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# Models as ‘Analytical Similes’: On Nicholas Georgescu-Roegen’s Contribution to Economic Methodology

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## ARTICLE HISTORY

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## Abstract

This paper investigates the methodology of Nicholas Georgescu-Roegen and his conception of economic models as analytical similes. His approach has received little attention from mathematical economists and economic methodologists. Thus, the purpose of this paper is to characterize his perspective and situate it in the broader spectrum of economic methodologies. It shows that Georgescu-Roegen criticized the lack of significance of certain economic models and attempted to give philosophical foundations to this criticism. He also provided a set of methodological principles that are illustrated by his practice of economic modeling. This perspective placed Georgescu-Roegen in opposition to the axiomatic approach that dominated postwar economics, and in line with economists such as Marshall, Wicksell, and Keynes, on the limited and subordinate role of mathematics in the discipline. Overall, the paper shows that Georgescu-Roegen’s methodological contribution is still relevant to contemporary debates on the status of economic models.

## KEYWORDS

Georgescu-Roegen, methodology, mathematical economics, models

If I finally realized that I was running against one current or another, it was not from any crossing of intellectual swords with my fellow economists, who have systematically shunned such an encounter, but from their personal attitudes toward me. I was a darling of the mathematical economists as long as I kept contributing pieces on mathematical economics.

–Nicholas Georgescu-Roegen, *Eminent Economists: Their Life Philosophies* (1992)

## 1. Introduction

Nicholas Georgescu-Roegen's relationship with mathematical economics was one of love and hate. He is both remembered as a pioneer of the rigorous formalization of neo-classical theory and as a virulent critic of subsequent developments in mathematical economics. Thus, the main motivation of the present paper is to understand better Georgescu-Roegen's conception of economic models as analytical similes and to situate it in the broader spectrum of economic methodology.

Georgescu-Roegen has been a witness—and a participant—of the transformation of economics in the twentieth-century. He was part of the nascent mathematical economics community in the interwar period and became once again an active member at the end of the 1940s, when mathematical economics was rising to dominance in the discipline. His progressive critical turn is an illustration of the divergences underlying this program. It allows investigating conceptions of the role of mathematics in economics that have challenged the dominant trend. Since Georgescu-Roegen had contacts with many eminent mathematical economists, it also provides information on how they received—or ignored—such criticisms.

Georgescu-Roegen's position has sometimes been caricatured as a definitive rejection of mathematical formalism in economics. Thus, it is important to say from the outset that, instead, he criticized specific practices in economic modeling and defended his own conception of the appropriate use of models. His methodology certainly downgraded modeling to a lower rank than it occupies in modern economics, but it did not preclude it altogether. Moreover, while the present paper focuses on Georgescu-Roegen's conception

of economic modeling, this issue does not exhaust the content of his methodological reflection. He also intended to rehabilitate institutional and historical approaches in economics. While the paper hints at these aspects on various occasions, it does not examine his conception and practice of these approaches in full detail.

In so far, Georgescu-Roegen's methodology and his conception of the role of mathematics in economics have received little attention. The work of Philip Mirowski (1989) on the relationships between mechanics and neoclassical theory—as a vehicle for the introduction of mathematical formalism in economics—constitutes one of the most developed investigations of one of Georgescu-Roegen's insights. Shortly after, Mirowski (1992) wrote the first general overview of Georgescu-Roegen's contribution to economics. It provides some interesting elements on his methodological perspective but remains incomplete with respect to his conception of economic modeling. Beyond this, there is practically no mention of Georgescu-Roegen's work in the main journals and books on economic methodology. Historians of economic thought have mostly investigated Georgescu-Roegen's theoretical views, in particular those developed after the 1960s. These contributions give some hints on his economic philosophy, especially articles dealing with his evolutionary perspective (Bobulescu 2012; Heinzl 2013; Missemmer 2017). However, they do not provide a comprehensive account of his position on economic models.

The present paper aims to fill this gap and thus to contribute to the history of economic methodology. For this purpose, section 2 provides a brief account of Georgescu-Roegen's career in economics and analyzes the reception of his methodological contribution. The main reason why mathematical economists paid little attention to Georgescu-Roegen's criticism was that they were confused by the philosophical framework in which he developed his arguments and could not see its practical consequences. Therefore, section 3 attempts to clarify and characterize his methodological stance, focusing on his conception of economic modeling. Based on this reconstruction, section 4 compares Georgescu-Roegen's methodology with that of other eminent economists and with the recent literature on the philosophy of economic modeling.

## 2. From Mathematical Economics to its Criticism

### 2.1. A Mathematician Turned Economist

To better understand where Georgescu-Roegen's methodological reflection came from, a brief overview of his career in economics is useful.<sup>1</sup> Georgescu-Roegen was born in Romania in 1906. After successful studies in mathematics, he earned a scholarship to complete a Ph.D. in theoretical statistics at the Sorbonne in France, under the direction of Emile Borel. His dissertation was on the cyclical components of time series, and it was published in the *Journal de la société française de statistique* (1930). By the end of 1930, he went to the United Kingdom, where he spent a year working under the supervision of Karl Pearson on the method of moments to study random variables and published his results in *Biometrika* (1932). Georgescu-Roegen thus benefited from Pearson's broad intellectual interests. Pearson's epistemological perspective, exposed in *The Grammar of Science* (Pearson 1892), particularly influenced him.<sup>2</sup> After this very successful training in Western Europe, Georgescu-Roegen returned to Romania and was appointed professor of statistics at the University of Bucharest.

Georgescu-Roegen first came to the United-States in 1934 as a Visiting Rockefeller Fellow. In this interwar period, American economics remained pluralistic, both in theoretical and methodological terms (Morgan and Rutherford 1998). The Econometric Society had recently been created to promote mathematical and statistical tools in the discipline, but this vision was far from dominant. Georgescu-Roegen initially intended to work for the Harvard Economic Barometer. As the program had been shut down when he arrived, he contacted Joseph Schumpeter, who taught business cycles at Harvard.<sup>3</sup> Schumpeter incited Georgescu-Roegen to use his analytical skills for the formalization of neoclassical economics. Georgescu-Roegen also participated in Schumpeter's weekly seminar, where he met and became friends with Wassily Leontief and Paul Samuelson, among others.

Georgescu-Roegen quickly made important contributions to the neoclassical research

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<sup>1</sup>Most biographical details are taken from Georgescu-Roegen's autobiographical writings (1989; 1992; 1993).

<sup>2</sup>Pearson's *Grammar* was a very influential treatise of philosophy of science at the beginning of the twentieth-century (Porter 2004).

<sup>3</sup>Schumpeter embodied the pluralistic atmosphere of this period. His work was in the historical school lineage, but he was very interested in the developments of mathematical economics.

program. His papers dealt with both production theory (1935a) and consumer theory (1935b; Pigou *et al.* 1936). His most outstanding contribution from that period is ‘The Pure Theory of Consumer’s Behavior’ (1936). This paper dealt with the conditions under which a utility function can represent a set of preferences, also known as integrability problem. Georgescu-Roegen’s approach was not a mere mathematical concern. It touched upon the methodological foundations of consumer theory and the question of which observations economists can use to construct that theory—such as introspection and experiments (Lenfant 2012). In this perspective, mathematics was a useful tool to clarify the conditions under which utility functions may exist. However, Georgescu-Roegen considered that only factual experience could tell whether these conditions are satisfied or not.

These contributions opened a promising career to Georgescu-Roegen, with a proposition to join the economics faculty at Harvard and the project of a treatise on theoretical economics with Schumpeter. He dismissed the offer to return to Romania in 1937, where he felt he could be useful to his native country. On his return there, he was appointed deputy director of the Central Statistical Institute, in charge of economic statistics. At the end of the Second World War, he became General Secretary of the Armistice Commission and participated in the negotiations over the reparations that Romania would pay to the USSR. All these activities left Georgescu-Roegen little time to work on theoretical issues. Retrospectively, he considered this period as one of ‘intellectual hibernation’ (1993, 3).

When the communists came to power in Romania, Georgescu-Roegen had to flee because of his ties with Western countries and his role as an advocate of Romania’s sovereignty in the armistice negotiations. With Leontief’s help, he came back to the United-States in July 1948 and got a temporary position in the recently created Harvard Economic Project.<sup>4</sup> Times had changed, and the interwar period’s pluralistic atmosphere was giving way to the hegemony of neoclassical theory and mathematical tools. Along with the Econometric Society, the Cowles Commission for Research in Economics was leading the way, under the supervision of Tjalling Koopmans (Düppe and Weintraub

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<sup>4</sup>The Harvard Economic Project was the institute where Leontief developed his methods of input-output analysis from the late 1940s to the early 1970s. It was a central place for the advancement of new analytical tools and one of the first sites where economists used computers for research purposes (Carter and Petri 1989).

2014). The conference on ‘Activity Analysis of Production and Allocation’ organized by the Cowles Commission in 1949 played a significant role in introducing new mathematical tools in the discipline. Georgescu-Roegen presented three contributions on linear models of production during the conference (1951b; 1951c; 1951a). Thus, with an additional overview of the state of input-output analysis in *The Review of Economics and Statistics* (1950a), he had quickly found his way back into the community of mathematical economists.

By the end of 1949, Georgescu-Roegen earned a permanent position as an economics professor at Vanderbilt University, where he spent the rest of his career. In the 1950s, he devoted much attention to the theory of choice, dealing with various issues such as hysteresis, uncertainty, and threshold effects (1950b; 1954; 1958b). These contributions were methodologically consistent with mathematical economics, even though some of their theoretical innovations were quite original in the literature (Hands 2006).

In 1950, Georgescu-Roegen was elected a Fellow of the Econometric Society and appointed associate editor of *Econometrica*. In this position, he was responsible for the reviewing process of the Arrow-Debreu model of general equilibrium. His final decision of acceptance came with a set of seventeen remarks that anticipated many of the methodological discussions surrounding this model (Weintraub and Gayer 2001, 435). Georgescu-Roegen (1960a) later developed some of his criticisms, claiming that the Arrow-Debreu model was irrelevant because it assumed that every agent has an income sufficient to survive independently from the market. More generally, he considered that neoclassical theory was not appropriate to deal with peasant societies, for which he maintained a particular interest because of his experience in Romania (1969).

Georgescu-Roegen’s paper on ‘The Nature of Expectations and Uncertainty’ (1958a) was another important step in his progressive critical turn regarding mathematical economics. In this paper, he claimed that some expectations escape formalization by probabilities because uncertainty is not reducible to risk—in the words of Frank Knight. Thus, mathematical formalization was only able to capture some aspects of expectations, not the whole human experience to which it referred. More generally, he concluded that ‘there is a limit to what we can do with numbers, as there is to what we can do without them’ (1958a, 29).

These methodological preoccupations became more important in Georgescu-Roegen's work during the 1960s, as he tried to give philosophical foundations to his criticism of mathematical economics. The introduction he wrote for a collection of articles entitled *Analytical Economics* (1966) was his first extended investigation of these issues. In the foreword, Samuelson (1966) showed how ambiguously mathematical economists welcomed this contribution. On the one hand, he considered that Georgescu-Roegen's introduction was a 'long, and profound essay that goes to the very foundations of the possibility of a purely quantitative economic science' (vii). On the other hand, he claimed that the achievements of mathematical economics had defeated past criticisms—such as those of Marshall, Pigou, and Keynes. Even though he did not say it explicitly, he presumably considered that Georgescu-Roegen's criticism might suffer the same fate.

## ***2.2. The Reception of Georgescu-Roegen's Criticism***

Georgescu-Roegen's methodological reflection was fully developed in *The Entropy Law and the Economic Process* (1971). As the title suggests, the book argued that the laws of thermodynamics should be better taken into account to deal with the physical aspects of economic activities.<sup>5</sup> But this book was also a much broader treatise on the philosophy of science. Georgescu-Roegen discussed the ideas of philosophers, such as Plato, Aristotle, Friedrich Hegel, and Henri Bergson, as well as those of philosophically inclined scientists, such as Henri Poincaré, Emile Borel, Alfred North Whitehead, and Bertrand Russell. Based on this discussion, he analyzed the specific position of economics among sciences and developed his own methodological perspective. The role of mathematical models occupied a central place in this reflection. The following quotation shows that Georgescu-Roegen was critical of certain practices of modeling in economics but recognized the usefulness of models under specific conditions:

Lest this position is misinterpreted again by some casual reader, let me repeat that my point is not that arithmetization of science is undesirable. Whenever arithmetization can be worked out, its merits are above all words of praise. My point is that wholesale arithmetization is impossible, that there is valid knowledge even without arithmetization,

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<sup>5</sup>For this reason, Georgescu-Roegen was a pioneer of environmental issues in economics. He has been particularly influential in the school of ecological economics (Røpke 2004; Ould Boye 2014).



and that mock arithmetization is dangerous if peddled as genuine. (Georgescu-Roegen 1971, 15)

In the same period, other eminent economists formulated similar criticisms of mathematical economics. The most notable one was certainly Leontief's presidential address to the American Economic Association (AEA) in December 1970, where he asserted:<sup>6</sup>

Uncritical enthusiasm for mathematical formulation tends often to conceal the ephemeral substantive content of the argument behind the formidable front of algebraic signs. [...] By the time it comes to interpretation of the substantive conclusions, the assumptions on which the model has been based are easily forgotten. But it is precisely the empirical validity of these assumptions on which the usefulness of the entire exercise depends. (Leontief 1971, 1-2)

The criticisms of Leontief and Georgescu-Roegen shared significant aspects. Both were concerned by the tendency of economic modeling to turn into purely mathematical exercises without economic significance. They also argued that econometric tests do not provide a satisfying standard of empirical validation because they rely on unverifiable stochastic assumptions. Despite these similar concerns, they did not collaborate more closely on this issue.<sup>7</sup>

More generally, Georgescu-Roegen's book received little attention from mathematical economists, none of whom published a book review or reacted publicly in any other way.<sup>8</sup> This lukewarm reception reflects the ambivalent position of Georgescu-Roegen in the discipline at that time. Around the same period, he received two prestigious honors: he was Richard T. Ely Lecturer in December 1969, and he became a Distinguished Fellow of the AEA in 1971. However, he earned these rewards mostly in recognition of his early contributions to mathematical economics. On the contrary, there were signs that the discipline did not welcome his new critical orientation.<sup>9</sup> The short text that came with

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<sup>6</sup>Another example of such criticism is Ragnar Frisch's address to the First World Congress of the Econometric Society in 1965, later published in a volume in honor of Sir Roy Harrod (Frisch 1970).

<sup>7</sup>Georgescu-Roegen later acknowledged Leontief's criticism (1975, 365f, 41). However, nothing in Georgescu-Roegen's correspondence with Leontief available at the David M. Rubenstein Rare Book and Manuscript Library of Duke University deals with these issues, even though some of their exchanges date back to this period.

<sup>8</sup>This is in stark contrast with the reception of the two-page note on mathematical economics by David Novick (1954). This note triggered a vigorous answer from a collection of eminent mathematical economists such as Samuelson, Solow, and Koopmans (Samuelson et al. 1954). See Mirowski (2002, 396-406) for more details on this debate. Georgescu-Roegen (1979, 318) later referred to this antecedent.

<sup>9</sup>Georgescu-Roegen (1992, 157) mentions two events in particular: a conflict with Edmond Malinvaud—the

his nomination as a Distinguished Fellow of the AEA captured this ambivalent position, mentioning both the importance of his contributions to mathematical economics and his critical considerations on the subject:

No American economist has more successfully combined in his training and publications the fields of economics, mathematics, and statistics. Yet Georgescu-Roegen has remained a signal defender of the view that many important problems are beyond the reach of numbers. (American Economic Association 1972)

The most renowned economist to publish a review of Georgescu-Roegen's book was Kenneth Boulding (1972). Frank Adelman (1972), a physicist, wrote another review for *The Journal of Economic Literature*.<sup>10</sup> Four other reviews appeared in *The Journal of Economic Issues* (Schlegel et al. 1973), the recently created journal for institutional economics. Finally, another review was written by Robert A. Solo (1974), who defined himself as 'a heretic outside the gate' of mathematical economics.

All these reviews favorably welcomed the broad philosophical ambition of the book. Adelman (1972, 458), for instance, noticed that it was 'concerned far more with the philosophy that must inevitably underlie valid and useful theories and models of economic activity than it is with the law of entropy.' Even though most of these reviews dedicated some attention to the purely physical aspects of the economic process, the subject that occupied the central stage was the methodological perspective of Georgescu-Roegen. For instance, Boulding (1972, 1099-1100) mentioned that he had some 'sympathy' for Georgescu-Roegen's critical stance on mathematical economics, even though he considered that he 'provides no real substitutes.' The institutionalists felt that Georgescu-Roegen's perspective gave support to their skepticism regarding mathematical models in economics. This support was even more important in a time when heterodox approaches were trying to gain ground in the discipline (Lee 2004). In this conflicting atmosphere, no doubt that standard economists could perceive Georgescu-Roegen's criticism as a betrayal, while heterodox economists welcomed it as a distinctive support from the inside of neoclassical theory.

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co-editor of *Econometrica*—over a comment regarding one of Georgescu-Roegen's (1960b) article; and the fact that the Fellows of the Econometric Society scheduled their annual meeting at the same time as his Ely Lecture.  
<sup>10</sup>Frank and Irma Adelman (1959) had performed the first computer simulation of a macroeconomic model, the Klein-Goldberger model. Beyond that, Frank Adelman's contribution to economics is limited.

To understand how mathematical economists received the methodological contribution of Georgescu-Roegen, one may also explore his archives. Unfortunately, little elements deal with this question, despite the fact that he still had contacts with mathematical economists. For instance, his correspondence at that time included exchanges with Samuelson and John Hicks. Hicks even mentioned that, after reading his book, he was ‘very much in sympathy with [his] general position,’ (Georgescu-Roegen Papers, box 23, folder: Hicks, John, 1973-1975). But he did not go further into discussing Georgescu-Roegen’s arguments. Hicks and Samuelson also participated in the conference held in honor of Georgescu-Roegen at Vanderbilt in 1975, along with other eminent economists: Joseph Spengler, Simon Kuznets, John Chipman, James Moore, and Boulding.<sup>11</sup> However, the collected papers of the conference show that none of the contributions directly engaged with the methodological issues raised by Georgescu-Roegen (Tang, Westfield, and Worley 1976).

One of the possible reasons why mathematical economists did not seem concerned by Georgescu-Roegen’s critical stance is that he rarely aimed personally at them. It is particularly true for Hicks and Samuelson, whose work Georgescu-Roegen continued to praise in private exchanges.<sup>12</sup> One rare exception, when Georgescu-Roegen aimed personally at someone, is his article on ‘Methods in Economic Science’ (1979), which provided a condensed and updated version of his methodological position. On this occasion, he asserted that ‘the most incriminating *corpora delicti* of empty mathematization got into print with the direct help of none other than Koopmans’ (318). This judgment concerned the market with a continuum of agents first formulated by Aumann (1964) and later extended by Brown and Robinson (1972). Georgescu-Roegen disparaged this model on the basis that one could not consider a continuum of agents as an approximation of a real finite market. Thus, he blamed Koopmans for supporting the article of Brown and Robinson before the National Academy of Science.<sup>13</sup>

Beyond Georgescu-Roegen’s attitude toward the founding members of mathemati-

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<sup>11</sup>Jan Tinbergen was also invited. He could not come, but he contributed to the book that was published afterward.

<sup>12</sup>Even by the end of his life, Georgescu-Roegen (1992, 155-156) considered that Hicks was his ‘exemplar’ of the ‘legitimate use of mathematics in economics.’

<sup>13</sup>Koopmans did not reply to Georgescu-Roegen’s criticism, but a former student of him, Salim Rashid (1981), commented on the paper. He tried to defend the assumption of a continuum of agents and the position of Koopmans. However, Rashid also recognized that Georgescu-Roegen had been ‘the methodological conscience of the profession for over a decade’ (183) and that his arguments had received ‘no satisfactory answer’ (186).

cal economics, another reason may explain the lack of reactions to his methodological criticism. This reason permeates from Samuelson's foreword to a book in honor of Georgescu-Roegen published after his death:

After the age of 60 he moved ahead from his mainstream mathematical economics researches into a new phase. It is not easy to be both profound and at the same time clear. What is his new kind of economics that goes beyond the Newton-Bacon logic of observation and theoretical rationalization thereof, and which asserts that 'B can be both A and non-A?' What will be the fruits of a methodology that rejects the 'superstition as dangerous as the animism of old: that of the Almighty Arithmophonic [*sic*] Concept'?

(Samuelson 1999, xiii)

Samuelson suggested that Georgescu-Roegen's methodological stance was not clear. In particular, his philosophical approach, based on the distinction between arithmomorphic and dialectical concepts, appeared as an obstacle to understanding the more practical implications. Thus, one presumable reason why mathematical economists did not answer to Georgescu-Roegen's criticism is that they were reluctant to engage on the philosophical ground on which he set the issue. A reexamination of Georgescu-Roegen's methodology should shed light on these aspects and clarify the nature of the criticism he addressed to mathematical economics.

### **3. Georgescu-Roegen's Methodology**

Most of the overviews of Georgescu-Roegen's contribution to economics deal at some point with his methodological stance (Mirowski 1992; Maneschi and Zamagni 1997; Beard and Lozada 1999; Missemer 2013). However, none of them provides a comprehensive understanding of his position regarding mathematical modeling. Khan (2014) is the only one to focus exclusively on the status of economic models in Georgescu-Roegen's methodology, but he does so from a particular perspective. He focuses on the debate about models with a continuum of agents, and he relies on a framework built by Wollheim for the history of art. This gives only a narrow understanding of Georgescu-Roegen's position regarding models, leaving aside most of his methodological discourse and actual practice of modeling.

To fill this gap, it is necessary to investigate Georgescu-Roegen's methodology in more detail. Even though other contributions can provide additional insights (1966, [1966] 1976b, 1976a, 1979), *The Entropy Law and the Economic Process* (1971) is the most important source for this purpose.<sup>14</sup> However, the aim here is not to provide an overview of this book, which covers many issues in the philosophy of science and economics. Instead, I only consider those aspects relevant to understand Georgescu-Roegen's methodology and his conception of the role of mathematical models.<sup>15</sup>

### ***3.1. Ontological Foundations: Arithmomorphism and Dialectics***

First, it is necessary to disentangle the meaning of Georgescu-Roegen's distinction between 'arithmomorphic' and 'dialectical' concepts, which appeared puzzling to Samuelson. On the one hand, Georgescu-Roegen characterizes concepts that are discretely distinct as 'arithmomorphic.' He builds this neologism on the Greek root *arithmos* (number), because 'any particular real number constitutes the most elementary example of a discretely distinct concept' (1971, 44). According to him, even though we speak of the 'continuum' of real numbers, each number does not overlap with any other—not only at the level of symbols but also at the level of concepts. Therefore, discrete distinction is the essence of logic and mathematics. In economics, analytical models extensively rely on such arithmomorphic concepts as utility and Pareto optimality.

On the other hand, dialectical concepts 'are surrounded by a penumbra within which they overlap with their opposites' (1971, 44). This approach echoes Hegelian philosophy, but Georgescu-Roegen (1971, 46f, 27) warns that 'it does not follow Hegel in all respects.' One difference is that, for him, even though a dialectical concept overlaps with its opposite, it is partially distinguishable from it. The problem is located only at the frontier. As an illustration, Georgescu-Roegen suggests that 'life' in natural sciences belongs to this category because 'there are some crystal-viruses that constitute a penumbra between living and dead matter.' In economics, he claims that the concept of 'want' belongs to the same category because 'any particular want [...] imperceptibly slides into other wants.' In both cases, the laws of logic do not apply to these concepts

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<sup>14</sup>In this section and the following when only a date is mentioned, it refers to the corresponding contribution of Georgescu-Roegen.

<sup>15</sup>Georgescu-Roegen mostly discusses these aspects in chapters II, III, IV, and XI.

because they do not abide by the principle of non-contradiction that ‘B cannot be both A and non-A’ (1971, 46). Thus, it is not possible to apply the methods of mathematics and logic to dialectical concepts straightforwardly.

This distinction immediately raises questions regarding the status of language. As Georgescu-Roegen acknowledges, words are as discretely distinct as numbers. More generally, ‘the elementary basis of discrete distinction is the distinction between two written symbols’ (1971, 43). We use these symbols as substitutes for both dialectical and arithmomorphic concepts for communication purposes. However, only for arithmomorphic concepts, ‘the property of discrete distinction should cover not only symbols but concepts as well’ (44). Conversely, when words represent dialectical concepts, their meaning is not completely exhausted, and a certain degree of vagueness remains. This point is highlighted by Khan (2014, 68), who notices that Georgescu-Roegen ‘has a sophisticated understanding of the fact that language hits and misses at the same time, and that it simultaneously leads and misleads understanding.’

While this is a major limitation of dialectical concepts, according to Georgescu-Roegen, it allows them to deal with qualitative change. In his perspective, qualitative change is a continuous evolution of social and natural entities that imperceptibly leads to radically new ones. In other words, qualitative change is not a movement along successive discretely distinct states but a phenomenon that happens inside the penumbra surrounding dialectical concepts. Consequently, ‘qualitative change eludes arithmomorphic schematization’ (1971, 63), and dialectical concepts alone can be useful to apprehend it. This insistence on qualitative change is one reason for Georgescu-Roegen’s dissatisfaction with Lionel Robbins’s standard definition of economics: the study of how given means allow one agent to achieve given ends. Instead, according to Georgescu-Roegen (1971, 330), the most critical aspects of the economic process are related to qualitative changes of the available means and the desirable ends, which cannot be captured by arithmomorphic concepts alone.

All this philosophical edifice rests on an inductivist conception of knowledge due to Pearson’s influence. Georgescu-Roegen (1992, 129) mentions that, from ‘Karl Pearson’s splendid *Grammar of Science*,’ he reached the conclusion that, ‘for us nature consists of just what we can perceive.’ From a Pearsonian perspective, sensory impressions provide

the elementary facts of science. The brain then processes these perceptions to formulate general categories and propositions (Porter 2004). This last step implies that scientific theories are not simple images of the world but human constructs that we must continuously question. Following this path, Georgescu-Roegen (1971, 75) criticizes the belief ‘that natural phenomena can be reduced to signal registrations alone.’ He argues instead that the mind ‘is as indispensable an instrument of observation as any physical contrivance.’ For him, mental categories artificially cut the world into pieces and are inherently dialectical. Accordingly, ‘dialectical reasoning,’ as Georgescu-Roegen calls it, must be the starting point of any scientific investigation.

Before going further, it is useful to summarize the essence of Georgescu-Roegen’s distinction between arithmomorphic and dialectical concepts. My suggestion is that it is best understood as an *ontological* distinction, in the sense that it is concerned with the nature of reality at the most fundamental level. Georgescu-Roegen himself does not use the term ontological. Hence, to distinguish clearly the concepts he uses from those I introduce, I use quotation marks for the former and italics for the latter.<sup>16</sup> To go back to the ontological foundations of Georgescu-Roegen’s approach, discrete distinction appears as an elementary property of logic and mathematics. This property is the bedrock on which the analytical methods proper to these fields have been developed. Instead, continuous overlapping between entities characterizes the natural and social world that surrounds us. To describe it, we must rely on dialectical concepts that are not directly amenable to the same kind of formal manipulations. The central issue of Georgescu-Roegen’s methodology is to understand how to build bridges between these two ontological facets while maintaining an inherent discrepancy.

### ***3.2. Models as Logical and Pedagogical Tools***

In this framework, a model is the transposition of dialectical reasoning into an arithmomorphic form. However, in economics, Georgescu-Roegen considers that arithmomorphic concepts only help build an ‘analytical simile’ of the dialectical reasoning to check its correctness.<sup>17</sup> The notion of ‘simile’ reflects two important aspects of his approach:

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<sup>16</sup>In that second category, I also include concepts taken from the philosophy of economic modeling.

<sup>17</sup>The term ‘analytical’ is used by Georgescu-Roegen as a synonym for ‘arithmomorphic,’ and so does the present article.

on one side, a model is a simile in the sense that it mimics as closely as possible some dialectical reasoning; on the other, it is *only* a simile because the analytical transposition of the dialectical reasoning is necessarily imperfect and does not abolish the distinction between arithmomorphic and dialectical concepts. For this reason, the idea of models as analytical similes synthesizes well Georgescu-Roegen's perspective on mathematical economics.

More precisely, Georgescu-Roegen (1971, 337) suggests two functions for models in economics: 'bringing to light important errors in the works of literary economists who reasoned dialectically'; and, 'illustrating certain points of a dialectical argument in order to make them more understandable.' Stated otherwise, models perform logical and pedagogical functions that allow one to think more rigorously and clearly. This position is relatively trivial and uncontroversial in mathematical economics. However, as we will see in the next subsection, Georgescu-Roegen has a relatively demanding conception of the constraints that these functions impose on model-building, as implied by the concept of analytical simile. Moreover, Georgescu-Roegen follows this approach in his actual practice of modeling. In addition to his work in decision theory, we can mention here his article on the Marxist theory of the breakdown of capitalism (1960b). In this paper, he demonstrates that Marxist theory's main theoretical assumptions do not imply that the economy needs to collapse in the long term, therefore questioning the logical validity of Marx's intuition.

So far Georgescu-Roegen's position is rather consensual. On the contrary, he strongly opposes the standard idea that economists can empirically test their models. According to him, in physics, empirical tests are made possible by measuring instruments that set an objective standard of accuracy for the model. Conversely, he claims that in social sciences, 'there is no such objective standard of accuracy' (1971, 333). In particular, Georgescu-Roegen's criticism aims at econometrics. Even though he was trained as a theoretical statistician and had practical experience in economic statistics as deputy director of the Central Statistical Institute in Romania, he made little contribution to the econometric program after turning to economics. In fact, in his few writings on the topic, he adopted a very critical position ([1966] 1976b). Following Corrado Gini's (1956; 1957) disillusion regarding econometrics, Georgescu-Roegen suggests that it faces several



important problems. One of them is that statistical tests require to make assumptions on the stochastic properties of the phenomenon under consideration—assumptions which cannot be tested themselves. Another problem is that even if these assumptions are correct, the estimated relation may not reflect the actual law governing the phenomenon.<sup>18</sup> But Georgescu-Roegen’s strongest criticism is that econometric estimates tend to turn into a game of choosing the adequate variables to obtain a good fit, a trend accelerated by computers. To illustrate this issue, he repeatedly uses the following metaphor: ‘one can always prove that inside any log there is a beautiful Madonna’ (1971, 340). Stated otherwise, a good fit with the data may be only a numerical artifice without any scientific significance. It is only if the estimated model is able to fit new data that we may give it some credit. This turns out not to be the case for most economic models.<sup>19</sup>

For Georgescu-Roegen (1971, 333), the consequence of these problems is that ‘there is no acid test for the validity of an economic model.’ Even though he does not explicitly mention it, this means that he considers the Popperian approach, in terms of falsification, as irrelevant in economics. Similarly, his methodological perspective opposes the instrumentalist approach usually associated in economics with Milton Friedman (1953). As a result, Georgescu-Roegen denies the possibility of making economics an empirical science. It certainly explains why he focuses on purely theoretical aspects in his actual practice of modeling. However, the interpretation that precedes holds only as long as we conceive tests in quantitative terms. On the contrary, there is no evidence that Georgescu-Roegen’s approach is incompatible with the idea that models provide *qualitative* predictions.

It seems that Georgescu-Roegen has this kind of qualitative predictions in mind when he considers the use of models in policy-making. According to him, since we cannot rigorously validate and calibrate models from empirical data, their predictive reach is limited. Thus, economic models cannot serve as ‘guides to automatic action’ (1971, 333), contrary to the situation which prevails in physics. It does not mean that economic models do not provide some useful elements for understanding concrete economic phenomena. However, policy makers must use these analyses with ‘delicacy and sensitivity

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<sup>18</sup>This is the old problem of ‘identification’ faced by early econometricians (Morgan 1990).

<sup>19</sup>Notice that the criticisms Georgescu-Roegen formulates are shared, at least to some degree, by some early contributors of econometrics, such as Gini and Leontief. Despite that, to my knowledge, there has been no direct answer to Georgescu-Roegen’s arguments.

of touch.’ Georgescu-Roegen’s (1976c) contribution to the debate on inflation in Latin America—one of his rare forays into the realm of macroeconomic policy—illustrates well this position. It begins with a criticism of the application of general equilibrium theory in developing countries.<sup>20</sup> Instead, Georgescu-Roegen proposes a semi-formalized framework—relying on graphic representations—to articulate monetary questions with issues related to the productive structure and distribution between social classes. His approach results in policy recommendations aimed at restricting the size of the luxury goods sector to allow the expansion of the standard goods sector. In parallel, he argues for an increase in wages at the expense of the most privileged classes. Hence, these policy recommendations stem from a general and semi-formalized understanding of the mechanisms at work behind the phenomenon of inflation, rather than from an empirically-based model.<sup>21</sup>

We can now characterize Georgescu-Roegen’s conception of models according to the epistemic functions identified by Morgan (2008). The notion of epistemic function refers to the cognitive purpose that underlines the use of a model. Morgan’s approach recognizes the diversity of these objectives among economists and intends to put descriptive labels on it. On the contrary, Georgescu-Roegen’s perspective is normative, and it is useful to identify which functions he endorses or not. Clearly, his approach is mostly concerned with *modeling as theorizing*. He considers models as tools that help to think more clearly and rigorously about a specific problem, a position well reflected by the idea of models as analytical similes. Conversely, Georgescu-Roegen downplays the function of *fitting theories to the world*, due in particular to his severe verdict on econometrics. It leads him to reject the ambition of making economics into an empirical science. Finally, this influences his appreciation of how models can serve as *investigative instruments* in policy-making. According to him, models cannot provide precise quantitative policy assessments. However, by improving the general understanding of the underlying mechanisms, they can help make qualitative predictions. Overall, Georgescu-Roegen has a restrictive conception of the role of models in economics, excluding many functions tra-

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<sup>20</sup>In particular, Georgescu-Roegen considers that the theory of inflation developed by Friedman rests on a Walrasian conception of the economy and is incompatible with the reality of Latin American economies.

<sup>21</sup>For a contextualized and more in-depth analysis of Georgescu-Roegen’s contribution to the debate on inflation in Latin America, see de Carvalho and Suprinyak (2019). Georgescu-Roegen’s discussion of unemployment gives another instance of his critical position regarding models’ ability to resolve policy issues (Fitoussi and Georgescu-Roegen 1980).

ditionally attributed to economic models. This is one facet of his critical standpoint on modeling practices in economics. The other facet pertains to the principles at work in the construction of models.

### ***3.3. Principles of Model-Building***

In Georgescu-Roegen's approach, models are essentially useful to clarify and validate the logical consistency of some reasoning. Since this perspective is rather consensual among mathematical economists, one may wonder why Georgescu-Roegen blames them. The answer lies in the idea that 'an arithmomorphic model has no value unless there is a dialectical reasoning to be tested' (1971, 341). It is the first facet of the notion of analytical simile, as discussed above. In other words, Georgescu-Roegen's criticism does not aim at modeling *per se*, but at models that do not rest on a careful conceptual investigation of the subject matter. Deprived of its philosophical apparatus, this criticism comes down to a standard denunciation of the lack of economic significance of certain models: 'there are endeavors that now pass for the most desirable kind of economic contributions although they are just plain mathematical exercises, not only without any economic substance but also without mathematical value' (1979, 317). The case on which he insists the most in the latter part of his career is the neoclassical production function.<sup>22</sup> He presents it as an 'illustration of the harm caused by the blind symbolism that generally characterizes a hasty mathematization' (1970, 1). For Georgescu-Roegen, ever since the original formulation by Philip Wicksteed (1894), conceptual foundations for the production function have been missing.

On the contrary, Georgescu-Roegen's approach provides some guiding principles to build conceptually relevant models. I propose to summarize these principles by three successive steps, respectively labeled as *idealization*, *isolation*, and *arithmetization*. As the first two notions are widely used in economic philosophy, it is important to underline that they have a specific meaning here, tailored to match Georgescu-Roegen's methodology. To some extent, this can diverge from the conventional understanding of these notions in the literature.

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<sup>22</sup>Other examples include his criticism of 'pseudo-economics' in many contributions to utility theory ([1966] 1976b, 256) and models with a continuum of agents (1979).

Dialectical reasoning is the starting point of scientific inquiry, according to Georgescu-Roegen. Thus, it is legitimate to wonder how he conceives this first step. An interesting hint on this topic stems from his discussion of Wesley Mitchell's criticism of neoclassical theory as 'imaginary individuals coming to imaginary markets with ready-made scales of bid and offer prices' (Mitchell 1925, quoted in Georgescu-Roegen 1971, 319). Georgescu-Roegen considers that this criticism misses the right point. He advocates instead that 'abstraction is the most valuable ladder of any science.' Following up, he claims that the first task of economics should be to construct 'an ideal-type that would make 'pragmatically clear and understandable' ' the features of a given economic reality. Georgescu-Roegen explicitly refers to Max Weber on this point. This is consistent with contemporary literature in economic philosophy, where Weber is one of the main methodological sources regarding idealization. In particular, he considered rational individual economic behaviors and the market as viable ideal-types (Morgan and Knuuttila 2012, 61-62).

For these reasons, we may refer to this step as *idealization*. In Georgescu-Roegen's perspective, this is a synonym of simplification by abstraction. Stated otherwise, idealization performs a *qualitative* simplification to provide a more manageable picture of a given entity, such as an economic agent. Despite that, Georgescu-Roegen insists that idealization should be in close connection with economic reality. Therefore, his methodology is *realist* in the sense of Mäki (2000), meaning that it explicitly considers the relation between economic theory and reality.<sup>23</sup> The notion of dialectical concepts is crucial in this respect. It combines the idea that idealization must rely on sensory perceptions and, at the same time, is an abstract product of the intellect. Moreover, Georgescu-Roegen's conception of sensory perceptions does not restrict to observable objects in the physical sense. It also includes other aspects of human experience, for instance, those accessible through introspection, such as preferences, expectations, and social norms. Therefore, it is closer to what Mäki (2000, 8) considers as *commonsensibles*, that is 'familiar parts of our commonsense view of the social world within which we live our daily lives.'

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<sup>23</sup>As underlined by Hausman (1998, 2000), most economists and economic methodologists are realists in the sense that they believe the objects of economics exist independently of economic theory. But this does not mean that they explicitly tackle the nature of the relationship between these objects and economic theory, whereas Georgescu-Roegen does.

The second step in Georgescu-Roegen's methodology consists in producing some dialectical reasoning to address a specific problem based on the idealized concepts elaborated in the first place. However, if we want to test the logical consistency of this dialectical reasoning with an analytical simile, it must comply with some constraints. In particular, Georgescu-Roegen (1971, 340) argues that only 'simple-minded' models are relevant, because they remain under 'our mental control.' He vividly criticizes, for instance, the use of complex macroeconomic models, composed of hundreds of variables and equations. Again, this is because adequate measuring instruments—such as those of physics—are missing in economics, leaving mental control as the only way to ensure the relevance of a model. Consequently, in elaborating a dialectical reasoning, one must care to 'pick up a few but significant elements from the multitude of cluttering facts.' In other words, the reasoning should involve only a restricted set of entities and relationships.

This process constitutes another form of simplification, which I propose to name *isolation*. The goal of isolation is twofold: to select a limited number of relevant elements; and to combine these elements into a consistent dialectical reasoning. In this sense, the set of elements is isolated from the multitude of other phenomena that interact with it in reality. Thus, isolation is about a *quantitative* simplification, which distinguishes it from the qualitative nature of idealization. It is somewhat different from the standard view in contemporary economic philosophy. For instance, Mäki (2009) considers isolation as the outcome of the idealization process. Notwithstanding this remark, I believe that the labels used here are well-suited to describe Georgescu-Roegen's methodology.

The third important step in Georgescu-Roegen's approach concerns the actual transposition of a dialectical reasoning into an analytical simile, labeled here as *arithmetization*. In particular, Georgescu-Roegen (1971, 338) states that an analytical simile 'must be formulated with the utmost rigor,' and that 'there is no room in 'pure theory' even for pseudo-arithmomorphic concepts, such as price index, cost of living, aggregate production, and the like.' Thus, every concept at the arithmomorphic level must correspond to some concept at the dialectical level, and beyond, to some entity of which we have a more or less direct experience. Conversely, Georgescu-Roegen's examples of 'pseudo-arithmomorphic' concepts are statistical constructions that we cannot connect to any actual entity in the world.

Georgescu-Roegen is particularly concerned with the distinction between ordinal and cardinal variables. A variable is ordinal if it serves to order different situations. A cardinal variable is an ordinal variable to which we can apply additions and subtractions. Georgescu-Roegen insists on the fact that cardinality requires strong conditions. It presupposes ‘the abstraction of any qualitative variation’ (1971, 97). Only under this condition is a common entity underlying the cardinal variable, subject to addition and subtraction. Thus, Georgescu-Roegen opposes a cardinal conception of utility because he considers that there is no ‘reservoir where the utilities and disutilities of a person accumulate’ (98). When these conditions are not valid, ordinal measurement is still possible, but it is not legitimate to apply additions and subtractions. In any case, the mathematical properties of a given variable should be consistent with the properties of the entity it represents.

This very tight relationship between dialectical concepts and the arithmomorphic concepts representing them in a model may seem contradictory with the initial distinction introduced by Georgescu-Roegen. To handle this apparent contradiction, he relies on the idea that an arithmomorphic concept can only display one facet of the dialectical concept it represents. For instance, Georgescu-Roegen asserts that ‘the dialectical spectrum of human wants [...] has long since been covered under the colorless numerical concept of ‘utility’ ’ (1971, 52). It does not mean that he rejects the concept of utility altogether, but he considers that it does not reflect the full complexity of human wants. In this perspective, arithmetization combines two aspects: a quantitative equation of one-to-one correspondence between dialectical and arithmomorphic concepts; and a qualitative loss between the two levels. These two aspects reflect the two facets of the notion of analytical simile as previously characterized.

Overall, the steps of idealization, isolation, and arithmetization provide the guiding principles of Georgescu-Roegen’s methodology. However, even though they appear as a relatively consistent set of guidelines, they are not deprived of difficulties. The most important one is the tension between realism and simplicity. To some extent, this echoes the traditional question of how economic models can be true despite incorporating unrealistic assumptions (Mäki 2012). One possible answer to this puzzle is that the truth of models lies elsewhere, for instance in the causal mechanism that they identify.

Georgescu-Roegen provides a somewhat different perspective on this issue. He insists that each entity of the model must have a well-defined referent in reality. In particular, he considers that aggregate variables have no conceptual foundations and that we should not use them in purely theoretical models. For instance, different capital goods ‘are not all qualitatively identical and, hence, have no common measure’ (1971, 244). Instead, to preserve the simplicity of the model, Georgescu-Roegen suggests setting aside the elements of reality that seem the least relevant to study the specific problem under consideration. This perspective does not preclude the elaboration of general theoretical principles that will serve as a basic structure for various models. However, in each situation, one must ask what elements are most crucial for the issue.

To conclude this section, notice that the principles of model-building identified above are actually at work in Georgescu-Roegen’s modeling practice. It is true for his work before *The Entropy Law and the Economic Process* (1971), such as his contribution to the integrability problem and his analysis of the breakdown of capitalism in Marxist theory. It is even clearer in the flow-fund theory of production, which he elaborates simultaneously as his methodological reflection, from the middle of the 1960s onward. There is no room here for a detailed presentation of the flow-fund theory. Still, I can briefly sketch how this approach reflects the methodological principles above.<sup>24</sup> As mentioned earlier, Georgescu-Roegen vividly criticizes the lack of conceptual foundations of the neoclassical production function. Therefore, the first step in elaborating his own theory of production is a cautious discussion of the concepts of process, boundary, flows, and funds, illustrating the principle of idealization. Flow elements (resources, intermediary goods, etc.) are defined as the *objects* of the transformation, whereas fund elements (labor, capital, etc.) are the *agents* of the transformation. Once settled these conceptual foundations, the relevant flow elements and fund elements are determined according to a given problem, as stated by the principle of isolation. For instance, when Georgescu-Roegen examines energy issues, he explicitly introduces different forms of energy (fossil, solar, etc.). However, energy flows are not necessarily taken into account when they do not appear as important for the problem at stake. Finally, the principle of arithmetization leads to flow-fund tables representing the interdependence of a restricted set of

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<sup>24</sup>The most complete exposition of the flow-fund theory is in chapter IX of *The Entropy Law and The Economic Process* (1971). For a comprehensive examination of this theory, see for instance Couix (2020).

production processes. These tables are strictly disaggregated models of production with purely countable coordinates. Of course, this is possible only because Georgescu-Roegen pursues theoretical objectives with this kind of model and does not pretend to develop tools of empirical analysis, contrary to Leontief's input-output tables.

#### 4. Connections and Divergences with other Methodological Perspectives

##### 4.1. *Images of Mathematics*

To put Georgescu-Roegen's methodology in perspective, we can rely on the notion of *image* of mathematics, used by Weintraub (2002) to analyze the transformations of economics in the twentieth-century. An image corresponds to a particular conception of rigor in the use of mathematics. For Weintraub, during the nineteenth-century, the dominant view of mathematical rigor rested on a physical substrate for mathematical reasoning. At the beginning of the twentieth-century, a series of paradoxes in physics and mathematics led to profound transformations. The dominant image became that of *axiomatics*, which consisted in identifying the smallest set of axioms from which we can logically derive the other propositions. This approach favored the formal structure of the theory over the relationship with factual experience. The most preeminent representatives of axiomatics were David Hilbert and the members of the Bourbaki group. They influenced economics through mathematicians such as John von Neumann and Gérard Debreu. This conception of mathematics thus became dominant in economics after the Second World War.

Even though he does not use the word, Georgescu-Roegen's criticism aims at axiomatics in the first place. His conception of a rigorous economic model emphasizes conceptual foundations and their consistency with our perception of economic reality. The formal purity of the model is secondary. On the contrary, Georgescu-Roegen considers that the quest for mathematical purity leads to irrelevant assumptions such as the idea that every agent has an income sufficient to survive independently from the market—in the Arrow-Debreu model—and the assumption of a continuum of agents—in the Aumann-Brown-Robinson models. More generally, Georgescu-Roegen views most of the contributions deriving from this image of mathematics as purely mathematical



exercises deprived of any economic significance.

One may wonder if Georgescu-Roegen's perspective finds an echo in another image of mathematics. According to Weintraub (2002, 66), the main alternative image in twentieth-century economics is the idea that rigor 'is associated with the connection of the conceptual categories in an underlying physical reality.' Two mathematicians, Vito Volterra and his student Griffith C. Evans, defended this image in the early developments of mathematical economics. They stressed the need to use observable and measurable quantities in models.<sup>25</sup> Even though Volterra and Evans initially lost the fight against axiomatics, it seems that their image of mathematics became dominant after the 1970s, in the 'age of the applied economist' (Backhouse and Cherrier 2017). Formal theoretical research has not disappeared, but it has diversified, and the need to apply it to specific questions has led to the abandonment of axiomatic concerns.

To a certain extent, Georgescu-Roegen also fits into this perspective because of the attention he pays to conceptual and measurability questions. The common interest of Volterra, Evans and Georgescu-Roegen for the question of integrability illustrates this link.<sup>26</sup> However, to my knowledge, there is no explicit reference to Volterra's and Evans's methodological views in the work of Georgescu-Roegen. Conversely, there are signs that his approach differs significantly. In particular, Georgescu-Roegen's concern with measurability is mostly a theoretical question. He wonders about the possibility of representing a given entity by a cardinal variable, but he never shows interest in going further and confronting the models with empirical data.

For the same reasons, Georgescu-Roegen's methodology differs significantly from that of Leontief. As reflected by his presidential address to the AEA, Leontief (1971) shares the criticism that formal preoccupations tend to take over economic significance in modeling practices. His way out of this dead-end is to focus on the connection between empirical observations and theoretical concepts (Akhbar 2019), much like the Volterra-Evans tradition. As a result, Leontief places a great deal of importance on empirical methods, while Georgescu-Roegen shows no interest in these issues and concentrates

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<sup>25</sup>For this reason, Weintraub suggests linking this approach to that of Lawrence Klein and more generally to econometrics and applied economics.

<sup>26</sup>Volterra raises the integrability issue for the first time in a debate with Pareto. Evans takes it up and 'refocuses his attack on utility theory through the integrability problem' (Weintraub 2002, 63). Later, Georgescu-Roegen (1936) provides the most complete analysis of this question.

on conceptual questions. The best illustrations of this discrepancy are their respective theories of production. Input-output analysis and the flow-fund approach share a conception of production in terms of processes interacting with each other. However, Leontief explicitly designed the former for empirical purposes, while Georgescu-Roegen only contemplates theoretical applications of the flow-fund model. These diverging methodological outlooks determine the specific assumptions endorsed in each case and explain the differences between both approaches (Couix 2020).

Georgescu-Roegen's few explicit references to the methodology of other economists point in a slightly different direction than the Volterra-Evans tradition. In particular, he refers to the position of Knut Wicksell, for whom a mathematical model is useful 'to facilitate the argument, clarify the results, and so guard against possible faults of reasoning—that is all' (Wicksell 1954, quoted in Georgescu-Roegen 1971, 341, emphasis added by Georgescu-Roegen). Georgescu-Roegen adds that this approach 'goes back to Marshall who, moreover, practiced it by relegating his mathematical similes to the back of his *Principles*' (341f, 89). This reference is consistent with the image of mathematics that Weintraub (2002, 23) attributes to Marshall, according to which mathematics serves 'as an exemplar of the path to truth, to constructing indubitably true arguments.' Moreover, Weintraub argues that this conception is incompatible with both the axiomatic approach and the empirically-oriented perspective. Therefore, Georgescu-Roegen's conception of models as analytical similes finds here a methodological tradition that suits it.

Finally, Georgescu-Roegen also relates his position to that of Keynes, for whom the object of economics is 'to provide ourselves with an organized and orderly method of thinking our particular problems' (Keynes 1936, quoted in Georgescu-Roegen 1971, 341f, 89). This is consistent with other accounts of Keynes's position regarding the use of mathematics in economics. O'Donnell (1990) shows in particular that Keynes attributed a 'limited and subordinate' role to mathematics (41), such as 'discovering errors in reasoning' (42) and 'a symbolic aid to thought' (44). It clearly shows a convergence with the position expressed by Georgescu-Roegen, according to which the only epistemic function of models is that of reasoning more clearly and more rigorously on a given problem. Once again, the originality of this position is not in the function itself, but in

the fact that it excludes other functions, empirical ones in particular.

A Marshall-Wicksell-Keynes tradition stems from what precedes. Georgescu-Roegen's contribution to this tradition is important in many respects. First, while his predecessors disseminated their reflections in various works, he tried to collect the arguments in favor of this view and give them philosophical foundations. Second, the quick development of economic modeling in the middle of the twentieth-century informed his position, as he was a witness and an actor of this trend. Third, he provided methodological principles consistent with this general position on the role of mathematics in economics and put them into practice. The notion of analytical simile thus synthesizes this conception of economic modeling. It does not mean that Georgescu-Roegen's position is the only acceptable one in economics, nor that it contains no ambiguities and practical difficulties. But we must at least recognize that he offered a clearer view of the foundations on which this position rests and of its implications.

Finally, Georgescu-Roegen considers that qualitative variations across space and time impose limits on the relevance of models. In particular, Georgescu-Roegen agrees with the criticisms that the historical and institutional schools address to neoclassical economics: 'if man's economic actions were independent of his cultural propensities, there would be no way to account for the immense variability of the economic pattern with time and locality' (1971, 342). For instance, he considers that utility theory 'reflects an institutional trait proper (and, perhaps, specific as well) to the large urban communities of industrialized societies,' where 'only those goods and services an individual can enjoy personally influence his satisfaction' (324). Conversely, he argues that 'in peasant communities the happiness of the individual depends not only on the quantities of goods and services at his disposal but also on other social variables.' Thus, Georgescu-Roegen underlines that economic realities in different places are qualitatively different and should be accounted for by different theoretical and analytical frameworks, in the spirit of institutional economics. His contribution to development economics illustrates particularly well this perspective (Suprinyak 2020). On this occasion, Georgescu-Roegen (1960a) argues that standard theory is a theory of capitalist economies and is ill-suited for agrarian economies, where the main limitative factor is land.

Similarly, this perspective shapes Georgescu-Roegen's understanding of the changes

that affect a given economy through time. For this purpose, he distinguishes between ‘dynamics’ and ‘evolution.’ The former corresponds to quantitative changes occurring in an economy whose qualitative features remain invariant. An analytical simile can represent it, but this representation is only relevant on a limited time-scale. In the longer run, ‘the evolutionary nature of the economic process [...] precludes a grasping of all its relevant aspects by an arithmomorphic scheme’ (1971, 330). For Georgescu-Roegen, the economic process evolves through qualitative changes, which are inherently dialectical phenomena out of the reach of arithmomorphic models. Consequently, he considers that ‘most relevant part of history is a story told in words’ (1979, 325), which sounds like a plea to give more room to economic history in the discipline.<sup>27</sup>

The conclusion is that Georgescu-Roegen considers models only as an instrument of limited relevance in a broader methodological toolbox. He attempts to reconcile analytical methods of modeling with institutional and historical approaches, echoing the pluralist interwar atmosphere in which he learned economics (cf. subsection 2.1).

#### ***4.2. Contemporary Philosophy of Economic Modeling***

Georgescu-Roegen’s methodology echoes in many respects contemporary debates in the philosophy of economic modeling. One can identify three main trends in these debates, labeled respectively as the ‘explorationist,’ the ‘fictionalist,’ and the ‘isolationist.’<sup>28</sup> These different approaches do not exhaust the variety of the literature, but they provide useful reference points. Moreover, they are not so much antagonistic positions than increasingly demanding normative requirements. All of them share the idea that conceptual exploration is a fundamental function of economic models. The distinctive feature of the explorationist perspective is that it considers conceptual exploration as the *only* function of models. Thus, from this perspective, models have no direct connection with the real world (Hausman 1992). On the contrary, the fictionalist approach considers that conceptual exploration is only meaningful if the model is a credible counterfactual world that allows making inductive inferences. Credibility rests on a broad

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<sup>27</sup>In particular, Georgescu-Roegen praises on repeated occasions the historical aspects in the work of Marx and Schumpeter. Himself dedicates attention to historical processes in some of his work, for instance, when dealing with unemployment related to technological change (Fitoussi and Georgescu-Roegen 1980) and energy transitions (Georgescu-Roegen 1984).

<sup>28</sup>Grüne-Yanoff (2009) already uses the last two labels.

similarity between the model and the world, which we cannot reduce to a set of unequivocal criteria (Sugden 2000, 2009). Therefore, it remains a difficult notion to capture. While recognizing the importance of credibility, the isolationist's stance emphasizes that models should isolate causal mechanisms. These causal mechanisms are the ultimate truth-bearers of models. Hence, the required realisticness of an assumption should depend on its proximity with the central causal mechanism of the model (Mäki 2009, 2011).

Reiss (2012) blamed these three perspectives for failing to solve the 'explanation paradox' inherent to economic modeling. This explanation paradox consists of the following three propositions, which together create a contradiction: 1) models are false, 2) models are explanatory, 3) truth is necessary for explanation. Even though each author has defended his approach against the attack (Hausman 2013; Sugden 2013; Mäki 2013), this debate shows that the status of models is still a controversial issue in economic methodology.

The approaches above share several features with Georgescu-Roegen's conception of models as analytical similes. They are mostly interested in theoretical models and dedicate little attention to the relevance of empirical methods. Thus, the only non-controversial aspect of models remains their ability to check the logical validity of a reasoning, which is also at the heart of Georgescu-Roegen's perspective. Beyond that, all these approaches are looking for some normative principles to assess the quality of models. They consider that economists generally do not say enough about the purpose and the relevance of their models for real-world issues. Therefore, they underline the importance of discussing models with standard language under the form of commentary or casual empiricism. Similarly, the notion of analytical simile encapsulates the idea that the model must mimic some dialectical reasoning as closely as possible, which constitutes the main link between the model and its target system in the real world.

However, there are also some notable differences between the approaches above and Georgescu-Roegen's methodology. It constitutes a fourth conception of modeling, which we can label the 'similist' perspective. Among the differences with the other approaches, Georgescu-Roegen does not focus on causal mechanisms as much as they do—the isolationist in particular but the others as well. Instead, he concentrates on 'valid analytical

representations of the relations among facts' (1992, 130). It is why the principle of arithmetization is so important in his methodology. According to it, the model must represent the different components of the dialectical reasoning and their relationships to one another as accurately as possible. Thus, a model represents a set of reciprocal relationships between different elements rather than a causal mechanism. For Georgescu-Roegen, the final cause of a phenomenon always lies outside of the model, in some qualitative change that modifies the relationships and triggers a response from the system.

It also explains why the notions of idealization and isolation appear in a slightly different way in Georgescu-Roegen's methodology. In the isolationist approach, idealization is the process toward isolation, and both aspects focus on the identification of causal mechanisms. In Georgescu-Roegen's perspective, instead, they appear as distinct principles of model-building. Idealization involves some qualitative simplification in the elaboration of descriptive dialectical concepts. Isolation, instead, performs a quantitative simplification that selects relevant aspects within these conceptual foundations to formulate a dialectical reasoning. In the similitist approach, these two steps are the necessary foundations of a model. Without them, it loses its status as an analytical simile, and therefore its purpose.

Regarding the main problem of the relationship between the world and the model, Georgescu-Roegen emphasizes dialectical idealization as the true cornerstone of economic theorizing. Modeling is conceived only as a tool to check the logical validity of a very well circumscribed dialectical reasoning, which may be part of a much broader theoretical edifice. Thus, an analytical simile is not primarily related to the real world, but to the theoretical concepts we build to account for it. Even though the simile does not exhaust the dialectical reasoning it represents, it can support its logical validity. It does not guarantee the logical validity of the whole theory, even less so its validity as an accurate conceptualization of the world. For this last purpose, only common sense judgment seems relevant to Georgescu-Roegen. In this perspective, models are subordinate to the theory and play only a very circumstantial role. They do not represent the starting point of inquiry, as they do in modern economics, but only tools of limited relevance.

In this sense, Georgescu-Roegen's perspective is consistent with a pluralism of mod-

els of the kind recently advocated by Rodrik and refined by economic methodologists (Rodrik 2015; Mäki 2018; Aydinonat 2018). More precisely, the simulist approach seems compatible with both ‘quantitative’ and ‘qualitative’ pluralism of models in the sense of these authors. Quantitative pluralism denotes the derivation of multiple models from a common theoretical framework. In Georgescu-Roegen’s methodology, the step of isolation produces this kind of pluralism by selecting the relevant elements from a pool of pre-established dialectical concepts. Idealization, in turn, leaves room for qualitative pluralism—that is, the coexistence of models with different theoretical backgrounds dealing with the same issue—since nothing guarantees that there is only one way to conceptualize the world. Georgescu-Roegen’s approach goes even further and advocates a broader methodological pluralism that aims at combining historical, institutional, and analytical methods of investigation. Thus, in the simulist perspective, a model only makes sense if it pertains to a wider research program where these various methods cross-fertilize. Conversely, contemporary philosophy of economic modeling considers models in a more isolated way and pays little attention to the connections with other methodological outlooks.

## 5. Conclusion

In his foreword to the book in honor of Georgescu-Roegen, Samuelson (1999) suggested that Georgescu-Roegen’s methodology was somewhat peculiar and that its practical implications were not clear. This paper shows that it is not the case. Georgescu-Roegen’s methodological position is not unfamiliar in economics; it largely coincides with authors such as Keynes, Marshall, and Wicksell. This position consists in considering models only as a means of clarifying some reasoning and validating its logical consistency. Likewise, the criticism formulated by Georgescu-Roegen against mathematical economics is quite standard. This criticism targets the lack of economic significance of a growing number of mathematical models used in economics. Instead, the truly interesting aspects of Georgescu-Roegen’s methodological reflection reside in its philosophical basis—the ontological distinction between dialectical and arithmomorphic concepts—and its principles for practical implementation—idealization, isolation, and arithmetization.

Thus, Georgescu-Roegen's conception of models as analytical similes is a distinctive contribution to the methodology of economics. It represents an interesting attempt at understanding the achievements and limits of models in economics. This contribution echoes in many ways the perspectives of other economists and economic methodologists while having some truly original aspects. This paper has proposed a first synthetic account of Georgescu-Roegen's methodology, clarifying the nature of his criticism toward standard economic modeling and highlighting his principles of model-building. However, his position certainly requires further critical investigation, exploring, for instance, the consistency of his ontology and the relevance of his criticism of empirical methods. Given the complexity of the issues at stake, it is not surprising that Georgescu-Roegen did not provide an all-encompassing account of economic modeling. Nevertheless, he deserves a place among important contributors to economic methodology.

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