthropologists call a "scientific tribalism" (Bailey, 1977) which do not make impossible exchanges between communities as Bailey (1977) wrote it:

> Each tribe has a name and a territory, settles it own affairs, goes to war with others, has a distinct language or at least a distinct dialect and a variety of symbolic ways of demonstrating its apartness from others. Nevertheless the whole set of tribes possess a common culture: their ways of constructing the world and the people who live in it are sufficiently similar for them to be able to understand, more or less, each other's culture and even, when necessary, to communicate with members of other tribes. Universities possess a single culture which directs interaction between the many distinct and often mutually hostile groups (Bailey, 1977, p. 35).

This cultural ability of scientists to interact often generates the apparition of sub-disciplinaries (Becher, 1994). However, Galison (1997) explained that this kind of interactions between two scientific communities requires the development of a "pidgin" which refers to an interim language based on partial agreement on the meaning of shared terms (between involved disciplines) (Klein, 1990). In other words, a real collaboration between economists and econophysicists requires the integration of theoretical concepts used in each discipline in such way that the new shared framework will make sense in each discipline. As Farmer and Foley (2009), Rosser (2010) and Jovanovic and Schinckus (2013) emphasized it, such a dialogue could be fruitful for each fields for the development of a new theoretical tools. Although this kind of integration does not exist yet between economics and econophysics, this section paves the way for the potential elaboration of an interim language between these two fields. More precisely, we will show that several conceptual aspects used in statistical econophysics are consistent with the methodology proposed by J.S. Mill to study economic phenomena. Six arguments sustaining this claim are detailed in this section.

4.1 Emergence as invariance

When he observed emergent properties in a complex phenomenon, Mill explained that there is a constant characterizing the relation between micro states. More precisely, Mill wrote that:

> The different actions of a chemical compound will never, undoubtedly, be found to be the sums of the actions of its separate elements; but there may exist, between the properties of the compound and those of its elements, some *constant relation*, which, if discoverable by a sufficient induction, would enable us to foresee the sort of compound which will result from a new combination before we have actually tried it, and to judge of what sort of elements some new substance is compounded before we have analysed it (Mill, 1843/1973, p. 375).

Therefore, Mill implicitly considered that "something" is constant and can characterize the complexity of the observed phenomenon. In other words, according to Mill, although the sum of the actions of separate elements of a complex phenomenon cannot describe the macro level of the system, this macro level can be described through a constant relation between lower and upper states. In a sense, this constant relation allows us to give a meaning to this phenomenon. Moreover, Mill also emphasized the existence of an "constancy" in different social phenomena:

> Yet in any large country, the number of murders, in proportion to the population, varies (it has been found) very little from one year to another, and in its variations never deviates widely from a certain average. What is still more remarkable, there is a similar approach to constancy in the proportion of these murders annually committed with every particular kind of instrument. There is a like approximation to identity, as between one year and another, in the comparative number of legitimate and of illegitimate births. The same thing is found true of suicides, accidents, and all other social phenomena of which the registration is sufficiently perfect; one of the most curiously illustrative examples being the fact, ascertained by the registers of the London and Paris post-offices, that the number of letters posted which the writers have forgotten to direct, is nearly the same, in proportion to the whole number of letters posted, in one year as in another. "Year after year," says Mr. Buckle, "the same proportion of letter-writers forget this simple act; so that for each successive period we can actually foretell the number of persons whose memory will fail them in regard to this trifling, and as it might appear, accidental occurrence (Mill, 1843/1973, p. 932).

According to Mazlish (1988, p. 23), this idea that emergence can be associated with a constant relation (which implicitly appears as a scientific law) shows the positivist influences observed in Mill's works.

We have the same way of characterizing complex phenomena in statistical econophysics. Basically, this constant relation between compound and components evoked by Mill, corresponds to what we call today a scaling law, i.e. a constant ratio between the probability of observing an event of magnitude x and observing one of x'. This ratio does not depend on the standard or measurement; it is constant whatever the "scale of observation." In other words, when a system is characterized through a scaling law, a constant relation is then presupposed between components and the system. The emergence of a such constant relation is very important for economics and especially finance because it implies that statistical distribution do obey to scaling relations at different time horizons (daily, weekly, monthly, etc.). This concept of scaling allows us to describe a financial distribution through the same statistic features independently of time horizon.

These scaling laws evoked in the previous paragraph are statistical patterns resulting from complex interactions between microscopic states whose interacting individual behaviors cannot be described[32]. This importance of statistical regularities in complex phenomena can also be found in the eighth edition (1872) of Mill's treatise who have been acquainted with statistics thanks to Buckle's popularizing efforts (Morgan, 1990). In line with phenomenological regularities that Holland (1999) called macro laws, these regularities are presented as persistent patterns whose results are more than the mere sum of micro patterns governing all particles implying a specific case of the "theory of broken symmetry" defined by Anderson (1972) and summarized by Gallegati *et al.* (2006) when they explained the broken symmetry between the macro-configuration of a system and the micro states composing this system:

> […] (statistical) equilibrium of a system no longer requires that every single element be in equilibrium by itself, but rather that the statistical distributions describing aggregate phenomena be stable, i.e. in a state of macroscopic equilibrium maintained by a large number of transitions in opposite directions (Gallegati *et al.*, 2006, p. 22).

By associating emergence with no deducible, no reducible and no predictive macro laws[33], statistical econophysics provides a strong and synchronic emergentism in line with the classical British emergentism proposed by J.S. Mill.

4.2 The macro perspective

The macro perspective is very important in the Millian works. The economic phenomenon, for example, is so complex that Mill preferred to focus on "macroscopic effects" that result from the influence of the progress of society and government rather than on "microscopic effects." Indeed, although Mill (1843/1973, p. 879) wrote that "the Composition of Causes is the universal in social phenomena," he considered economics as a specific discipline that "may admit of being carved out of general body of the social sciences" (Mill, 1843/1973, p. 901). More precisely, Mill wandered economics from what he called the "political ethology" whose main objective was to define the "type of character belonging to a people or to an age" (Mill, 1843, p. 905). This field was supposed to study the influence of a macroscopic feature (example, the national character) on the behaviors of individuals.

Defining individual economic behavior only initiated by the motive for the "desire for wealth," economists did abstract the effects of "aversion to labor, and desire of the present enjoyment of costly indulgences" (Mill, 1843/1973, pp. 322, 902). However, as Persky (1995, p. 3) wrote, Mill is eager for a measure of the separate effects resulting from these two motives on the desire of wealth mentioning that it is a study which is too complicated and sophisticated to be studied from a strictly micro-perspective (Akdere, 2010)[34]. Mill (1843/1973, p. 330) thought that these effects "have not fallen under the cognizance of the science" but "our attention is not unduly diverted from any of them" (Mill, 1843/1973, p. 330). In a Millian perspective then, complex economic systems must be studied with a macro-approach in which "the qualities displayed by the collective body are able to judge what must be the qualities of the majority of the individual composing it" (Mill, 1843/1973, p. 902).

As previously explained, this preference for the macro-analysis is also essential in statistical econophysics where individual economic behaviors are seen too complicated and sophisticated to be individually studied. Only the statistical macro-regularities emerging from components' interactions can then scientifically be studied. These statistical patterns appear to be emergent properties founded on what Mill called a heteropathic causality that we detail in the following section.

4.3 The heteropathic perspective

Classical economics is based on a methodological individualism which presupposes a linearity and homogeneity of elements composing the economic systems (Colander *et al.*, 2008). Equilibrium, for example, often results from an addition of homogeneous maximizing behavior of individuals who are supposed to have the same expectations. Because the macro phenomena is reduced to the simple addition of individual behaviors, this approach can be considered as linear in a sense that it does not consider a potential endogenous emergence resulting from a complex interaction between elements. Colander *et al.* (2008) explained a lot of macro-concepts such as "market" or "systemic risk" are usually misunderstood in economic theory because these notions are based on an inappropriate causation[35]. Methodological individualism implies a homeopathic causation in which all macro phenomena result from the total effect of several causes acting in concert is identical to what would have been the sum of the effects of each of the individual causes (actors) acting alone (O'Connor and Wong, 2006). As previously explained, Mill emphasized the heterogeneity of causes through what he called a heteropathic causation referring to situations where the joint action of multiple causes is not the sum effects of the causes acting individually. In line with this perspective, statistical econophysicists presuppose an heterogeneity of interactions, all of which depend on the initial conditions (positions in the system) and the distance between particles[36]. For example, Donangelo and Sneppen (2000), as well as Shinohara and Gunji (2001), have approached the emergence of money through studying the dynamics of exchange in a system composed of many interacting heterogeneous agents. By developing a reciprocity model in which interactions between agents are asynchronous[37], these authors showed that fluctuations in exchanges can be quantified by through a non-Gaussian statistical pattern. More precisely, these authors provided a non-linear and heteropathic causality in which joint action (emergence of the same means of payment, money) of multiple causes (interactions between bartering agents) is not the sum of effect of the causes acting individually. Moreover, the dynamics of this joint action (emergence of money) can be characterized with a specific statistical macro-law. This way of dealing the emergent properties through a heteropathic causation is directly consistent with the Millian methodology presented in the previous part of this paper.

4.4 The downward causality

Heteropathic causation defined by Mill implies a downward causation which is also observed in statistical econophysics. As previously mentioned, econophysicists describe macro regularities emerging from a complex system in terms of statistics. Rickles (2007) explained how econophysics mainly use "power laws[38]" for characterizing macro patterns. More formally, a power law can be summarized as $p(x) \sim x^{-\alpha}$ (where $p(x)$ is the probability of there being an event of magnitude x and the scaling exponent α is a constant which is set by the empirically observed behavior of the systems). From a statistical point of view, these macro laws restrict the lower levels. In other words, the micro levels must be organized in accordance with a specific macro factor which is, for the power laws, the scaling exponent. More precisely, the scaling exponent α will restrict the micro level of data[39]. In other words, given the exponent α characterizing a complex system (whose micro states are undefined), we have information about the potential configuration of the micro level[40] (Kitto, 2006).

A less technical example can easily be found in arguments such as "stock market volatility made investors nervous" which conveys the impression that the higher level entity (the volatility of the market) partly determines how individual agents behave (McCauley, 2006). In other words, all fluctuations of this macroscopic volatility will determine the behavior of lower level actors in a system within micro-components are said to be determined by macro properties as Rickles (2008, p. 7) explained it:

> The idea is that in statistical physics, systems that consist of a large number of interacting parts often are found to *obey* "universal laws" – laws independent [causally] of microscopic details and dependent on just a few macroscopic parameters.

We can, for example, mention some works dealing with this downward causation in econophysics such as Chatterjee and Chakrabarti (2007) or Aoyama *et al.* (2011), who described complex economic systems (dynamics of competition between firms) through a specific network structure which directly influences all the subunits (companies).

4.5 The empirical argument

The importance of empiricism can be seen as another similarity between Millian framework and econophysics since both frameworks presuppose that complexity studies need an empirical approach. Facing to a chemical (complex) phenomenon, the empirical dimension appears to be, in a Millian framework, the only way to understand the emergence. While Thierry (1998, p. 157) explained that "Mill is an empiricist close to Macaulay" who "rejects the idea to found a knowledge on a general theoretical principles[41]," Smart (1999, p. 246) also stressed the empiricist dimension of Mill who claimed that heteropathic complexity must be empirically studied:

> In the cases where heteropathic effects is a transformation of its cause […] the problem of finding the causes resolves itself into the one of finding an effect which is the kind of inquiry that admits of being prosecuted by direct experiment"[42] (Mill, 1843/1973, p. 42).

According to Thierry (1998), the emphasis on the importance of empirical approach of Mill helped, at his time, to economics to declare its independence from moral philosophy. As Maricic (1992, p. 530) puts, "one of the task to accomplish, for J.S. Mill, here and there of boundaries of the discipline: it's to precise the nature of its scientificity."

In econophysics, “the real empirical data are certainly at the core of this whole enterprise [Econophysics] and the models are built around it, rather than some non-existent, ideal market [as in Economics][43]” (Rickles (2007, p. 6). Stanley (1999, p. 157) underline that, dimension by explaining that “in contrast to standard economics, econophysicists begin empirically with real data that one can analyze in some detail but without prior models.”

By starting with real data, econophysicists set empirical dimension in the heart of complexity studies. Because econophysicists continuously emphasize the necessity to develop data-driven models, their field is considered as a very empiricist one founded on a neo-positivist epistemology[44] (Schinckus, 2011). Although this data-driven methodology perspective is not really used in economics, it could be useful in economics as Colander *et al.* (2008, p. 11) explained it:

> We recommend a more dada-driven methodology. Instead of starting out with ad-hoc specification and questionable ceteris paribus assumptions, the key features of the data should be explored via data-analytical tools and specifications tests.

This section stressed that econophysicists and Mill seems to be on the same wavelength about the importance of empirical dimension in the study of complex economic systems.

4.6 The “free will” argument

According to Mill, the development and use of “free will” are the essence of political thought and it is also a necessity for science to take it into account (Heydt, 2006):

> Our will causes our bodily actions in the same sense, and in no other, in which cold causes ice, or a spark causes an explosion of gunpowder. The volition, a state of our mind, is the antecedent; the motion of our limbs in conformity to the volition, is the consequent.” (Mill, 1843/1973, III.v.11).

Despite the fact that econophysicists do not justify their approach by using a political argument, the statistical emergence they developed seems to be directly in line with political ideas of Mill. As Rosser (2003) explains, “econophysics formulations implicitly assume heterogeneous actors,” i.e., “large numbers of interacting subunits that display free will” (Amaral *et al.*, 1999). This link between the probabilistic nature of the laws of statistical (and quantum) mechanics and free will was developed by Majorana (1942) and summarized by Bouchaud (2002, p. 24) as follows:

> The statistical framework is particularly well adapted to describe the *free will* (real or supposed) of individuals. Each actor is at liberty to act as he/she wants according to personal and complex reasons that are difficult to understand. The collective behaviours, observed in their anonymous totality, have a regularity as we can find in physics.

Several authors (Liu *et al.*, 1997) have underlined this possibility to theorize individuals’ free will in econophysics. Artemi (2009) provides some analyses concerning the connection between econophysics and politics by providing a parallel between the statistical approach used in econophysics and democracy. Some econophysical models applied to game theory (Jimenez, 2004) try to parameterize this “free will” through the notion of entropy. This parameter is a measure of dispersion, disorder and uncertainty in the dynamic process (Dionisio *et al.*, 2005). In this perspective defining the micro complexity through the individual free will as econophysicists do it, could be seen as a Millian argument.

5. Conclusion: “Duality is not a story […] duality is a complexity” (E. Norton – *Fight Club* movie)

The last economic crisis called our ability to understand economic systems into questions. In this challenging context, a dual knowledge combining economics and physics could be very useful to better grasp the increasingly complex economic systems. Although some authors (McCauley, 2006; Schinckus, 2010a; Gingras and Schinckus, 2012) wrote that econophysics and economics are different fields, we claim in this paper that the methodology developed by the first is more embedded in the latter than econophycisits claim it. Indeed, whatever they pretend, econophysicists deal with notions that have already been studied in economics. This methodological paper shows how some key concepts used by econophysicists can be founded in economics and, more precisely, within the methodology developed by one the Father of Liberalism: J.S. Mill. In this perspective, the contribution of this paper is twofold, beyond emphasizing the contemporary relevance of Mill's methodology; it shows that conceptual bridges between economics and econophysics exist, favoring therefore the elaboration of a dual knowledge based on these two fields whose collaboration, in a challenging context, would not be superfluous in order to clarify economic complexity.

Notes

1. This paper will show that economists already know these concepts.
2. See Rosser (2008) on that point.
3. See PhysicsWorld.com.
4. New PhD programs in econophysics have recently appeared. Available at: phys.uh.edu/research/econophysics/index.php and Kutner and Grech (2008).
5. That Jovanovic and Schinckus (2013) called a "transdisciplinary approach."
6. We acknowledge the existence of other common methodological similarities; we just investigate here the case related to the notion of emergence developed by J.S. Mill.
7. There is a huge literature dedicated to the influence of physics on economics: Mirowski, (1989), Ingrao and Israel (1990) and Schabas (1990). For an excellent introduction to the analysis of methodology transfer between physical sciences and economics, see Le Gall (2002).
8. Let us mention some exception such as Fisher Black, for example, who was physicists but decided to "come" into financial economics. See Mehrling (2005).
9. Catastrophe theory originated with the work of the French Mathematician René Thom in the 1960s. It became popular in the 1970s as a result of the efforts of Christopher Zeeman (1974, 1977) who proposed the term "catastrophe theory." This theory is a special case of singularity theory, which is in turn the key of bifurcation theory, part of the study of nonlinear dynamical systems (see Rosser, 2007, for further information about this theory applied in economics).
10. This term was proposed by Serge Galam in a 1982 article. In his view, one of the reasons why physicists attempt to explain social phenomena stems from a kind of mismatch between the theoretical power of physics and the inert nature of its subject matter: "During my research, I started to advocate the use of modern theory phase transitions to describe social, psychological, political and economical phenomena. My claim was motivated by an analysis of some epistemological contradictions within physics. On the one hand, the power of concepts and tools of statistical physics were enormous, and on the other hand, I was expecting that physics would soon reach the limits of investigating inert matter" (Galam, 2004, p. 50).
11. The influence of physics on the study of financial markets is not new, as witnessed by the work of Bachelier (1900/1995) and Black and Scholes (1973). Nevertheless, we cannot yet refer to Black and Scholes' model as econophysics in the term's current meaning, since it was completely integrated into the dominant theoretical current of economics and finance (Kast, 1991). In opposition to the conceptual translation of heat diffusion process that Black proposed in his famous option pricing model (Black and Scholes, 1973), econophysicists do not translate physical concepts they are using into an existing economic framework.
12. See Chakraborti *et al.* (2011a, b) or Schinckus (2013b) for a detailed presentation of these approaches.

13. See McCauley (2004) for further information about the importance of macro-regularities in econophysics.
14. In this perspective, statistical econophysicists avoid the difficult task of theorizing about the individual psychology (or rationality) of investors since they do not care about rational agent theory or the personal characteristics (utility and so on) of individuals (Brandouy, 2005).
15. See Charkraborti (2011b) and Schinckus (2013a) for further details about agent-based econophysics.
16. Hierarchical complexity can be looked on as a necessary but not sufficient condition to have the "small tent complexity" (Arthur *et al.*, 1997).
17. Simon added that entities involved in complex systems can be decomposable through a vertical and a horizontal analysis (that the author compared this organization to Chinese boxes). Vertical interactions imply that entities interact with other entities from the same level of hierarchy while horizontal coupling means that entities "at a particular level tend to cluster into weakly interacting sub-systems whose detailed dynamics are independent of one another" (Lane, 2006, p. 85).
18. Before Anderson (1972), the only law characterizing the emergence referred to the classical emergentism and the fact that the whole is more than the mere sum of components.
19. For example of macrolaws, see Chapter 10 of Holland (1999).
20. See Lane (2006, p. 95) for a critical perspective of the Holland's definition of persistence.
21. See Cunnigham (2001) for a taxonomy of emergence.
22. The logical confusion emphasized by Hempel and Oppenheim (1948) refers to the fact that, for emergentists, emergent properties are not deducible from the micro ones. Hempel and Oppenheim (1948) explained that we cannot deduce properties. We can only deduce propositions in a formal language from other propositions formulated in this same language. If a macro-proposition (theory explaining the whole) contains terms that are not terms of the micro-propositions (theory explaining the parts) then of course it is impossible to deduce macro level from propositions from the micro theory. In this perspective, the "whole" is not deducible from parts for purely logical reasons and then, the emergence is trivially not a deducible concept. Hempel and Oppenheim (1948) and, more recently, Stephan (1992) showed that the non-deducibility is always relative to the proposition (i.e. to a specific formal language) used to characterize the micro and macro levels. There is no absolute or ontological emergence as the classical emergentists claimed it.
23. The expression "Bristish Emergentism" comes from McLaughlin (1992).
24. There were also emergentists outside the British tradition: The American philosopher Sellars (1922) or the pragmatist tradition with James, Dewey and Mead - see Stephan (1992) for a presentation of these frameworks.
25. Let us mention that Mill never used the term "emergence" which is attributed to the Philosopher of Science Georges Henry Lewes. However, in his work *Problems of Life and Mind* (1923), Lewes emphasized that this notion had been developed by J.S. Mill: "The concept of emergence was dealt with (to go no further back) by J.S. Mill in his *Logic* (Bk.III. Chapter VI. §2) under the discussion of 'heteropathic laws' in causation" (Sawyer, 2001, p. 553).
26. Let us mention that novelty is not a necessary condition for emergence (see Francescotti, 2007, p. 49).
27. Mill provided a dynamic view of emergence in which macro level of the system results from a non-simple process between lower levels. By contrast with Mill, Alexander (1920) and Morgan (1923) proposed a more static view emergence that appears then a simple macro-empirical fact (O'Connor and Wong, 2005).
28. This concept must not be confused with emergence that refers to a macro phenomenon whose result appears to be more than the sum of components' properties.
29. Let us mention that the Millian idea of emergence is directly derived from chemistry and not from physics. Physics was considered as the master discipline of science in which causality referred to

the sum of composing elements (i.e homopathic causality in Millian terms). In this perspective, chemistry appeared as the only field in which it was possible to observe a more complex (heteropathic) causality. This observation is not the case today since physics has been enlarged by sciences of complexity. That the reason for why we can study econophysics through a framework based on heteropathic causality.

30. Whatever the definition of emergence (synchronic or diachronic emergence), this concept is based on a downward causation (Francescotti, 2007).

31. "There are problems with the notion of downward causation, notably that any causal chain from an emergent property E to some property P of the subunits (which subunits, you will recall, form the "base" B "'generating" E) is underdetermined by the base itself, i.e. whenever there is E there is B (or something resembling B in terms of its causal powers and its ability to generate E-E being multiply realizable), so whenever we say that E "downwardly causes" P we might just as well say B causes P and dispense with the notion of downward causation altogether." (Rickles, 2007, p. 5). However, according to Hooker (2004) or O'Connor and Wong (2006), this problem disappears once we realize that emergence is a not a synchronic relationship between the subunits and the unit but a dynamical process (and hence a diachronic relationship)" (Rickles, 2007, p. 5).

32. In this statistical approach, agents are implicitly assumed heterogeneous because of the statistical mechanics models (Rosser, 2008, p. 15). It is worth mentioning that statistical physics is a broader field than thermodynamics in which all properties of micro states are well defined (Roehner, 2002). Econophysicists mainly refer to the contemporary statistical physics in which microscopic states are not necessary well known. While traditional thermodynamicists use statistics to describe the macro level resulting from the behaviors of a great numbers of defined microscopic states, econophysicists rather apply statistics in order to explain the behaviors of a lot of undefined micro states.

33. The predictability in econophysics must be understood in a very specific way: macro laws are not predictive (i.e. deduced or anticipated) because they must be observed from empirical data. The only thing statistical econophysicists are able to predict is that a statistical invariance will appear in specific complex systems but they are unable to predict the evolution of these complex systems. Statistical econophysicists are not able to define a priori the emerging invariance without observing empirical data. In this perspective then this emerging invariance is not predictable since it always appears from a historical analysis of data.

34. When the principles of political economy are to be applied to a particular case, then it is necessary to take into account all the individual circumstances of that case; not only examining to which of the sets of circumstances contemplated by the abstract science the circumstances of the case in question correspond, but likewise what other circumstances may exist in that case, which not being common to it with any large and strongly-marked class of cases, have not fallen under the cognizance of the science. These circumstances have been called disturbing causes. And here only it is that an element of uncertainty enters into the process – an uncertainty inherent in the nature of these *co*mplex phenomena, and arising from the impossibility of being quite sure that all the circumstances of the particular case are known to us sufficiently in detail, and that our attention is not unduly diverted from any of them.

35. Because economic activity is interactive in essence, this perspective is more appropriate for understanding the connections between all parts of economic systems (firms, banks, households). Moreover, all these elements can be seen as different structures having different characteristics in function of their "position" in the economic system or the kind of interaction they are submitted to.

36. In physics, particles interact through a field which usually decline with distance according to a particular inverse law.

37. Each exchange needs a reciprocal situation and must have a particular duration.

38. Epistemologically, econophysics is founded on the idea that statistical properties appear and reappear in many diverse phenomena but which can be expressed through a power law, as Stanley *et al.* (1996, p. 288) express it: "It is becoming clear that almost any system comprised of a large number of interacting units has the potential of displaying power law behavior.

Since economic systems are, in fact, comprised of a large number of interacting units has the potential of displaying power law behavior, it is perhaps not unreasonable to examine economic phenomena within the conceptual framework of scaling."

39. Indeed, even if they imply weak hypotheses (Mandelbrot and Hudson, 2004), scaling laws statistically restricted the data. Under very general conditions, only three possible limiting behaviors describe the categories of α:
    (1) There is a maximum value for the variable.
    (2) The distribution vanishes for values greater than this maximum and $\alpha < 0$. The tails decay exponentially and $1/\alpha = 0$ (as normal distribution, for example).
    (3) There are fat tails that decay as a power law with $\alpha > 0$. Power laws used in econophysics are often characterized by a slow decay of probability mass in the tails of the distribution (that is the reason for why these distributions are known as "fat tailed"). These characteristics restrict the data since they must be in one of these three categories (and especially the third if we want to describe a complex system with a power law). Another example of restriction of data : the fact that power law with $\alpha > 0$ is not integrable at 0 and with $\alpha \leqslant 0$, it is not integrable at infinity – that means that a power law distribution cannot be exactly true for a variable with an unbounded range (Farmer, 1999, p. 29).

40. This downward causation must not be confused with reducibility since the micro levels cannot be deduced from the macro patterns but we know that the latter confer statistical properties to the first.

41. We can draw an analogy between debates opposing economics and econophysics and the opposition between Mill and Bentham. Indeed, whereas Mill (econophysics) provided an empirical and inductive approach of knowledge, Bentham (economics) developed a more deductive framework based on an a priori (axiomatic) principles – for further information about this, see Akdere (2009).

42. See Akdere (2008) for further information about the notion of "experimental heteropathic laws."

43. For concerning debates about these oppositions between economics and econophysics, see Lux and Ausloos (2002), Rosser (2005), Gallegati *et al.* (2006) and McCauley (2006).

44. Although econometrics is sometimes presented as a positivist approach in economics, this positivist dimension in economics is overvalued from an epistemological perspective (Boland, 1997). See Schinckus (2010) for a detailed distinction between econometrics and statistical econophysics.

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