Generalized Darwinism and evolutionary game theory as a unified project

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Abstract: Evolutionary game theory and evolutionary economics are both fields with few interactions between them. However, we argue that generalized Darwinism as an ontological project and evolutionary game theory as a methodological tool pursue the same scientific endeavor. Because as a set of mathematical propositions evolutionary game theory is devoid of any empirical content, we show that evolutionary game theorists actually generalize Darwinian mechanisms to study biological and socioeconomic phenomena. This is precisely the ontological project of generalized Darwinism. Therefore, we point to the possibility of a cooperation between both fields, albeit in the historical perspective which is at the core of evolutionary economics.

Key words: Generalized Darwinism, evolutionary game theory, evolutionary economics, ontology, models interpretation.

JEL codes : B25, B41, B52, C73

1. Introduction

As a growing area which attracts an increasing number of scholars (Silva and Teixeira 2009), evolutionary economics is the subject of several methodological and theoretical discussions and controversies. Currently, there is an intense debate on the proper meta-theoretical framework needed to study evolutionary phenomena such as the growth of institutions or of firms. Proponents of generalized Darwinism (Aldrich and *al.* 2008 ; Hodgson 2002 ; Hodgson and Knudsen 2004, 2006a, 2006b) argue that the evolution of all complex systems of population respond to the three Darwinian principles of variation, retention and selection. The argument goes as follow: every complex system of population is made of numerous similar but non-identical entities which struggle in a context of relative scarcity. Entities that solve the better the different adaptation problems will reproduce at a bigger rate than those who are less efficient in these problem solving activities. Therefore, the structure of the population will progressively change. This explanation contains the three principles of variation – entities should not be identical and therefore some mechanisms have to generate variety, retention – entities should retain and pass on their strategies used to solve adaptation problems to their offspring, and selection – there is a differential rate of replication among entities in the population. Because those principles apply to every system of population at both the genetic and the socioeconomic level, every evolutionary explanation has to rely on those Darwinian principles.

This thesis is contested by several authors from different methodological and theoretical perspectives. The main one is the "Continuity hypothesis" (Cordes 2006, 2007, 2009 ; Witt 2003) which denies that evolutionary processes at the socioeconomic level follow the three principles of Generalized Darwinism. Socioeconomic evolution is founded on and constrained by (Darwinian) biological evolution but operates through completely different mechanisms. Ulrich Witt (2008) recently makes it clear in an attempt to categorize the different approaches in evolutionary economics. In the process, he also underlines the potential gain of trades between evolutionary economics and evolutionary game theory.

Here, we want to follow this path while focusing on generalized Darwinism. More precisely, we ask what are the convergences between the ontological project of generalized Darwinism (GD) and the theoretical one of evolutionary game theory (EGT) to study evolutionary phenomena at the socioeconomic level. We will show that though their starting point is not the same GD and EGT share the same goal and more importantly the same ontological and epistemological preconceptions. Therefore, they form a true unified project. In the process, we will also argue that when we acknowledge this last point, the disagreements between GD and the Continuity hypothesis largely disappear. The paper is organize as follows: in a second section we state that despite the absence of exchange, evolutionary economics and EGT share the same conceptual problems and objectives. We consider in a third section the ontological and epistemological preconceptions of GD. In a fourth part, we do the same for EGT. In a fifth part, we argue that the relation between GD and EGT is largely dependent of the question of the interpretation of game-theoretic model. We are able then in a sixth part to show that GD and EGT are lead to defend the same conception of evolutionary phenomena at the socioeconomic level and that as scientific project they converge at some conditions. We conclude in a seventh part by reflecting on the consequence of our argument on the methodological discussions ans theoretical orientations in evolutionary economics.

2. Evolutionary economics and EGT: Conceptual problems and objectives

Ulrich Witt (2008, 564) has recently observed that researchers in evolutionary economics and EGT barely make notice of each other. Despite its name, EGT's relations with evolutionary economics are ambivalent. For example, Silva and Teixeira (2009) in their bibliometric account of evolutionary economics treat EGT separately and distinguish it from the rest of the field. It takes no pain to show that works by evolutionary economists hardly appear in any work on EGT or using it[1]. The converse is also largely true: evolutionary economists sometimes use evolutionary game-theoretic models but again cross-references with works by evolutionary game theorists are anything but systematic. Nelson (2001) notes that EGT is more equilibrium oriented than evolutionary economics and has also less interest in empirical and historical problems. Those two points could explain why evolutionary economists are not attracted by the works in the EGT literature. In the same vein, one can argue that EGT has been imported in economics as a substitute for the research program of equilibrium refinements in classical game theory. This is what Robert Sugden (2001b: F217-F221) calls the "recovery program": the goal is to rediscover the results of classical game theory without its constraining assumptions about the rationality of the players. EGT is used for this prospect in an axiomatic fashion which seems to contradict the preconceptions of evolutionary economics.

These are probably good explanations for the failure of evolutionary economics and EGT to take notice of each other[2]. However it should not mean that some sort of cooperation or convergence is impossible. In fact, as Witt (2008: 564-5) argues in the case of what he calls naturalistic approaches in evolutionary economics and as we will show below in the case of GD, there *is* room for mutual cooperation. Beyond the differences underlined above, it should be noted that evolutionary economics and EGT share the same Darwinian roots. Though Joseph Schumpeter famously reject any Darwinian understanding of his evolutionary account of the economic process, other founding fathers of evolutionary economics like Thorstein Veblen (1898 ; 1899 ; 1914) or Richard Nelson and Sidney Winter (1982) quite the contrary claim to reintroduce the intellectual heritage of Darwin. For its part, EGT originates in the work of evolutionary biologists such as John Maynard Smith and George Price (Maynard Smith 1964 ; 1982 ; Maynard Smith and Price 1973) who use it as a way to formalize the Darwinian theory of natural selection. Moreover, it is fairly clear that EGT and evolutionary economics share the same interest in explaining evolutionary processes and discussing their property and consequences.

Nevertheless, it does not mean that evolutionary economics and EGT are perfectly isomorphic. Quite the contrary, evolutionary economics is clearly a more general scientific enterprise. As such, it overlaps ontological, epistemological, methodological, theoretical and empirical concerns. Ontological and epistemological questions in evolutionary economics are for example illustrated by the debate between GD and the proponents of the “Continuity hypothesis” (Vromen 2008). And, as for any research program, evolutionary economics has to determine the tools which are needed and how to use them (methodology), to state hypothesis and derive propositions from them (theory), and finally to use those theories to obtain insights about the empirical world. If we accept this classification, then it seems that EGT is restricted to the area of methodology and theory: it is a set of methodological tools because it offers some particular (and non exhaustive) ways of studying evolutionary phenomena; it is as its name indicate a theory because it relies on several hypothesis and gives rise to propositions which then can be tested empirically. However, *it does not mean that EGT is devoid of any ontological and epistemological content*. Quite the contrary, as Witt (2008) convincingly argues, EGT faces the same ontological and epistemological divisions than evolutionary economics. Evolutionary game theorists are typically agnostic on ontological and epistemological questions[3]. As a research program, EGT is not concern with ontological and epistemological debates. But to take position on these questions is irrepressible[4].

In summary, we have been able to show that evolutionary economics and EGT are overlapping research programs and have some common concerns. Since GD is an intellectual project primarily concerns by ontological and epistemological problems and EGT is primarily concerns by methodological and theoretical problems, we can argue two things: GD and EGT face different but complementary questions; *however*, because EGT as an ontological and epistemological content, the existence of gains from trade between it and GD is *prima facie* an open question. As such their mutual ignorance is not an answer to it. To answer this question we have to delve deeply in the ontological and epistemological presuppositions of both EGT and GD.

3. Ontology and epistemology in evolutionary economics: the case of GD

Approaches in evolutionary economics can be divided along their ontological stance, their epistemological (or heuristic) strategies and their methodology as Witt (2008) argues. This author notes that methodology is essentially a question of pragmatism: virtually all approaches in evolutionary economics use several tools to study socioeconomics phenomena and to take into account their historical dimension (historical narratives, quantitative studies, complexity modeling, etc.). Matters are different for ontological and epistemological commitments since each approach seems to have its own perspective. Witt proposes to distinguish respectively two ontological commitments (assumptions about the structure of reality) and two epistemological strategies (ways to apprehend reality and to conceptualize it). Because ontology and epistemology (heuristic) are independent, four possible configurations arise in the context of evolutionary economics (see Fig. 1 below):

Fig. 1: Ontological and heuristic commitments in evolutionary economics (Witt, 2008: 555)

	Ontological stance		
		Monistic	Dualistic
Heuristic strategy	Generalized Darwinian Concepts (variation, selection, retention)	**Generalized Darwinism**	**Neo-schumpeterians** (Nelson and Winter) topics: innovation, technology, firm routines, industrial dynamics, innovation, etc.
	Generic concepts of evolution (novelty, emergence & dissemination)	**Naturalistic approaches** (Veblen, Hayek, North) Topics: institutional evolution, production, consumption, long-run development, etc.	**Schumpeter**

We obtain what Witt considers to be the four major approaches (or clusters of approaches) in evolutionary economics narrowly defined (*i.e.* without including works in evolutionary game theory). Ontological stance describes how reality is structured, here in an evolutionary perspective. The dualistic perspective claims that natural evolution and social evolution are totally independent and different. This ontological perception makes one ignoring biological and genetic evolution when studying economic phenomena. The monist perspective consists in the idea that biological and socioeconomic evolution are related. There is an ontological continuity between those two realms but it doesn’t mean that they are identical. In fact, both GD[5] and what Witt calls the "naturalistic approaches" underline differences between the evolutionary processes in these two realms.

Heuristic strategies are the means by which evolutionary economists conceptualize evolutionary processes, that is concepts making possible a framing of reality. Witt proposes a distinction between two generic ways to frame evolutionary processes : the generalization of the Darwinian tryptic of variation, replication and selection on the one hand and the conceptualization of evolution as a process of novelty's discovery and dissemination on the other hand. The first heuristic strategy is due to Donald Campbell's works in evolutionary epistemology (see Campbell, 1965) and has been since imported in economics under the name of Generalized Darwinism (Aldrich and *al.*, 2008; Hodgson, 2002; Hodgson and Knudsen, 2004, 2006a, 2006b). Because Nelson and Winter (1982) have also used, in an analogical fashion, the concepts of variation, replication and selection to construct their evolutionary framework Witt considers that they adopt the same heuristic strategy than proponents of GD. The second heuristic strategy is reminiscent of what Witt and others have elsewhere called the "Continuity Hypothesis" (Cordes, 2006, 2007a, 2009; Witt, 2003). The basic thrust of this approach is that the generic features of any evolutionary process (emergence and dissemination of novelties) don't originate in works in biology and therefore is a true ontological generalization while Generalized Darwinism relies on an abstract analogy.

If the heuristic strategy of GD does not need more explanation, its ontological stance deserves some further considerations. Here, it is useful to distinguish between the evolutionary theories of *communality* and the theories of *interaction* (Hodgson 2009: xiv). The monism of GD means that biological evolution and socioeconomic evolution both lie on the same mechanisms. The mechanisms of variation, retention and selection are *common* to all ontological levels. However, as such a monistic ontology is agnostic on the question of the *interaction* between those levels. We could imagine that evolution at the socioeconomic level is independent of biological factors. Or one can argue the evolutionary processes at the socioeconomic level are constrained by it. This is precisely the claim of the "continuity hypothesis" which states that "*[c]ulture evolves following its own regularities on the foundations laid before by natural selection in the form of innate human dispositions*" (Cordes 2007a: 531). GD accepts this proposition (Hodgson 2007); in fact, it embraces the idea of multilevel selection perspective (Hédoin, forthcoming) which states that evolutionary processes and in particular selection operates at the level of the individuals but also at other levels such as the group. The theory of multilevel selection does not imply but allow the possibility of interdependencies between different levels of selection and more generally of evolution.

4. EGT and its ontological and epistemological presuppositions

It seems reasonable to use the same framework to distinguish the different approaches in EGT. In fact, Witt (2008: 562) argues that the same divide in ontological and epistemological strategies can be found in EGT as in evolutionary economics. However, this author does not provide us with the same graphical presentation and reduces the typology to two conflicting interpretations: a first one builds on an analogical interpretation of algorithms taken from evolutionary biology to study human learning processes. The formal background is that of the replicator dynamic. The second one is quite the contrary builds on a naturalistic interpretation: EGT is used to study evolutionary processes at the genetic level from which originate some of human preferences like altruism or some conception of fairness and equity. Witt (2008: 546) goes on to suggest that it could exist gains from trade between naturalistic approaches in both evolutionary economics (*i.e.* the continuity hypothesis) and EGT.

This validity of this argument depends of the truthiness of the ontological and epistemological criteria. We study this question in the case of evolutionary economics in the next section. Here we concentrate on EGT. If we try to reproduce the same chart as for evolutionary economics, then we obtain Fig. 2 below:

Fig. 2: The two approaches in evolutionary game theory

	Ontological stance		
		Monistic	Dualistic
Heuristic strategy	Analogical use of evolutionary game theory's concepts (replicator dynamic, evolutionary stability)		**Formalization of human learning processes** Ex : Fudenberg and Levine (1998), Sugden (2005), Young (1998)
	Use of evolutionary game theory to explain genetic origins of preferences (altruism, moral)	**Naturalistic evolutionary game theory** Ex: Bergstrom (1995), Binmore (1994, 1998), Gintis and *al.* (2005,ed)	

The upper left cell and the lower right one are empty: a dualistic ontology implies an analogical use of evolutionary game theory's concepts like replicator dynamics while any use of evolutionary game theory to study the genetical origins of preferences relies on a monistic (naturalist) ontology. We have add for each approach some works which might be representative. Sugden's (2005) and Young's (1998) study of human coordination through conventions typically use evolutionary game theory to analyze learning processes. However, this use is devoid of any biological content as both authors make clear. Still following Witt's typology, Binmore's (1994, 1998) study of the evolution of human's fairness norms and Gintis and *al.* (2005, ed) work on strong reciprocity are of a naturalistic sort: in both cases fairness norms and strong reciprocity originate in the history of human genetic evolution.

If we accept this presentation, then it seems that GD and EGT have nothing in common and therefore are independent projects. It should be noted that because here ontological stances and epistemological strategies are not independent, this argument holds on the distinction between analogy and naturalism. As we want to show that GD and EGT are actually a unified project, we have to demonstrate that this distinction is dubious. It is easy to see that the whole argument lies on a crucial assumption: EGT is a methodological tool whose primary application is in the biological domain. When it is applied to study evolutionary processes at the socioeconomic level, EGT should be understood as an analogy or a metaphor, not an actual projection of the mechanisms it describe to the socioeconomic world. But it brings a question whose answer is not straightforward: is EGT a methodological tool whose natural domain of application is biology? In fact, an analogy consists to underline the partial resemblance between two domains. Then, if the use of EGT is analogical only in the case of socioeconomic phenomena, it means than we consider biology as the natural domain of application of EGT. This demonstration is dubious as it can be shown by focusing on two majors evolutionary game-theoretic concepts : replicator dynamic and evolutionary stable strategy[6].

a) Replicator dynamic

Replicator dynamic has been proposed as a simple model to study the dynamic of evolutionary games by Taylor and Jonker (1978). In its simplest, continuous time form, it can be wrote as follows :

(1) $$\mathrm{d}p/\mathrm{d}t = p[e_x(p) - \bar{e}(p)]$$

Here, p is the fraction of the population who adopts strategy x; $e_x(p)$ is the payoff yields by strategy x as a function of the value of p at some definite time[7]. Finally, $\bar{e}(p)$ is the mean payoff in the population as a function of p. If there are only two strategies x and y, then $\bar{e}(p)$ is simply $[p.e_x(p) + (1 - p).e_y(p)]$. Replicator dynamic indicates that the growth of a given strategy in a population is a (linear) function of its relative fitness, that is the difference of payoffs it yields with the mean payoffs in the population. More generally, it states that the mean behavior in a population is a function of the degree of variety in behavior across the population (Metcalfe 1994: 329). This equation can enriched to take into account some specificities. For example, a more complex version can look like this (Bowles 2006: 73):

(2) $$\mathrm{d}p/\mathrm{d}t = \omega p \beta [e_x(p) - \bar{e}(p)]$$

Parameters ω and β respectively measure the fraction of the population which can update its strategy and the sensitiveness of individuals to the difference of payoffs between strategies. Under reasonable value for these parameters, the enriched version of the replicator will behave in a similar fashion to the simple one, but the pace of the dynamic can be significantly altered.

As such, replicator dynamic is a mathematical expression which expresses the growth of a particular variable as a function of other variables. It emerges in a discussion about stability properties of some games' equilibrium in the context of various cases of animal conflicts as those studied by Maynard Smith and Price (1973) and Maynard Smith and Parker (1976). However, *prima facie* there is no biological content or implication in it. In fact, at the beginning of their article, Taylor and Jonker (1978: 146) wrote about the dynamic they used:

> "*The basic idea is this: the more fit a strategy is at any moment, the more likely it is to be employed in the future. The mechanism behind this is either that individuals tend to switch to strategies that are doing well, or that individuals bear offspring who tend to use the same strategies as their parents, and the fitter the individual, the more numerous his offspring. In any case, as time goes on, the strategy mix may change*".

Strategies and payoffs could be interpreted in several ways. In a biological perspective, payoffs express biological fitness, that is the number of offspring an individual will have. Strategies then are seen as phenotypical traits which organisms bear. Alternatively, in a more cultural or social fashion, payoffs could be the expression of some social, economic or cultural value of a strategy. The bigger this value, the more probable the strategy will proliferate in the population by imitation or some other transmission mechanism. In this case, strategies are behavior (or ideas or any other cultural or socioeconomic items) whose replication depends of their cultural fitness. Is this second interpretation an analogy ? It is not obvious why it must be so. It is true that replicator dynamic (and EGT as a whole) has been primarily and essentially developed to study biological evolution and animal behavior. However, as a mathematical expression, it has no empirical content; there is only one underlying empirical assumption behind replicator dynamic, namely the fact that it exists some transmission mechanisms which allow the retention and the replication of the strategy. There can be little doubt that such mechanisms are ubiquitous in the natural and the social worlds[8].

By the way, since the 1980's replicator dynamic has been regularly used by economists and social scientists to study *cultural* evolution with no reference to biological evolution (for example Bowles 2006 ; Skyrms 1996, 2004 ; Sugden 2005). In those works, replication of strategies occur no through reproduction and genetic transmission but through (phenotypical) *imitation*. For example, Brian Skyrms (2004: 21) writes: "*This [replicator dynamic] arose in biology as a model of asexual reproduction, but more to the point here, it also has a cultural evolutionary interpretation where strategies are imitated in proportion to their success*". Nowhere the term "analogy" arises. In fact, to use replicator dynamic to study cultural evolution is *not* an analogy since as such it has no biological content. More precisely, to use replicator dynamic in this way is no more an analogy than to use it to study biological evolution. However, the heuristical value of replicator dynamic *is* an empirical question both in biology and in economics (and sociology, anthropology, etc.). Empirical works in biology seem to indicate that it is a good approximation of biological dynamics, at least when some assumptions are verified (Schuster and Sigmund 1983). The value of replicator dynamic to understand socioeconomic evolution is still an open question. J.S. Metcalfe (1994: 329) explicitly indicates that he uses replicator dynamic as a *mathematical* expression which as no biological origins. He treats it as a good proxy of the industrial dynamic in the case of market competition. Several works has also shown that replicator dynamic fit well with some kind of cultural evolution (Skyrms 2000). Authors such as Robert Sugden (2005) have however suggested that replicator dynamic ignores important questions such as those of salience. We will return to these question in the sixth section. Other formal expressions have been proposed to study economic evolution and learning dynamics. For example, Peyton Young (1998) constructs models build on fictitious play and best reply dynamics. In this case, individuals are assumed to maximize expected utility given their knowledge of a fraction of their previous interactions in the history of the game. However, best reply and replicator dynamic can reach very similar results (Lesourne, Orlean and Walliser 2002, chap. 3).

b) Evolutionary stable strategy (ESS)

ESS is an important concept of stability introduces by Maynard Smith and Price (1973). An ESS is a strategy such that, if all members of a population adopt it, no mutant strategy could invade the population through some selection process (Maynard Smith 1982: 10). More formally, evolutionary stability can be expressed through two mathematical conditions of uninvadability (Maynard Smith 1982: 14). A strategy *a* will be evolutionary stable if and only if at least one of the two following conditions is satisfied:

(3a) $$U(a,a) > U(b,a)$$

(3b) $$\text{if } U(a,a) = U(b,a), \text{ then } U(a,b) > U(b,b)$$

We define $U(i,j)$ as the fitness of strategy *i* when opposed to the strategy *j*. Here, *b* is any mutant strategy that could invade a population dominated by the strategy *a*. Those two conditions simply state that a strategy is evolutionary stable if it does better against itself than any other mutant strategy *or*, when there is at least one mutant strategy which does as well, if it does better against the mutant strategy than the mutant strategy against itself. ESS is still the major concept of evolutionary stability used in EGT because despite of its relative simplicity it is relatively robust (in general, equilibrium in EGT are ESS). Maynard Smith and Price (1973) formulate this definition in the context of animal contests. Therefore it has a straightforward biological interpretation along some specific assumptions: infinite population, asexual reproduction, symmetric contests between two opponents. When one of these assumptions is not verified, then the above definition of ESS is no longer true[9].

The fact that the ESS concept has a biological flavor is clear from the use by Maynard Smith of the term “fitness” in a clear biological meaning. However, as for the case with replicator dynamic, the definition of the ESS concept is a set of purely *mathematical* conditions. It has no empirical content other than the conditions given above and which equally apply in a cultural context[10]. The function $U(.,.)$ above needs not to be a biological fitness function. We could interpret it, as in the case of replicator dynamic, as a function which measures the propensity of a strategy or a trait to be *imitated* in the next period. Or we could argue that it expresses monetary payoffs and that strategies reproduce as a function of those monetary payoffs. Again, the proper interpretation is an empirical question but *prima facie* the concept of ESS is no more legitimate in evolutionary biology than in evolutionary economics. One should be attentive not to conflate the historical origin of a scientific concept with its ontological and heuristic meanings.

The fact that both replicator dynamic and ESS are formally devoid of any biological content means that evolutionary game-theoretic models of cultural/socioeconomic evolution are no more analogy than those of biological evolution. In other words, we could equally says that when one uses an evolutionary game-theoretic model to study animal conflicts or any genetic or biological related questions, he is making an analogy with the socioeconomic world. We tend to be surprised by such a statement because *historically* evolutionary models of cultural evolution have been constructed by mimicking biological models through the importation of EGT in economics. However, biology *has not logical priority* over economics (or any other social science) to use evolutionary game-theoretic models. This statement is even more stronger when we compare models done by evolutionary biologists with those of economists. Robert Sugden's (2009) interpretation of Maynard Smith and Parker's (1976) model of asymmetric contest in the case of animal behavior is suggestive. He proceeds to a comparison of the way in which Maynard Smith and Parker use their model and relate it to the empirical reality with that of Banerjee's (1992) model of herd behavior. Sugden convincingly shows that the relation between the empirical reality and the model is the same in both works. *A propos* of those two papers and of two other seminal papers in economics (Akerlof's market for lemons and Schelling's model of racial segregation), Sugden (2009: 16) writes:

> "*In each of these four papers, the central contribution is a theoretical model (or set of models). Each model is a fully-specified, self-contained and counterfactual world. The authors show that (human or animal) behaviour in their models is governed by certain mechanisms or exhibits certain regularities. We, the readers, are invited to conclude that we have been given some additional reason to believe that mechanisms or regularities similar to those in the models will be found in the real world; but the authors seem reluctant to say what that reason is. Although the model world and the real world are both discussed, very little is said explicitly about the relationship between one and the other*".

Maynard Smith and Parker, in their study, abstract themselves from many of the complexities of the empirical world. Notably, they make the assumption of asexual reproduction which permits the use of the concept of "evolutionary stable strategy". More generally, Maynard Smith and Parker's analysis is very dried in that it makes many simplifying assumptions regarding the number of strategies and the transmissions mechanisms by which strategies reproduce themselves. As Sugden (2009) shows, it is only towards the end of their article that the authors explicitly confront their model to the reality to make sense of it. What is example shows is that biologists use evolutionary game-theoretic models in a similar fashion than economists use their models, evolutionary or not. To make the analysis tractable, they abstract from many empirical details. Therefore, if it's true that economists generally use replicator dynamic as a convenient device to formalize human learning processes, biologists largely do the same thing. As Sugden (2009) argues, they construct *counterfactual world*s which are similar in significant respects to the empirical one, but not more. This brings us to the problem of the interpretation of evolutionary game-theoretic model and how it relates to the ontological perspective of GD.

5. GD and the interpretation of evolutionary game-theoretic models

In the preceding section, we tried to make an important point: *there is a logical independence between the formal structure of EGT as a set of mathematical theorems and propositions and its empirical content*. This claim can be made clearer if we acknowledge the crucial role of narratives in the process of evolutionary game-theoretic models elaboration and interpretation.

Till Grüne-Yanoff and Paul Schweinzer (2008) argue along the same line for game-theoretic models generally[11]. The authors argue that any game-theoretic model is the product of three components: the theory proper, the game form and the model narrative. The theory proper specifies the concept of a game, provides the mathematical elements that are needed for the construction of a game form, and it offers solutions concept for the then constructed game form (Grüne-Yanoff and Schweinzer 2008: 135). The game form and the model narrative associate to form the game-theoretic model. As such, the model relates the theory to the empirical world. The game form is simply the matrix or the tree which represents the basic interaction which is to be modeled and explained. The game form rests on two things: first, the theory proper which provides the mathematical theorems and propositions to construct the model. Second, the game form needs a narrative to connect with the empirical world. Narratives are stories which provide an understanding of the situation to observers through common language. But the model narrative is not a simple translation of game theoretic language in plain English (or another language for that matter). It serves the crucial role of specifying the precise context in which the theory will be used and makes the link with reality. In other words, it gives the model its empirical content. As Grüne-Yanoff and

Schweinzer (2008) make clear, one should not underestimate the importance stories play in applying game theory to empirical problems.

Our argument made in the preceding section can now be reformulated in a more precise way. Replicator dynamic and ESS are part of the theory proper. They are mathematical expressions and express analytical truths. For instance, if we identify fitness with rate of replication, then *by definition* entities with higher fitness expands faster than entities with a lower fitness (Grüne-Yanoff and Lehtinen 2007). The same minimal definition of fitness gives the ESS concept the same analytical truth. In other words, EGT as a theory is a set of mathematical propositions. To use it to study evolutionary phenomena, it is necessary to construct models. The narrative takes an essential place at this point because it gives an interpretation of the model in regard to the empirical phenomena it aims to explain. The example of the Maynard Smith and Parker's (1976) paper studied by Sugden (2009) provides a great illustration: the game theoretic model is construct along several assumptions and put in perspective with an empirical fact (animal contests). As Sugden shows, it is not required that the story perfectly fit the empirical world but only that it gives an interesting vision of it *from a particular point of view*.

We can extend this argument by saying that any stylization of reality through theoretical lens necessarily relies on abstraction of the "*as if*" kind. The narrative precisely serves the function to justify the abstraction. This is of a decisive importance for the ontological and epistemological meaning of EGT. We can make this clearer with the example of the hawk-dove game described below (see Fig. 3):

Fig. 3 : The Hawk-Dove game

		B	
		Hawk	Dove
A	Hawk	(V - C)/2 ; (V - C)/2	V ; 0
	Dove	0 ; V	V/2 ; V/2

With V < C we have the hawk-dove game (or "chicken game") with two pure Nash equilibria (Hawk ; Dove) and (Dove ; Hawk) and a Nash equilibrium in mixed strategy where a player plays Hawk with a probability of V/C. The last one is also the sole evolutionary stable equilibrium. This game is particularly interesting because evolutionary biologists have used it quite frequently to model animal contests. But economists also have used it to illustrate the emergence of conventions of property (see for example Sugden 2005: chapter 4). If the same game form can be used to study such different empirical phenomena as animal behavior and human conventions, it is necessarily the narrative which is different. The story which permits the interpretation of the model will be constructed by identifying the players, by defining what precisely “hawk” and “dove” mean and by specifying what is the meaning of payoffs. If the game is used to study a biological phenomena, then payoffs will be given in biological fitness. In the case of a socioeconomic application, payoffs could be monetary gains or express some probability to be imitated.

The story can be made a little bit more complicated by considering an asymmetric version of the game. For example, one of the player could be identified as the “owner” and the other the “intruder”. This allows new strategies such as Maynard Smith’s (1982) “bourgeois strategy”[12]. The asymmetric version of the hawk-dove game is particularly useful because it allows a story of how property conventions could have emerged both in the animal and the human worlds. However nobody imagine that such a story is a precise description of the empirical world, animal or human. But its justification is heuristic: it provides a sensible way to understand a particular aspect of several phenomena despite the fact that they are very different. Narratives serve the function of offering different interpretations of the same formal reasoning.

Because every (evolutionary) game-theoretic model needs a narrative to be useful for the study of the empirical world, we are led to the conclusion that the distinction between naturalism and analogy is a distraction. *Every* game-theoretic explanation is built on an abstraction which leads to make an analogy between the model and its components (theoretical propositions, game’s form and narrative) and the empirical world. This is what Sugden (2009) calls “models as credible world”. The story serves to make the model more credible, but this is true in evolutionary biology as well as in economics. As such, the use of evolutionary game theory to study biological phenomena is not much “natural” than to study cultural or socioeconomic one. One can argue that the details of the working of replication and mutation differ greatly between the social world and the biological one. But as a rule, evolutionary game-theoretic models generally treat these mechanisms in a quite abstract manner, even when they directly apply to genetic phenomena. This is an important point for GD and evolutionary economics. GD defines the three principles of variation, retention and selection very loosely. The sources of variations could be intentional or random. The precise workings of retention is not explained, only an assumption of continuity between a parent and its (cultural or biological) offspring is required. Finally, selection is simply the product of a differential rate of replication. This principle is empirically empty and can be stated in a pure formal way[13].

As we have shown in the preceding section, the same generality applies in EGT. The mutation mechanism it describes is independent of the cognitive capacities of the players since it is a purely mathematical definition. We have note that different formal expressions can be used to model selection (replicator dynamic, best reply). Replicator dynamic is only a subclass of *qualitatively adaptive dynamics.* According to those types of dynamics, a strategy that is not extinct increases its proportion in the population if its fitness is higher than the population average (Skyrms 2000). This is a fairly loose class of dynamics which can be expected to fit with a fairly large number of phenomena – biological or cultural. The common element is the core mechanism of differential replication which is always present – which is inevitable since selection is *by definition* differential replication. This leads us to the conclusion *that applied EGT could be interpreted as a generalization of Darwinism*: it proceeds by a form of ontological expansion and generalization of some very abstract mechanisms, in a similar manner than GD. We could say then because those mechanisms have first been first in the study of species their application to socioeconomic phenomena is analogical or metaphorical. But this claim is rhetorical and is analytically inoffensive as Vromen (2008) makes it clear in the case of GD.

We are therefore lead to considerably reduce the difference between GD and the "Continuity hypothesis". In fact, Ulrich Witt (2003 ; 2008) argues that the "heuristic strategy" of the Continuity hypothesis is to view all evolutionary phenomena as the result of two mechanisms of emergence and dissemination of novelties. However it is not clear how these two mechanisms are different from those of variation and selection. In fact, from the point of view of EGT, they are formally equivalent : emergence *is* mutation and dissemination *is* selection. The same mathematical expressions could expressed these concepts; only the rhetoric (and so the narrative) around really changed. It is not clear however how different these stories really are in substance[14]. Is therefore evolutionary economics and EGT formally identical? We argue that the answer is negative in the last section.

6. Evolutionary economics as an historical approach

Since we argue that EGT is a kind of generalization of Darwinian mechanisms and that GD and the Continuity hypothesis are formally equivalent one could think that EGT and evolutionary economics (at least in its monistic form) conflates. However, a key difference remains between the major part of the literature in EGT and evolutionary economics: the scientific goal which is pursued. In fact, EGT is originally a tool constructed in a clear empirical and historical perspective. EGT is largely a product independent from the development of game theory since Von Neumann and Morgenstern's *Theory of Games and Economic Behavior*[15]. Its elaboration is primary the result of a search for a theoretical tool useful to study empirical questions. Hence, as Maynard Smith (1982: 8) wrote:

> "*There are two kinds of theories which can be proposed: general theories which say something about the mechanisms underlying the whole process, and specific theories accounting for particular events.(…) [evolutionary] game theory is an aid to formulating theories of the second kind; that is, theories to account for particular evolutionary events. More precisely, it is concerned with theories which claim to identify the selective forces responsible for the evolution of particular traits or groups of traits*".

It is clear from the above citation of its founding father that EGT is empirically oriented. It is a tool build to make case studies, not grand theory of some kind. But since economists have imported EGT in their field, we have seen a dramatic change in perspective. This the "recovery program" as Sugden (2001b) has named it. Some major game theorists have seen in EGT a remedy to overcome some of the major difficulties faced by the equilibrium refinement research program in classical game theory. Hence, Sugden (2001a) argues that the "evolutionary turn" in game theory has not radically change the field of game theory. In other words, economists have transferred their axiomatic theoretical project to EGT. This is pretty clear in both Fudenberg and Levine (1998) and Young (1998) where the principal result is that stochastic learning games permit to "rediscover" some important results from classical game theory. Larry Samuelson (2002: 58) also underlines that one of the major result of EGT has been to provide a motivation for Nash equilibrium[16].

This axiomatic orientation of EGT in evolutionary economics could explain the mutual ignorance of both fields as Nelson (2001) notes. Evolutionary economics has always been cautious regarding axiomatic work *per se*. As part of the broad historicist-institutional-evolutionary tradition in economics[17], evolutionary economics takes seriously the historical dimension of socioeconomic phenomena. This historical orientation is clearly compatible with both GD and the Continuity hypothesis and joins Sugden's (2001a) appeal to a more empirically-oriented use of EGT in economics. As well as EGT is a tool for evolutionary biologists to conduct natural case-studies, EGT can be a tool for evolutionary economists to conduct case studies in several domains : evolution of norms and institutions, evolution of routines and industries, etc. Therefore, we can offer a new picture of the relations between EGT and evolutionary economics (see fig. 4 below):

Fig. 3: Gains from trade between evolutionary economics and evolutionary game theory

	Ontological stance in evolutionary economics		
		Monistic	Dualistic
Heuristical use of evolutionary game theory	Explanation of historical specificites and processes	**Materialistic and historical evolutionary Economics** Generalized Darwinism and Continuity Hypothesis	**Schumpeterian and Neo-Schumpeterian Economics**
	Axiomatization and theoretical refinements	**Materialistic and axiomatic evolutionary game theory** Ex: Bergstrom (1995), Binmore (1994, 1998)	**Evolutionary game theory and learning processes** Ex : Fudenberg and Levine, Young (1998)

The grey area in the above figure symbolizes the more promising encounter between evolutionary economics and evolutionary game theory. The term “materialistic” should be understood in the Darwinian sense of a continuity between different ontological level. On the side of evolutionary economics it regroups both GD and the Continuity hypothesis since we argue that those approaches can accommodate with evolutionary game theory as a methodological tool. On the side of evolutionary game theory, we find works using game theory in a non axiomatic fashion to explain historical processes. What count is not the naturalistic perspective (*i.e.* to use evolutionary game theory to study biological evolution) but the aim and the narrative which surround the use of the game theoretic tool. Since, as we have showed above, evolutionary game theory is devoid of any empirical content *per se* it makes it compatible with both Generalized Darwinism and the Continuity Hypothesis. In fact, when studying evolutionary phenomena in a non axiomatic fashion, we could argue that evolutionary game theorists *de facto* generalized Darwinism without acknowledging it. It is probably not a coincidence that scholars who use evolutionary game theory in this way are also prone to use agent-based modeling, a methodological tool sometimes used by evolutionary economists in general and proponents of Generalized Darwinism in particular (*e.g.* Hodgson and Knudsen 2008). This pattern as a straightforward explanation : agent-based modeling, unlike analytical modeling, do not aim to prove theorems but is rather oriented towards the discovery of patterns and emergent properties (Axelrod 1997: 4). This is an objective shared with evolutionary economics and also institutional economics (Wilber and Harrison 1978). This is therefore probably at this intersection that most of the gains from trade between evolutionary economics and evolutionary game theory are to be found.

7. Conclusion

We have argued that GD, as an ontological project, and EGT as a methodological tool, are for a large part a unified project. This is clear once we recognize that despites its name EGT is not particularly biologically grounded but is a theory whose models can be interpreted is several ways. We have showed that as such the mechanisms that EGT formalize are identical to the principles of variation, retention and selection which are at the core of GD. The only caveat we have formulated is that EGT should be used outside the "recovery program" in a more historical perspective.

This last point is important because since EGT and GD can be unified into a large ontological-methodological-theoretical approach, they also have to face the same challenges. To finish the paper, we would like to formulate two of them. First, in biology, the biological content of EGT is given when the Mendelian laws of genetics are introduced. This laws empirically state the process of replication in biology. Evolutionary game-theoretic models often abstract from these laws even in biology but to gain a better understanding of socioeconomic evolutionary processes, social scientists will have to work to find transmissions laws at the cultural level. Progress have already been made with the work of evolutionary anthropologists (Boyd and Richerson 1985 ; Heinrich 2004 ; Richerson and Boyd 2005) and evolutionary economists as well as evolutionary game theorists could integrate their insights in a more systematic fashion.

Secondly, one of the peculiarity of socioeconomic phenomena is their interpretative dimension. As Sugden (1998) notes, contrary to the biological world interpretation and pattern-recognition is an essential feature in socioeconomic interaction. It gives the concept of salience an importance to understand the evolution of some norms or conventions. In addition to Sugden's (1998) work on this question, the analysis of the French school of the Economics of Convention (Dupuy and *al.* 1989) offer an interesting interpretative approach of norms and institutions and which could be inserted in an evolutionary framework.

End notes

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(1) See, for example, the bibliography of works like Fudenberg and Levine (1998) or Vega-Redondo (1996).

(2) See below.

(3) At least, they generally avoid any ontological and epistemological discussions.

(4) Lawson (1997) makes this point forcefully in the case of ontology.

(5) Witt (2008) uses the terminology « Universal Darwinism » in his article. However, since proponents of this approach (see Aldrich and *al.*, 2008) reject that term and prefer the denomination “Generalized Darwinism” we follow this last convention.

(6) EGT is the formalization of two mechanisms (Hargreaves-Heap and Varoufakis 2004) : a selection mechanism and a mutation mechanism. Replicator dynamic and evolutionary stable strategy are the respective more frequently used concepts to formalize those mechanisms. Note however that other concepts are sometimes used. For example, best reply and fictitious play (Fudenberg and Levine 1998 ; Young 1998) are alternative ways to formalize selection, though it frequently give similar results. Alternative evolutionary stability concepts such as stochastic stable strategy are also possible. In both cases, our argument could be extended to these alternatives.

(7) This assumption guarantees that payoffs are frequency-dependent as this is the case in EGT. Note that we are here in the simplest case where there are only two strategies in the population. With more than two strategies, we would wrote $e_i(S)$ with $S = (p_1, p_2 \dots p_n)$, $\sum p_i = 1$ the state vector of the population. Then, the fitness of some strategy *i* would be the function of the state of the population S.

(8) A second empirical assumption is that the population should be large such as the effect of chance averaged on the long term. Here again, social population are no different of biological population on this point.

(9) Maynard Smith (1982: 20-27) reviews these assumptions and proposes an extended definition of the concept of ESS when the payoff of a strategy is a function not of the strategy of a single opponent but of some average property of a population. In this case, we say that

individuals “play the field”. Maynard Smith (1982: 24) shows that a strategy *A* will be evolutionary stable if either of the following conditions is satisfied:

$$U(A,A) > U(B,A)$$

or, if $U(A,A) = U(B,A)$, then for a small q,

$$U(A,P_{q,B,A}) > U(B,P_{q,B,A})$$

with $P_{q,B,A} = qB + (1 - q)A$.

(10) One could ask what “asexual reproduction” means in a cultural context. In fact, cultural evolutionary model where the behavior of an individual (its phenotype) is determined by at least two cultural variants inherited from two or more cultural “parents” can be constructed. See for example Bergstrom (1995) and some models in Boyd and Richerson (1985). Therefore we differentiate between cultural evolutionary models where individuals acquired a cultural variant from only one individual from those where cultural variants are inherited from at least two individuals.

(11) The authors don’t study evolutionary game theory specifically. However their general argument can be extended to it.

(12) The bourgeois strategy can be described as follows: if owner, then always play hawk, if an intruder, then always play dove. It also exists a perfectly isomorphic strategy which Bowles (2006) calls the “Robin Hood” strategy. Interestingly, both strategies are evolutionary stable.

(13) Proponents of GD invoke the Price equation to defend their claim. The Price equation states that selection consists in the evolution of the value of some quantitative (phenotypical) trait in the population as the result of two additive effects: a selection effect and a transmission effect. The selection effect is the expression of a covariance between some quantitative value of the trait and the fitness value related to it. The transmission effect is the expected fitness value for an existing individual given a change in the quantitative value of his trait. As Knudsen (2004) notes, the Price equation depicts a selection principle devoid of any empirical content and can therefore be used to describe a large range of evolutionary phenomenas. Only two conditions are required for selection to operate : the confirmation of the retention principle and the relative stability of both the environment and elements which

are selected for. For deeper reflections on the Price equation and its application in economics, see Hodgson and Knudsen (2004a) and Knudsen (2004).

(14) Geisendorf (2009) convincingly makes this point. She also shows that the distinction between "internal selection" and "external selection" on which Witt relies to reject GD is largely artificial.

(15) The names of Von Neumann and Morgenstern are cited only once (at the very first page) in Maynard Smith's 1982 classic.

(16) However, note that the same author see empirical research as a promising field for EGT.

(17) Recall that both Schumpeter (see Shionoya 2005) and Veblen were both influenced by the German Historical School.

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