two faces of the same georgescu-roegen: from path-dependency and the imperfection of the human mind to institutional change and biophysical constraints*

duas dimensões do mesmo georgescu-roegen: da dependência da trajetória e imperfeição cognitiva humana às mudanças institucionais e restrições biofísicas

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Abstract

This paper claims that Georgescu-Roegen's intellectual trajectory is continuous in the sense that two elements from his "early works" (1930-1954), namely "path-dependency" and the "psychological threshold", are embedded on the limited cognitive abilities and the importance of "time". Thus, these concepts are the seeds of his "later works" (after 1970), when he

Resumo

O presente artigo argumenta que a trajetória intelectual de Georgescu-Roegen pode ser interpretada como um desenvolvimento contínuo, uma vez que subjacentes a dois elementos de seus trabalhos entre 1930-1954, quais sejam "path-dependency" e "psychological threshold", estão as limitações cognitivas dos seres humanos e a importância do "tempo". Destarte, esses conceitos estão

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attempts to reformulate economics by combining elements of economic development, institutional change and biophysical constraints. This is not a switch of interest, but rather a more mature version of his early writings grounded on the same epistemological stance. We highlight his distinction of "arithmomorphism" and "dialectics", his criticism of the "mechanistic epistemology" of neoclassical economics, and show that this clings to his introduction of entropy as the material basis of life.

Keywords: Path-dependency. Cognitive limitations. Entropy. Arithmomorphism. Dialectics.

fundamentados nos mesmos preceitos epistemológicos de seus trabalhos pós-1970, em que o autor propõe a reformulação da economia através da incorporação de restrições biofísicas, para se pensar em desenvolvimento econômico e mudanças institucionais. Destacam-se sua distinção entre "arithmomorphism" e dialética, sua crítica à "epistemologia mecanicista" da economia neoclássica e em que medida isso se relaciona à sua utilização do conceito de entropia.

Palavras-chave: *Path-dependency*. Limitações cognitivas. Entropia. *Arithmomorphism*. Dialética.

Introduction

During the interwar period, microeconomics was a plural field, with the integrability problem being a source of continuous controversy in which a number of approaches were proposed (Hands, 2006, 2009). Nicholas Georgescu-Roegen (henceforth G-R) was sceptical in what regards the assumptions underlying the *homo economicus*. More specifically, he claimed that human beings lack cognitive abilities to the extent necessary for the transitivity of choices to hold.

Our main claim is that G-R's "later works" (after 1970) draw on two central elements of his "early works" (1930-1954): the "psychological threshold" and "path dependency". Paramount to these concepts is the imperfection of the human mind and the importance of time (in the sense that history matters). G-R's search for "a theory moulded on a type of individual that really exists and not on a 'necessary and sufficient' one" (G-R, 1936, p. 587) is observable throughout his career. Although his later works did not focus on psychological issues *per se*, his epistemological stance does not change throughout time (*i.e.*, human beings have cognitive limitations).

As a caveat, the present paper refrains from normative considerations and we leave it as an open question whether economics should be reformed, and, if so, whether G-R offers a blueprint to rethink economics. Rather, our main interest is historical and our account has the much more modest goal to show the evolution (and continuity therein) of

G-R's ideas throughout time. The comparison between his "psychological" and "bioeconomic" works reveals his attempt to address economic problems on a broader canvas than his earlier works through his all-embracing theory of economic development, institutional change and biophysical constraints while keeping his critical methodological stance towards the *homo economicus*.

The work is organized as follows. Section one presents a brief account of the integrability problem. This provides the background for the second section where G-R's early works are assessed. Section three argues that G-R's later works share the same epistemological stance as his earlier works. The last section offers some final thoughts.

1. Integrability: the long road from preferences to utility

This section briefly assesses the integrability problem in order to provide some background for next section, since the psychological issues raised by G-R were motivated by this problem.

Hands (2009) argues that in the 1930's, endowment effects, reference dependence, and irreversibility of preferences were framed upon the integrability problem. The question was whether or not one could assume "the existence of stable well-ordered preferences as the basis for a theory of choice behaviour" (Hands, 2009, p. 12). In this sense, in order to derive the utility function from preferences, the latter would have to be non-reversible and endowment independent.

Hands (2006) divides integrability in a broad sense, prior to 1950, and in its narrow formulation gradually developed after 1950, which came to dominate microeconomics textbooks. Integrability was "once a portmanteau word that carried a wide range of criticisms and concerns, integrability was systematically transformed into a mathematical restriction on demand functions" (Hands, 2006, p. 153).

According to the author, integrability encompassed issues such as the order of consumption, path-dependency and global well-orderedness. Among the critiques, there were differences as to whether demand theory should be abandoned, slightly or greatly reformed. Although this debate "was seldom about exactly the same thing for any two different authors, it was never just about a mathematical restriction", it was em-

bedded in diverging "empirical, methodological, conceptual, mathematical, and even ontological" aspects of consumer choice (Hands, 2006, p. 169-170). Armstrong, in a similar vein, notes that "with regard to the nature of utility, the form of the utility function, and the way the indifference-class [...] is determined by the utility function, there are grave differences of opinion" (Armstrong, 1939, p. 454).

Mathematically, the question was whether or not indifference curves could be integrated from the differential equations expressing the marginal rate of substitution between goods. Evans, for instance, was sceptical of this possibility, arguing that even if one observes the marginal rate of substitution for a particular point, one "cannot extend it beyond a merely local field unless we are willing to make some transcendental hypothesis about the existence of such functions" (Evans, 1930, p. 122)[1]. The mathematical issue apart, for the purpose at hand what matters are the psychological assumptions about the human being's cognitive abilities which are necessary for a utility function to be built from preferences.

As G-R (1936) has shown, integral surfaces are not equivalent to indifference curves, for two points in a same integral surface may not be indifferent. Hence, the mathematical solution to the integrability problem does not solve the economic problem, *i.e.*, the mathematical solution concerns integral surfaces, but it does not imply that indifference curves can be derived from preferences.

G-R's argument was that the mathematical solution only extends to indifference curves if one assumes that preferences are transitive in the sense that $x > y \wedge y > z \Rightarrow x > z$. Nonetheless, his claim was that human

[1] There were a number of authors working on the integrability problem during this period and this it is not the place to provide an account of the different approaches proposed by them. A more detailed investigation of the mathematical issues involved can be found in Evans (1930). For a discussion of how psychological aspects relate to the integrability problem, see Armstrong (1939, 1948, 1950) and Bernardelli (1938, 1952). Notwithstanding the central role of psychological elements on the works of Armstrong and Bernardelli, we were only able to find one mention from G-R (1954) to Armstrong (1950), where he partially disagrees with him. Armstrong, Bernardelli, and G-R share too many elements, not only among each other, but also with recent developments in behavioural economics, to be dealt with here. We refer to Evans, a mathematician, and to Armstrong, an anthropologist who moved to economics later on his life (Gregory, 2004), as an illustration of the different quarters from which the integrability problem was criticised.

being's cognitive abilities are not sufficiently acute as to guarantee that the transitivity postulate holds.

Next section discusses the psychological elements in G-R's early works. For now it is suffice to notice that his critical stance towards Walras' attempt "of forcing human nature into the rigid frame of mathematical structure" (G-R, 1950, p. 125)[2] is strictly related to the integrability problem. The long road from preferences to utility necessarily goes through psychological considerations, he argued, only to be ignored by those who eventually "solved" the problem[3].

2. Georgescu-Roegen's early works: psychological threshold and path-dependency

This section highlights two central elements of G-R's early works, namely the "psychological threshold" and "path-dependency"[4]. His scepticism towards the integrability problem was due to these two ideas.

The "psychological threshold" introduced a stochastic element in the decision making process. The human being is subject to "errors of perception" (G-R, 1936) and time is included in the model. In a nutshell, the probability of choosing A over B, given that A is preferred to B, is a direct function of time. Thus, he argues that there is always some probability of choosing a less preferred good, although the probability of making mistakes decreases as one experiences a good more frequently

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2 It is out of the scope of this paper to discuss Walras, but it should be noted that this criticism is misdirected. Walras distinguished pure, applied and social economics and whereas G-R's criticism may apply to Walras' treatment of pure economics, it does not hold for Walras' discussion of applied and social economics. We would like to thank an anonymous referee for pointing that out.

3 As argued by Hands, "the key move in Samuelson 1950 was to shift the empirical basis of consumer choice theory [...] the key methodological move of making the demand functions themselves (the original explanandum) the observables for consumer choice theory was retained in all of the subsequent literature [...]. This move did not solve the problem – or, for that matter, even try to solve it – it just changed the question" (Hands, 2006, p. 171-172).

4 Although he does not use the expression "path-dependency", we use the concept for ease of exposition since he claims that history matters in the sense that, as the consumer moves through the choice-space, his experiences constantly change.

and/or for a longer period. Nevertheless, the probability of making an error would never be zero, rather it tends to zero as time tends to infinity.

In referring to this difficulty of comparing different goods he uses the expression "errors of perception". In this sense, the individual is able to choose among goods that he consumes, say on a daily basis, with a low probability of making an error. Put it differently, in the realm of choices familiarity does not breed contempt (G-R, 1936, p. 568-572). Regarding the implications of the "psychological threshold", he states that

> the individual's behaviour appears therefore as a resultant of two different types of measurement: a physical one, which is supposed to tell him the exact amounts of commodities, and a psychological one, which is his possibility of comparing satisfactions. (G-R, 1936, p. 572)

In 1950 he comes back to this point, stressing the importance of the time element in economic analysis when discussing the ophelimity postulate, which nowadays is called the completeness axiom, adding in a footnote that "it is rather curious that this time aspect of the problem has never been considered by the pioneers of marginal utility. The case they apparently had in mind was that of a consumer with perfect knowledge" (G-R, 1950, p. 129).

Path-dependency was an important theme of G-R's early and later works, in contrast to what has become the dominant view after 1950 in which the consumer is always in equilibrium and only moves virtually through the choice space.

G-R analyses the implications of the consumer moving from an initial position (or bundle) in his "preference direction" (G-R, 1936, p. 565-568); as one moves through the choice space, one's preferences would constantly change due to the experiences he has along the way. Thereby, the level of utility of a given bundle is subject to path-dependency, since previously consumed bundles affect the perceived utility of any given bundle. He illustrates this by means of a metaphor in the *International encyclopedia of the social sciences*:

> In the theory of binary or multiple choice, man's choice is analogous to that of a bird which, after surveying from above a large piece of ground, dives directly at the most preferred spot. In the theory of directional choice, man's choice is rather like that of a worm which, from any position,

chooses some direction and then moves along it. There are reasons to believe that the latter approach may be the more realistic. (Sills, 1968, p. 255)

Whereas in his early works he analyses the implications of path-dependency in the decision making process, in his later works his scope of analysis shifts from "micro to macro"[5], yet path-dependency plays an important part on his account of institutional change. History matters and he champions dialectical studies. The time element, thus, pervades his intellectual journey. It is the basis of his psychological threshold concept and path-dependency, as argued in this section, and underlies his later criticism of neoclassical economics, as next section shows.

3. Beyond psychology: G-R's later works

G-R, in his later works, shifts from trying to fix economics to suggesting that economics by itself would not suffice given the complexity of the world and the cognitive limitations of the human mind. Accordingly, in what follows we examine his later works (1970, 1971, 1977, 1979), stressing that he relentlessly sought a plural approach to economics after 1970, broadening considerably his approach by incorporating elements of economic development, institutional change, and biophysical constraints. More specifically, our point is that although he shifted from "micro to macro" (from consumer choice to an evolutionary analysis of the economic process), his mature writings, particularly his seminal work *The entropy law and the economic process*, draw on many of his previous ideas.

Our argument is partially similar to Gowdy and Mesner's claim that G-R's early works on pure theory and his later concerns with entropy and bioeconomics should be understood as an unbroken path:

[5] In his later works he still champions the "study of economic units", however he now suggests that it must be combined with studies of "entire economies": "The basis of knowledge cannot be reduced to either the whole alone or to the parts by themselves. The biologist must study molecules and cells and organism, just as the economist must study the economic units and the entire economies" (G-R, 1971, p. 14).

> From his earliest published work in the 1930s until his death in 1994, G-R insisted that descriptions of economic phenomena, especially mathematical descriptions, must go beyond relative market prices. They must be grounded in reality, that is, in the physical and social universe of which humans are embedded. (Gowdy; Mesner, 1998, p. 138)

Maneschi and Zamagni, in a similar vein, suggest that there is a connection between G-R's earlier and later works, by arguing that his theory of consumer behaviour

> offers some initial cues for his epistemological orientation [...] choices are always partly the result of hysteresis phenomena [...]. This led Georgescu to analyse the role of time in economic inquiry, and make a fundamental distinction between dynamic *vs.* historical time on the one hand, and qualitative *vs.* mechanical on the other. (Maneschi; Zamagni, 1997, p. 699)

We agree with Gowdy and Mesner on the continuity of G-R's intellectual trajectory, however their argument that what defines his methodological stance is that the analysis "must be grounded in reality" falls short in that it raises (but does not answer) a series of methodological issues regarding "realism". Thus, we argue instead that the continuity of G-R's work is rendered more intelligible when it is cast in terms of the cognitive limitations of the human mind and the importance of time (in the sense that history and evolution matter) as pervasive elements scattered throughout his works.

Whereas in his early years he criticised Walras' attempts "of forcing human nature into the rigid frame of mathematical structure" (G-R, 1950, p. 125), in *The entropy law and the economic process* he claims that the "rigid frame" of mathematics and logic imposes limits not only to mainstream economics but to science in general:

> Opposition to Walras' and Jevons' claim that "economics, if it is to be a science at all, must be a mathematical science," has not failed to manifest itself. But, in my opinion, during the ensuing controversies swords have not crossed over the crucial issue. For I believe that what social sciences, nay, all sciences need is not so much a new Galileo or a new Newton as a new Aristotle who would prescribe new rules for handling those notions that Logic cannot deal with. (G-R, 1971, p. 41)

In his seminal work, entropy assumes the highest possible rank in economics;"the material basis of life is an entropic process" (G-R, 1971, p. 10). Entropy is the "material basis" of life and "thermodynamics is largely a physics of economic value" (G-R, 1971, p. 276). This is a combination of Marxism and thermodynamics, since "like Marx", he sees "social conflict" as rooted "in material human conditions" (G-R, 1971, p. 306). Unlike Marx, he claims that "man's entropic struggle" (G-R, 1971, p. 307) is the material basis of life. Therefore, as argued by Maneschi, although he was deeply influenced by Marx[6], "whom Georgescu-Roegen cited most frequently in his books (1966, 1971, 1976) [...] his attitude toward Marx alternated high regard with sharp critique" (Maneschi, 2006, p. 106). Whereas Marx saw communism as capable of ending social conflict, for G-R social conflict derives from the entropy law and it is thus an inherent condition of mankind.

The entropy law states that the "the entropy of the universe (or of an isolated structure) increases constantly [...] there is a *continuous* and *irrevocable* qualitative degradation of free into bound energy" (G-R, 1971, p. 6). Everything in the universe starts with free energy (low entropy) and eventually transforms this free energy into bound energy (high entropy). The important point is that this process is "*continuous* and *irrevocable*", as a corollary, the economic process is evolutionary and there is no theory without history. Moreover, what physics teaches economics is that the methodological choice depends on the nature of the problem, the implication of the economic process being evolutionary is that "mechanics" does not provide a proper framework to analyse it:

> classical mechanics is mechanistic because it can neither account for the existence of enduring qualitative change in nature nor accept this existence as an independent fact. Mechanics knows only locomotion, and locomotion is both reversible and qualityless. (G-R, 1971, p. 1)

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[6] Maneschi (2006, p. 111) enumerates seven main influences of Marx over G-R: (1) the idea that the economy is an open system; (2) the distinction between dialectical and arithmomorphic concepts; (3) the importance of time, since the economy is an evolving system; (4) the shortcomings of mainstream economics; (5) economics should be based on the institutions of the "real world" instead of analysing isolated individuals; (6) Marx's concept of "constant capital"; (7) the production process must include the length of day.

G-R's critique was inspired by his methodological claim that economics should be embedded in a thermodynamic approach rather than a mechanical one, this is the gist of his distinction between "arithmomorphic model" and "dialectics". Since "not every element of the economic process can be related to a number [...] this process cannot be represented in its entirety by an arithmomorphic model" (G-R, 1970, p. 1). The economic process is dialectical in the sense that economic phenomena cannot be discretely separated from the environment "by a boundary consisting of an arithmomorphic void" (G-R, 1970, p. 2).

The author claims that the entropy law can be regarded "from an epistemological viewpoint [...] as the greatest transformation ever suffered in physics" (G-R, 1971, p. 9). Economists, notwithstanding, mostly ignored it. Thus, they embraced the concept of utility as if wants were reducible to mathematics:

> The complex notion of economic development has been reduced to a number, the income per capita. The dialectical spectrum of human wants (perhaps the most important element of the economic process) has long since been covered under the colorless numerical concept of "utility" for which, moreover, nobody has yet been able to provide an actual procedure of measurement. (G-R, 1971, p. 52)

Since desire and disdain overlap, wants are "dialectical concepts" in the sense that "they have no arithmomorphic boundaries; instead, *they are surrounded by a penumbra within which they overlap with their opposites*" (G-R, 1971, p. 45). Utility, on the other hand, is arithmomorphic since numbers are "a *distinct individuality*" (G-R, 1971, p. 45), subject to the principle of contradiction, *i.e.*, that B cannot be both A and non-A. Ergo, he proposes that dialectics should be used as *the* alternative to "arithmomorphic schematization":

> The undeniably difficult problem of describing qualitative change stems from one root: qualitative change eludes arithmomorphic schematization. The leitmotiv of Hegel's philosophy, [...] is apt to be unpalatable to a mind seasoned by mechanistic philosophy. Yet the fact remains that Change is the fountainhead of all dialectical concepts. [...] What makes "want" a dialectical concept is that the means of want satisfaction can change with time

and place: the human species would have long since vanished had our wants been rigid like a number. (G-R, 1971, p. 63)

Wants cannot be expressed by utility, or numbers, because they are dialectical, which means that (1) they change over time, (2) they are not precisely definable and its meaning overlaps with its antonym and (3) their complexity is such that a one-to-one correspondence between numbers and wants is not possible:

> Real numbers are not always sufficient for cataloguing a set of qualities. In other words, the manifold of our thoughts differs from the arithmetical continuum not only by its indivisible continuity but also by its dimensionality. As we say in mathematics, the continuum of the real number system forms only a *simple* infinity. (G-R, 1971, p. 76)

It is precisely the discussion of human wants *vis-à-vis* his arithmetical representation as utility that connects his later writings with his early works on the problem of integrability, the limits of human cognitive capacity, and the importance of time. The recurrent use of wants to illustrate difficulties of the arithmomorphic schematization supports the argument put forth on the present paper. The fact that he constantly refers to his previous works on the theory of choice on his seminal work (1971) is further evidence of the connection between the two faces of G-R.

The limits of logical formalism in representing the continuum are discussed by G-R using as illustration Borel's arithmetical continuum. This continuum, being formed only by discrete numbers, cannot appropriately represent the intuitive continuum, which is a dialectical concept with overlapping elements. The structure of the intuitive continuum, as suggested by Poincaré, is such that it is possible that $A = B$, $B = C$, but $C > A$[7]. In the reign of pure logic and formal mathematics, this is nonsense. Wants – or dialectical concepts in general – cannot be represented via arithmomorphic models by definition:

> The point is that an arithmomorphic simile of a qualitative continuum displays spurious seam that are due to a peculiar property of the medium chosen for representing that continuum. The more complex the qualitative

[7] See G-R (1971, chapter 3).

> range thus formalized, the greater the number of such artificial seams. For the variety of quality is continuous in a sense that cannot be faithfully mirrored by a mathematical multiplicity. (G-R, 1971, p. 79)

The first explicit appearance of his "later" ideas can be found in G-R (1954). In this paper, the author summarises his conclusions from previous works such as the "imperfections in the mechanism of choice caused by a psychological threshold" (G-R, 1954, p. 522) and the importance of time, since "*man* is a continuously changing structure" (G-R, 1954, p. 506). Moreover, he sketches some arguments which he would further develop in his later works. G-R differentiates "wants" and "utility" and argues that "there are no means for testing assertions involving the *continuum*" (G-R, 1954, p. 510). That is, wants are not translatable in utility without great loss of meaning, "the Jevons-Walras team [...] oversimplified with great enthusiasm the behavior of the individual by placing all his economic actions under a *unique* motor: utility" (G-R, 1954, p. 510). As hard as it may be to define precisely these "wants", it is pointless to substitute them by the also ambiguous concept of "utility":

> Lack of precise definition should not, however, disturb us in moral sciences, but improper concepts constructed by attributing to man faculties which he actually does not possess, should. And utility is such an improper concept, supported by other undefined concepts such as wants, uses, etc. (G-R, 1954, p. 512)

During the '70s all these points were further developed. He insisted that dialectical concepts are vague, but useful. The entropy law, for instance, does not determine exactly when something will happen, nor what will happen in a closed system, however it determines "the general direction of the entropic process of any isolated system" (G-R, 1971, p. 12). For the sake of clarity, G-R does not deny the importance of mathematics and logic to scientific inquiry, his point is that reducing social analysis to one single method is not the best way to proceed:

> Let me hasten to add that the usual denunciation of standard economics on the sole ground that it treats of "imaginary individuals coming to imaginary markets with ready-made scales of bid and offer prices" is patently inept [...]. In the social sciences, as Marx forcefully argued, it is all

> the more indispensable since there "the force of abstraction" must compensate for the impossibility of using microscopes or chemical reactions. However, the task of science is not to climb up the easiest ladder and remain there forever distilling and redistilling the same pure stuff. (G-R, 1971, p. 319)

Pure physical processes cannot lead to a description of the economic process. Therefore, the systems of equations of thermodynamics cannot be directly adopted by economists. The description of the economic process depends on purposive activity and enjoyment of life. Low entropy is scarce, thus it is necessary for economic value to exist. However, it is through purposive activity and aiming at the enjoyment of life that humanity sorts and directs environmental low entropy, and this activity is historically and geographically specific[8].

He thus paved the way for his attempt to rethink economics as bioeconomics. In *Inequality, limits and growth from a bioeconomic viewpoint* (1977) he coined the term bioeconomics. He confronts the human obsession for comfort and pleasure with the biological constraints imposed by nature. He also criticizes neoclassical economics on the grounds that "we have missed the essential part, namely, that the Walrasian equilibrium presupposes the existence of an initial income distribution and that this distribution is determined by the division into social classes" (G-R, 1977, p. 367).

G-R's concept of bioeconomics stresses the limited amount of available resources that are unevenly located and unequally distributed, further he argues that neither economics nor biology can account for the human nature in isolation:

> G-R's bioeconomics is a new style of scientific thought: it is not a new branch of economics, but a new discipline that combines elements of evolutionary biology, institutional economics and biophysical analysis associated with energy and mineral resources. (Mayumi, 2009, p. 1.237)

G-R also criticized the Solow/Stiglitz neoclassical view of production on the basis that natural resources played no role in the production function. Solow's use of capital and labour as the only production factors assumes that one can get something from nothing, his justification is

[8] See G-R (1971, chapter 10).

that "if it is very easy to substitute other factors for natural resources, then there is in principle no 'problem'" (Solow, 1974, p. 11)[9].

By use of the second law of thermodynamics[10], he states that entropic degradation is pervasive to economic activity. As opposed to the circular diagram commonly advocated by economists in which "the outcome of a market is identical with the principle of virtual displacements that is used in mechanics for determining the static equilibrium" (G-R, 1979, p. 321), thermodynamics provides the proper framework to address issues such as qualitative change, irreversibility and indeterminateness.

Once more, he argues that the "mechanistic epistemology" was the main culprit for "recent economic difficulties" and that it is "the imperfection of our minds that prevents us from using the laws of mechanics for knowing all the future" (G-R, 1979, p. 319).

G-R criticised neoclassical economics' "mechanistic epistemology" as being incapable of addressing the inherent qualitative changes imposed by evolution since it is analytic rather than dialectical, "novelty always represents a qualitative change. [...] no analytical model can deal with the emergence of novelty" (G-R, 1979, p. 321). This is so because an analytical model can only derive what is "logically contained in its axiomatic basis", however, the "economic system continuously changes *qualitatively*" (G-R, 1979, p. 321). In the previous section, we discussed his psychological threshold concept and the importance that he attributed to the time element. In his criticism of the "mechanistic epistemology", the passage of time also plays a crucial role, "the system always returns to any of the previous equilibria. *Everything is reversible exactly as in mechanics*, where locomotion consists only of a change of place, not of quality" (G-R, 1979, p. 321).

The passage of time and the novelties that it engenders imply that nature "has an infinite number of properties [...] the human mind cannot grasp actuality with aid of analysis alone; it also must use dialectics"

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[9] In the following paragraph, Solow admits that the consequences would be catastrophic if production was bounded by natural resources, but that this is a minor issue for the author considers that renewable and exhaustible resources are substitutes.

[10] He also created a fourth law of thermodynamics. According to Schwartzman (2008), however, his fourth law is fallacious since it conflates isolated and closed systems. Therefore, the author argues that if these terms were used rigorously by G-R, his fourth law of thermodynamics would be equivalent to the second law.

(G-R, 1979, p. 321). Finally, in his early works when discussing path-dependency he argued that the human choice is worm-like rather than bird-like in the sense that past events influence present decisions. He uses the very same logic when championing the need of dialectics to cope with a constantly changing world: "We cannot possibly have a bird's eye view of the future evolution of mankind. All we can have is a worm's eye view, that is, we can at most have some idea of what is likely to happen in the very near future" (G-R, 1979, p. 325).

He defended the need of historical and institutional studies in order to grasp the ever changing character of our world. Schumpeter's influence[11] over his work is noteworthy:

> Every one of his distinctive remarks were seeds that inspired my later works. In this way Schumpeter turned me into an economist – the only true Schumpeterian, I believe. My only degree in economics is from Universitas Schumpeteriana. (G-R, 1992, apud Mayumi, 2009, p. 1.237)

Being graduated in mathematics with his PhD in statistics he has only taken two courses in economics at the Sorbonne. Despite the lack of a formal education in economics it should be noticed that meeting Schumpeter led him to "many late-night discussions" with economists such as Wassily Leontief, Edgar Hoover, Frank Taussig, Oskar Lange, Fritz Machlup, Gerhard Tintner, Nicholas Kaldor and Paul Sweezy (Gowdy; Mesner 1998, p. 139).

We conclude on the note that, as G-R says in the preface of his seminal work: "A book of this nature cannot be written as a research project with a definite timetable. The ideas contained in it were worked out in my mind over many years (as many as twenty, I believe)" (G-R, 1971, p. xiv).

This might be read either as supporting our thesis, since he admits continuity, or as contrary to our argument since he does not explicitly say that his early works have influenced his seminal work. Although he

[11] He dedicates his 1971 book to his "teachers" and notes that "two of my teachers had the most decisive influence on my scientific orientation: Karl Pearson [...] and Joseph A. Schumpeter, whose unique vision of the economic process combined in a harmonious manner quantitative with qualitative evolutionary analysis" (G-R, 1971, p. xiv).

does not make reference to any paper, his 1954 paper is an important transition in the sense that many ideas from his early and later works are juxtaposed, as we have argued. Thus, this paper is a shift, in that his later ideas would appear (explicitly) for the first time, however – as the present paper has argued – the seeds of his ideas can be traced back to his early works. Paraphrasing G-R, the ideas he developed in the '70s were worked over G-R's mind over many years (as many as forty, we believe).

Final thoughts

Why has the Romanian economist received such little attention? In spite of writing 230 papers and many books (Maneschi; Zamagni, 1997), receiving more than twenty prizes and fellowships, and being nominated for the Nobel Prize several times, he was not able to influence a great number of economists (Szenberg, 1995). As Daly (2007) argues, although G-R became a Distinguished Fellow of the American Economic Association, which he resigned upon later in his life, he is not the kind of economist that populates economics textbooks. Furthermore, even in the Economics Department of Vanderbilt, where he taught for two decades, his influence cannot be easily traced.

Szenberg (1995) claims that his references to physics and biology make his ideas less accessible to economists, but that the main reason that prevented him from being more influential was his refusal to accept a position at Harvard and spending the next twelve years in Romania. Had he stayed in Harvard he would have had a great opportunity of influencing a generation of prominent economists.

Maneschi and Zamagni add that one must bear in mind G-R's unorthodox ideas in his later works, "which set him on a collision course with the neoclassical establishment", and the fact that he mocked many famous economists, some of them Nobel laureates, as "standard economists" (Maneschi; Zamagni, 1997, p. 705).

G-R has his own explanation for this question: using a Romanian proverb, he says that "in the house of the condemned one must not mention the executioner" (G-R apud Daly, 2007, p. 14). This passage hints at G-R's pretentious personality which may be a part of the answer as to why his ideas have been largely ignored, as Daly points out:

> The future should witness our catching up with G-R's thinking. I believe this will eventually happen. Although it is ungracious to say so, G-R's ideas may advance more rapidly now that he himself is no longer around to scare people away from them with his irascible nature and impatience to "suffer fools gladly". Some of G-R's secret admirers may now openly take up his cause, no longer fearful that the master will disown them because of some minor difference. (Daly, 2007, p. 14)

Perhaps this is part of the answer, but it is certainly just part of a much wider story, which would necessarily involve understanding the interplay between the history of mathematical economics and the sociology of the economics profession. This is certainly not the place to answer to this question. Instead, as a final note, we suggest two avenues of research related to two important questions left open by the present paper:

1) To what extent do the developments in Evolutionary Economics over the last decades tackle the problems stressed by G-R?
2) What contributions can be drawn from G-R's discussion of the limited cognitive abilities of human beings to the current debate about the need for pluralism in Economics?

Although this paper did not aim at answering these questions, the richness and depth of G-R's approach during his later works should be of interest not only for historians of economic thought, but for economists in general. As Maneschi notes, G-R denied Schumpeter's invitation to stay at Harvard and co-author a book with him, "which would have attracted attention to him and launched his career" (Maneschi, 2006, p. 106). Schumpeter's high esteem for G-R and his desire to write a book with him seem to suggest that Evolutionary Economists should look for insights in G-R's works. Moreover, G-R's works may contribute in the recent debate regarding the need for pluralism in economics. As pointed by Maneschi, G-R, Marx and Schumpeter "shared a deep knowledge of the history of economic thought, and drew their inspiration from intellectual fields that stretched far beyond economics" (Maneschi, 2006, p. 107). Further research would be necessary in order to examine whether his works can provide insights for evolutionary economists and for rethinking the economics curriculum.

As to this paper actual contribution, our claim was that G-R's later works can be read as unfolding from his early works, particularly the "psychological threshold" and path-dependency, which cling to the imperfection of the human mind and the need to include the time element in economic analysis.

His criticism of the mechanistic epistemology was embedded in his account of human behaviour developed in his early works and his attempt to reformulate economics derives from this scepticism towards neoclassical economics. Thus, rather than abandoning his earlier concerns one can argue that there was a continuous intellectual development throughout his career, broadening considerably his approach through the incorporation of elements from economic development, institutional change and biophysical constraints, shifting his scope of analysis, from micro to macro, while keeping the epistemological stance from his works during 1930-1954.

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