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Giovanni Scarano

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MARX'S POLITICAL ECONOMY FROM THE PERSPECTIVE OF DYNAMICAL SYSTEMS THEORY

Giovanni Scarano[*]
Roma Tre University
Department of Economics
giovanni.scarano@uniroma3.it

Abstract

The paper advances novel interpretations of Marx's original insights by situating them within the horizon of contemporary scientific approaches, notably dynamical systems theory and statistical physics.
Marx's dialectical method is a mode of analysis predicated on the insight that relations among parts cannot be adequately grasped in abstraction from the relation between the whole and its constituent elements – a defining feature of modern systemic approaches. This perspective renders it possible to reinterpret many of Marx's key concepts as emergent properties of economic systems.
The paper further contends that Marx conceived capitalist development as an intrinsically dynamic process that precludes the notion of equilibrium as a state of rest. In this light, the centrality of disequilibrium within the Marxian framework brings it into an alignment with contemporary theories of deterministic chaos, wherein systems persistently far from equilibrium are nonetheless amenable to rational analysis through the concept of attractors.

Key words: Complex systems, holism, reductionism, structuralism, disequilibrium.

JEL Classification Codes: A110, A120, B140, B400, B410.

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1. Introduction

Most mainstream economists have tended to regard Marx as an idiosyncratic and ultimately marginal figure within the history of economic thought. For example, Paul Samuelson and Anthony Brewer have approached his work primarily by situating it within a minor Post-Ricardian tradition (Samuelson 1957, 1962; Brewer 1995). Samuelson, moreover, while not denying Marx's significance as a philosopher, characterises him, from an economic standpoint, as 'an autodidact cut off in his lifetime from competent criticism and stimulus' (Samuelson 1957), and further charges him with an 'overelaboration of trivial points' and with committing 'errors in logic and inference' (Samuelson 1967).

Such trenchant judgements, however, may be construed as reflecting a fundamental misapprehension of Marx's *dialectical method* on the part of a thoroughly neoclassical economist, habituated to a *reductionist framework* and to the formal rigour of mathematical logic.

In point of fact, Marx was no run-of-the-mill 'pure' economist in the sense implied by the contemporary division of intellectual labour. More broadly, he should be regarded as a social theorist of considerable philosophical formation who turned to the analysis of economic phenomena because he took them to constitute the fundamental basis upon which the organisation and historical development of human societies rest (Rosdolsky 1977). His engagement with political economy thus stemmed from his own *materialist conception of history* – subsequently designated by Friedrich Engels as 'historical materialism'.

The main problem in approaching Marx from an economic viewpoint, therefore, is that he 'created a system that embraced all the social sciences and we can only consider his economics on its own by doing an injustice to his philosophical, sociological and historical ideas' (Blaug 1985). When we are forced 'to carve out Marxian economics from Marxism' (Blaug 1985), we are not only doing injustice to the other components of his system, but also risk losing sight of the original objectives of his reasoning.

Moreover, contemporary mainstream economics proceeds broadly along the lines of *classical physics*, grounding its analyses in logically derived propositions from hypotheses that must neither be arbitrary nor metaphysical, but instead generalised inductively from empirical observation and experiment (Cassirer 1951). Much like classical physics, it is distinguished by its reliance on quantifiable data and aspires to elucidate the universal order governing economic phenomena, thereby identifying the underlying laws that regulate them through the discernment of regularities embedded in measurable evidence.

Such laws are presumed to exhibit an all-pervasive form, manifesting to the human intellect in mathematical determinations and in structures ordered by measure and number (Cassirer 1951). Within this framework, empirical observation alone is taken to furnish the raw material of science, while principles and laws emerge from rigorous quantitative analysis. In this sense, economists, no less than physicists, are understood to uncover regularities immanent in the phenomena themselves, expressed as systematic quantitative relations among their measurable magnitudes.

Within the mainstream approach, moreover, economic reality is construed as a fundamentally quantitative system composed of elemental units – namely, *economic agents* – whose defining characteristics are posited in a transhistorical manner.

The mainstream approach in economics is thus typically *reductionist*; that is to say, it endorses the theoretical standpoint – prevalent across many branches of physics and chemistry – that complex phenomena may be adequately accounted for in terms of simpler, more fundamental constituents. On this view, complex systems are treated as little more than the aggregate of their parts, themselves reducible to a minimal set of invariant elements.

By contrast, Marx's approach is decidedly *holistic*, and it was precisely this feature of his political economy that captured the attention of certain mainstream economists.

Ken Shibata – a leading figure of the Japanese mathematical school of economics in the 1930s – observed that neoclassical general equilibrium theory was 'ineffectual in making clear systematically either the organisation of present-day capitalistic society or the laws of its development', whereas Marx's political economy appeared better equipped to account for the concrete dynamics of capitalism, insofar as 'the organization of capitalist production and the laws of its development are analysed in a direct way' (Shibata 1933). In advancing this claim, Shibata was, in effect, underscoring the contrast between Marx's holistic method and the reductionist orientation of the *Lausanne School*.

Oskar Lange (1935) – another leading exponent of mathematical economics, strongly influenced by the *Austrian School* – likewise maintained that the economics developed within the various neoclassical traditions rests, in essence, upon a static theory of equilibrium. Within this framework, analytical attention is directed towards the mechanisms by which prices and quantities produced and exchanged adjust to variations in exogenous psychological, technical, and institutional parameters that define any given equilibrium configuration. Such changes are typically treated not as outcomes of the economic process itself, but rather as contingent, *exogenous shocks* whose origins lie beyond the purview of economic theory.

Furthermore, many institutional parameters remain unspecified, with the result that the social dimensions of the analysis are effectively effaced. By contrast, Marxian economics places the explicit specification of the institutional and social characteristics of the economic system at the very centre of its inquiry and, above all, advances a theory of economic evolution rather than one confined to equilibrium (Lange 1935).

Although many of Marx's economic categories were drawn from the tradition of classical political economy, they were, in effect, reworked through a far-reaching *critique* and systematic development of his predecessors (McLellan 1973). A number of his central concepts – beginning with those of *exchange value* and *capital* – diverge significantly from those of Ricardo, owing in no small measure to his grounding in the philosophy of Hegel (Arthur 2004).

Marx thus operated from a distinctly philosophical standpoint, which sets his analysis apart from that of most economists. Many of the more distinctive features of his economic thought, and above all its *holistic* orientation, derive from his dialectical conception of the world, partly inherited from Hegelian logic. It is therefore unsurprising that several of Marx's dialectical presuppositions may appear, to mainstream economists schooled in reductionist methodologies and the formal logic characteristic of modern physical and social sciences, as somewhat metaphysical or even obscure.

Yet a number of these ostensibly anomalous features of Marx's thought, rooted in his particular philosophical formation, now reveal striking affinities with more recent theoretical developments, many of which likewise call into question the *reductionist*

paradigm that informed classical physics and served as a principal methodological touchstone for neoclassical economics.

In what follows, we explore possible reinterpretations of Marx's key insights and conceptual innovations in the light of these contemporary approaches – including structuralism, dynamical systems theory, chaos theory, and statistical physics - with a view to rendering the ideas of a thinker writing a century and a half ago more accessible and intellectually consonant with the analytical frameworks of present-day economists and financial analysts.

2. Marx's dialectical view and structuralism

In the postface to the second German edition of *Capital, Volume I*, Marx explicitly foregrounds his distinctive deployment of the *dialectical method* as a defining feature of his work, setting it apart from other approaches to economic analysis (Marx 1990 [1873]: 102; Mandel 1990: 19–22). This method is most systematically articulated in the well-known *Introduction* to the *Economic Manuscripts of 1857–58* (Grundrisse), where Marx contends that the procedure of 'advancing from the abstract to the concrete' constitutes the only genuinely scientific means by which 'thinking assimilates the concrete and reproduces it as a mental concrete' (Marx 1986 [1857–58]: 38). For Marx, 'the concrete is concrete because it is the synthesis of many determinations, hence the unity of the diverse' (Marx 1986 [1857–58]: 38). It follows that the concrete can be apprehended in thought only as a process of synthesis – that is, 'by means of the progressive reconstruction of the concrete from the most simple, abstract, definitions of the concrete itself' (Rosdolsky 1977: 26). Accordingly, the scientific analysis of political economy must proceed 'from the simple, such as labour, division of labour, need, exchange-value ... to the state, exchange between countries and the world market' (Marx 1973 [1857–58]: 100–101), in order to grasp the *capitalist mode of production* in its *totality*.

For Marx, however, the dialectical method exhibits a dual aspect: at once analytical and expositional. The latter is exemplified in the composition of Capital, where Marx deliberately 'coquetted with the modes of expression' characteristic of Hegel, partly as a gesture of intellectual indebtedness at a time when Hegel's philosophy was widely dismissed as that of a "dead dog" (Marx 1990 [1873]: 103).

Marx, however, drew a clear distinction between his own dialectical method of inquiry and that of Hegel. For Hegel, dialectic constituted the fundamental movement of the "Idea"; for Marx, by contrast, it is the immanent motion of the material world, with thought unfolding dialectically only insofar as it forms part of that world and reflects its dynamics.

Marx further contended that Hegel had mystified dialectics through its idealist formulation, even though he had succeeded in presenting 'its general form of working in a comprehensive and conscious manner'(Marx 1990 [1873]: 103). It therefore remained possible, Marx argued, to extract the 'rational kernel' of the dialectic from within its "mystical shell" (Marx 1990 [1873]: 103).

Marx's dialectic has accordingly often been characterised as Hegel's dialectic 'turned right side up again'. Yet, for all this inversion, it retains a number of fundamental affinities with its Hegelian source. The distinction between *appearance* and *essence*, for example, together with the endeavour to penetrate ever more deeply

into successive layers of phenomena in order to uncover the laws of motion governing their development, are directly inherited from Hegel's dialectical logic as an account of the movement of thought.

Hegel's dialectic is, in essence, a *form of logic* – where 'logic' is understood as the *science of thought and of knowledge*. On his account, dialectic constitutes the immanent 'method' of thinking itself, that is, logic conceived as the natural unfolding of thought in accordance with its own inner necessity. The term 'method', in this context, is to be taken in its original Greek sense as 'the way'. Hegel therefore did not set out to codify the dialectical method as a discrete technique for improving thought; rather, he regarded it as the very process through which thought unfolds, such that he could assert:

> That from logic one learns how to think […] – just as if one were to learn how to digest or to move first from the study of anatomy and physiology – this is a prejudice that has long been put to rest' (Hegel 2010 [1831]: 8).

For more than a century, there has been sustained debate concerning the logical principles and laws underpinning the dialectics of Hegel and Marx. Hegel's dialectic has often been dismissed by formal logicians as unscientific, on the grounds that it is taken to repudiate the *principle of non-contradiction* (Lefebvre 2009 [1940]). Yet this judgement is far from uncontroversial. Certain developments in modern logic – such as *multivalued*, *linear*, and *fuzzy logic* – no longer treat contradiction as intrinsically problematic in the manner characteristic of classical logic. Moreover, there has been no shortage of attempts to formalise Hegelian dialectic within the frameworks of the *theory of inconsistent formal systems* (da Costa 1974) and the *logic of action* (Apostel 1967).

The traditional defence of the dialectics of Hegel and Marx advanced by many Marxist theorists, however, rests on the contention that *formal logic* is, in essence, the logic of a static world, whereas dialectic ought to be understood as the logic of *becoming*. When things undergo change, they cease to be what they were in their initial state and thus can no longer be adequately captured by their prior determinations. This transformation is precisely what Hegel and Marx designate as the 'negation' of the preceding state, a notion that acquires its full significance only within the process of *becoming*. Becoming, in turn, constitutes the true 'negation of the negation' – often referred to as the 'synthesis' of the dialectical process[1] – namely, the form through which contradictions are superseded and rendered intelligible within a higher-order unity.

According to Marx, dialectic 'includes in its comprehension and affirmative recognition of the existing state of things, at the same time also, the recognition of the negation of that state, of its inevitable breaking up; […] it regards every historically developed social form as in fluid movement, and therefore takes into account its transient nature not less than its momentary existence' (Marx 1990 [1873]: 20).

Within the framework of Hegelian logic, contradictions arise from thought's very attempt to determine and delimit concepts. Every proposition, in effect, entails a partial negation of itself, thereby undermining the definition it seeks to establish. The 'negation of the negation' denotes the capacity of reason to apprehend a new conceptual configuration that resolves this tension, reconciling the affirmative content of the initial determination with its partial negation within a more richly articulated and internally coherent concept. It is through this dynamic that thought, in Hegel's account, advances

[1] Hegel himself never employed the term 'synthesis' – a designation more properly associated with the dialectic of Fichte – to characterise what he described as the 'negation of the negation'.

from the most elementary forms of consciousness to progressively more sophisticated and fully developed modes of conceptualisation.

Since Hegelian philosophy identifies reality with thought, the dynamic laws governing the latter are, by definition, those governing the former. The difficulty arises, however, with Marx's attempt to construe dialectic in terms of the dynamics of the material world. For Marx, what obtains is not a strict identity but rather an *isomorphism* between the movement of thought and that of reality: first, because human thought is itself an immanent moment of the material world; and secondly, because it serves to represent that world's dynamics through the construction of *abstract models*.

Accordingly, to turn Hegel's idealist dialectic 'right side up again' by recasting it as a materialist account of real-world processes requires a translation of the purely logical notion of 'contradiction' – which, for Hegel, constitutes the driving force of the movement of thought – into a genuinely dynamic concept adequate to material reality.

From a materialist standpoint, contradiction is typically understood in terms of the condition whereby any given state of perceptible reality is marked by mutually *conflicting aspects* (Colletti 1975). It is precisely this tension among the constituent elements of reality that compels transitions between states and underpins the dynamics of real systems.

Yet, insofar as conflict is itself a *relational phenomenon*, it also brings to the fore the network of interrelations among the various components of any given configuration, as well as the relation of those components to the whole. In this sense, it implicitly entails a *systemic approach*.

The tendency to construe Marx's dialectic in exclusively dynamic or temporal terms may be traced, in part, to Engels, who sought to codify the *laws of dialectic* as laws governing change over time (Engels 1987 [1878]). However, dialectical movement is not reducible to temporality alone. For both Hegel and Marx, it also designates the operation of thought as it strives towards higher levels of conceptual determination. In such cases, the distinct moments of the process need not be arranged in a strictly temporal sequence; rather, they may be understood as constitutive elements of a single, unified act – namely, the formation of a new concept, which, for the mind, represents a new *totality* capable of resolving the contradictions previously encountered in the course of reasoning.

From this perspective, the relation between the *positive*, the *negative*, and *the negation of the negation* may be construed as a relation between the parts and the whole within a given line of argument. This points to a non-temporal dimension of dialectic, which Christopher J. Arthur (1998) characterises as 'systematic', in order to distinguish it from 'historical dialectic'.

Indeed, much of the work of Hegel and Marx deploys forms of *systematic dialectic*, even where these are illustrated through historical examples. For Hegel, '[i]t is in this dialectic as understood here, and hence in grasping opposites in their unity' (Hegel 2010 [1831]: 35).

There is, therefore, a dimension of dialectic that is not intrinsically dynamic, but rather concerns the structural relation between the parts and the whole within a unified conceptual *totality*.

In the preface to *Phenomenology of Spirit*, Hegel explicitly affirms that '[t]he true is the whole', thereby maintaining that truth is not to be located in isolated facts or discrete instances, but rather emerges from a comprehensive grasp of the process of development and becoming in its entirety (Hegel 1977 [1807]).

Moreover, as Hegel further observes (Hegel 2010 [1831]):

> [T]he whole is equal to the parts and the parts are equal to the whole. Nothing is in the whole which is not in the parts, and nothing is in the parts which is not in the whole.
> The whole coincides with the parts only to the extent that the parts themselves are embedded in the structure of their interrelationships and their functional relationship to the whole.
>
> […]
>
> The whole is not an abstract unity but the unity of a diversified manifoldness; but this unity within which the manifold is held together is the determinateness by virtue of which the latter is the parts. The relation has, therefore, an indivisible identity and only one selfsubsistence.
>
> […]
>
> But further, the whole is equal to the parts but not to them as parts; the whole is the reflected unity whereas the parts constitute the determinate moment or the otherness of the unity and are the diversified manifold. The whole is not equal to them as this self-subsistent diversity but to them together. But this, their "together," is nothing else but their unity, the whole as such. In the parts, therefore, the whole is only equal to itself, and the equality of it and the parts expresses only this tautology, namely that the whole as whole is equal not to the parts but to the whole.

Similarly, Marx's deployment of the dialectical method is by no means confined to the analysis of social evolution. Rather, it reflects a more encompassing dialectical perspective on reality, one structured by the *relation between parts and wholes*.

In the *Grundrisse*, for example, society is conceived as a totality within which its various components constitute merely 'distinctions within a unity' (Kain 1986). Each historically determined mode of production gives rise to corresponding forms of consumption, distribution, and exchange, as well as to the overall configuration of relations among these distinct moments. A transformation in any one of these elements necessarily reverberates throughout the others, even though '[p]roduction is the dominant moment, both with regard to itself in the contradictory determination of production and with regard to the other moments' (Marx 1986 [1857–58]: 36).

For Marx, any given economic system is constituted by a determinate articulation of specific modes of production, circulation, distribution, and consumption. The mode of production – occupying the dominant position within this configuration – may itself be understood as the conjunction of two distinct components: the productive forces and the objective relations of production (Godelier 1967).

It is therefore hardly accidental that this systemic dimension of the dialectics of Hegel and Marx led Ludwig von Bertalanffy to identify them as precursors of modern *systems theory* (von Bertalanffy 1968).

Marx, moreover, construed the entirety of social life in terms of 'structures', advancing the hypothesis that specific modes of production are characterised by necessary correspondences between their economic bases and institutional superstructures. Within this framework, he sought to account for the 'evolution' of social systems through the emergence and development of 'contradictions' – that is, *conflicts* – between these two levels (Godelier 1967).

One of Marx's principal objectives was thus to analyse the relation between event and structure, and to elucidate the genesis and development of the latter (Godelier 1967).

In Marx's terminology, the *productive forces* comprise the ensemble of factors of production – resources, tools, and human labour – characteristic of a given society at a particular historical juncture, which must be combined in determinate ways in order to

produce the goods required for its reproduction. The relations of production, by contrast, refer to the social relations between social groups – namely, *classes* – that, independently of individual volition, prevail within the sphere of the production process and govern the control of the means of production.

Capitalist relations of production, in Marx's account, consist in the relation between a social class that holds private ownership of the means of production and a class devoid of such property, whose members are compelled to sell the use of their labour-power to the former in exchange for wages. Each class both presupposes and complements the other within the *totality of the economic system*.

For Marx, therefore, the application of the dialectical method to the analysis of economic phenomena entails that these are not to be considered in isolation, but rather in their internal interconnection as moments of an *integrated totality* structured by a determinate mode of production. The various elements of this economic totality are governed by specific *laws of motion*, which pertain to a historically determined mode of production and express nothing other than the unfolding of its immanent contradictions.

In this sense, one may discern the genuine synthesis of the two aspects of dialectic: the structure, with its internal tensions, gives rise to the dynamics of the system, while those dynamics, in turn, drive the transformation of the structure and the reconfiguration of its contradictions.

Accordingly, Maurice Godelier (1967) maintains that Marx's conception of the scientific understanding of social systems rests precisely on the principle of uncovering the inner 'structures' that lie concealed beneath empirical evidence. These structures do not take the form of conscious and immediately visible 'social relations'; rather, they constitute a level of reality that remains hidden from view, underlying what presents itself as immediate empirical appearance. The logic of the latter, however, is dependent upon the operation of these latent structures, whose rational elucidation alone renders it possible to account for the totality of observed phenomena.

According to Marx, for instance, in the day-to-day operation of the capitalist system everything proceeds as if wages were paid for the worker's labour, and as though capital possessed an intrinsic capacity for *self-valorisation*, yielding profit to its owner. There is no immediate or self-evident indication that capitalist profit derives from unpaid labour. From the standpoint of both the 'manufacturer' and the worker, matters present themselves as though wages constituted a fair remuneration for the totality of labour expended. As Marx puts it, this 'form of appearance […] makes the actual relation invisible, and indeed presents to the eye the precise opposite of that relation' (Marx 1990 [1873]: 680). If wages assume the appearance of the *fair price* of labour, profit can no longer present itself as unpaid labour and must, of necessity, appear as the product of capital itself.

For Marx, therefore, all empirical economic categories merely express the visible relations of everyday economic life and, although they may possess a certain pragmatic utility, they are devoid of genuine scientific value. When economic analysis confines itself to such empirical categories alone:

> [it] actually does nothing more than interpret, systematize and turn into apologetics the notions of agents trapped within bourgeois relations of production. So it should not surprise us that precisely in the estranged form of appearance of economic relations that involves these prima facie absurd and complete contradictions - and all science would be superfluous if the form of appearance of things directly coincided with their essence - that precisely here vulgar economics feels completely at home, these relationships appearing all the more self-

> evident to it, the more their inner connections remain hidden, even though they are comprehensible to the popular mind (Marx 1991[1894]: 956).

According to Godelier (1967), any systematisation of empirical notions can yield no more than a coherent theory of appearances. Scientific knowledge of social reality, however, cannot arise simply through abstraction from the immediate perceptions of individuals. On the contrary, it must call into question the apparent self-evidence of conceptions derived from empirical experience in order to bring to light the hidden, immanent logic of social life. Scientific models, in this sense, must correspond to a level of reality that lies concealed beneath the domain of visible phenomena.

The concealment of the real structure of social systems is not attributable to any deficiency of human consciousness, but rather to the nature of the structure itself. If capital is not a thing but a social relation – that is, a non-sensible reality – it cannot, for instance, present itself directly in a sensible form such as means of production or raw materials.

According to Marx, however, each determinate structure of the real world is associated with a correspondingly determinate mode of appearance, which necessarily constitutes the point of departure for any form of spontaneous consciousness of that structure. Scientific understanding of these real structures, therefore, does not entail the abolition of such spontaneous consciousness, but rather a reconfiguration of its role.

Taken together, these considerations underscore a striking affinity between Marx's approach and that of modern *structuralism*. What may appear unduly metaphysical from the standpoint of mainstream economics is, in fact, entirely consonant with a *structuralist mode of analysis*, as Maurice Godelier (1967) observes.

Structuralism is an intellectual movement that first took shape in anthropology before extending its reach to other social sciences – such as psychology, sociology, and even economics – in an effort to generalise the achievements of the 'structuralist revolution' in linguistics associated with Ferdinand de Saussure (Boudon & Bourricaud 1989). There exist, of course, a number of distinct strands of structuralism; yet they share a common commitment to the view that social, cultural, and psychological phenomena can be properly understood only in terms of the relations obtaining between their constituent elements (Blackburn 2005). The ensemble of these relations constitutes the 'structure' of a given phenomenon, characterised by underlying and relatively stable laws of operation and development that account for the apparent variability of its empirical manifestations.

From a structuralist standpoint, the endeavour to uncover the internal structures concealed beneath empirical evidence is not a metaphysical exercise, but rather a means of constructing *theoretical models* capable of accounting for the interrelations observed among empirical phenomena. In this respect, it is entirely consistent with the *model theory* developed within the field of mathematical logic.

The transition from a real system – which we often take to be deterministic, notwithstanding the fact that its evolution remains unpredictable from our limited standpoint – to the mathematical model devised to represent it is, of course, unavoidably arbitrary. The correspondence between the putative real system and the model constructed to describe it rests solely on the capacity of the latter to 'work well' in anticipating certain general tendencies and qualitative features of the former's behaviour. In other words, through the use of models, even though real systems remain inherently unpredictable, their evolution can nonetheless be rendered more intelligible (Bertuglia & Vaio 2005).

Structuralism, with its abstract and *a priori* models, has progressively assumed an increasingly prominent role across the social sciences – most notably in anthropology, sociology, and linguistics – by virtue of its capacity to elucidate the principal lines of *qualitative development* in social phenomena; as such, its scientific credentials are now widely regarded as beyond serious dispute.

3. Marx's dialectical view, systems theory and cybernetics

Structuralism, of course, bears no direct relation to *systems theory*. Nevertheless, Jean Piaget (1970) – widely regarded as one of the foremost exponents of structuralism in psychology – refers to Ludwig von Bertalanffy's *organicism*, itself the point of departure for *general systems theory*, as an explicit attempt to introduce a 'structuralist perspective into biology', drawing directly on the insights of *Gestalt psychology*.

Be that as it may, the concept of 'structure' is closely bound up with that of 'system', the latter being understood as a set of 'interdependent elements' (von Bertalanffy 1968).

Marx explicitly employs the concept of 'system' in a recognisably modern sense, referring to the 'factory system', the 'bourgeois economic system', the 'industrial system', the 'credit system', the 'monetary system' and the 'financial system' (Marx 1990 [1873]). He deals with 'social division of labour' as a 'complex system' (Marx 1990 [1873]: 133), in which 'the independence of the individuals from each other has as its counterpart and supplement a system of all-round material dependence' (Marx 1990 [1873]: 203).

At times, he also resorts to organicist analogies, as when he refers to 'social metabolism' (Marx 1990 [1873]: 198–99) or observes that:

> Among the instruments of labour, those of a mechanical kind, which, taken as a whole, we may call the bones and muscles of production, offer much more decisive evidence of the character of a given social epoch of production than those which, like pipes, tubs, baskets, jars etc., serve only to hold the materials for labour, and may be given the general denotation of the vascular system of production (Marx 1990 [1873]: 286)

Furthermore, for Marx, it is very clear that the inclusion of an element in a context of relations determines some new characteristics and behaviours of it, as is clear from the following passage:

> Since [worker's] work forms part of a system based on the social division of labour, he does not directly produce his own means of subsistence. Instead of this, he produces a particular commodity, yam for example, with a value equal to the value of his means of subsistence, or of the money for it' (Marx 1990 [1873]: 324).

The modern systems approach is, to some extent, a by-product of the technological tendency to generate artefacts of ever-increasing complexity and efficiency. It arises from the pragmatic necessity of grappling with 'complexities' – that is, with 'wholes' or 'systems' – across a wide range of fields, a development that has entailed a fundamental reorientation of scientific thinking and a corresponding shift in its basic categories (von Bertalanffy 1968).

In due course, a new scientific worldview began to take shape, particularly within the natural sciences – one that was required to be logically coherent while also capable of addressing a number of persistent theoretical difficulties: resolving the paradoxes associated with wave and particle physics, accounting for the *emergence* and

development of novel phenomena, and, above all, coming to terms with processes characteristic of the biological and social sciences, where recurrent patterns unfold and evolve over time.

The advances in molecular biology, genetics, and evolutionary theory, in turn, underscored the need for new 'organismic' approaches. The focus of biological inquiry gradually shifted from the physico-chemical and molecular levels – traditionally governed by the reductionist assumptions of classical physics – towards higher-order modes of understanding the organisation of living systems.

A comparable reorientation occurred in psychology, where explanations of human behaviour progressively moved away from 'mechanistic' stimulus–response models towards accounts informed by structuralist perspectives (von Bertalanffy 1968).

It was within this broader intellectual milieu that *General Systems Theory* emerged during the 1940s and 1950s (Goertzel 1994). Its ambition was to provide an axiomatic framework in which a set of general propositions concerning the properties of systems could be rigorously derived from the very notion of 'system' itself, together with an appropriate set of foundational axioms.

According to Ludwig von Bertalanffy – widely regarded as the founding figure of this approach – the oft-cited maxim that 'the whole is more than the sum of its parts', though it may carry a faintly metaphysical resonance, is in fact intended in a strictly methodological sense: namely, that the distinctive properties of a system cannot be accounted for solely in terms of the characteristics of its components considered in isolation. The properties of the whole thus appear as 'emergent' relative to those of its constituent elements taken separately.

At the same time, von Bertalanffy maintains that, provided one has adequate knowledge of a system's components and of the relations obtaining between them, the behaviour of the system as a whole becomes more readily intelligible. In other words, a proper understanding of any system requires that one consider, in tandem, both the totality of its parts and the structured pattern of their interrelations (von Bertalanffy 1968).

This is, of course, precisely what occurs in any system of equations, and it is for this reason that certain systems theorists have regarded general economic equilibrium models as a paradigmatic instance of the systems approach (Lilienfeld 1978). Systems theory, however, tends to concentrate on the interrelations governing changes in the measurable attributes of the system under consideration, whereas traditional neoclassical economics is chiefly concerned with the analysis of static equilibria among system components under varying environmental conditions.

Physical and social systems alike consist of sets of concrete elements that interact with one another and may exhibit either static or dynamic properties. Abstract systems, by contrast, are conceptual and non-physical constructs: models that can be expressed in mathematical form and are designed to capture, in a stylised manner, the essential features of tangible systems.

A finite tangible system may be understood as comprising n concrete elements. If each of these elements is, in turn, characterised by m measurable attributes, the system can be represented abstractly as a set of $n \times m$ interacting variables, where 'interaction' signifies that the vector $\mathbf{q}$ of attributes stands in a set of relations $\mathbf{R}$ such that the dynamics of any given attribute q_i within $\mathbf{R}$ differs from its behaviour either in isolation or under an alternative relational configuration $\mathbf{R}'$ (von Bertalanffy 1968).

An abstract system may thus be defined as an ordered pair Σ := (**q**, **R**), where **q** denotes the set of variables and **R** the set of relations obtaining between them. The elements of **R** can be specified as mathematical functions linking variations in the system's attributes over time – that is to say, delineating the range of possible behaviours exhibited by the system.

In many instances, therefore, an abstract system admits of representation in terms of a system of simultaneous differential equations, such as the following:

$$\dot{\boldsymbol{q}} = \boldsymbol{f}(q_1, q_2, \cdots q_{n\times m})$$

where:

- $\dot{\boldsymbol{q}}$ denotes the column vector of time derivatives of the *m* measurable attributes associated with the n elements of the system;

- $\boldsymbol{f}(q_1, q_2, \cdots q_n)$ represents a vector-valued function defined over the *n* × *m* measurable attributes of the system.

Within this class of models, it is the system of equations that furnishes the 'structure' through which the temporal interdependencies among the system's measurable attributes are represented.

Systems theory, accordingly, constitutes an approach to the study of complex phenomena premised on the view that mathematical modelling can assist both in the formulation of problems and in the identification of their solutions, by rendering 'the obscure obvious', as Richard Levins (1998) aptly puts it – an ambition not altogether alien to Marx's own intellectual project. At the same time, it may be regarded as an effort on the part of a broadly *reductionist scientific paradigm* to come to terms with complexity, non-linearity, and change by means of increasingly sophisticated mathematical and computational techniques. Notably, however, it makes no explicit appeal to dialectics, even though such a perspective may be said to inform its epistemological underpinnings.

However, as both Hegel and Marx demonstrate, mathematics may itself exhibit dialectical dimensions, notwithstanding their apparent tension with its grounding in formal logic. Systems theory and dialectics are therefore not to be regarded as mutually exclusive, even if the latter cannot be straightforwardly subsumed under the former as a merely mathematical approach to the analysis of multi-component systems.

In any event, both structuralism and systems theory, much like Marx, place emphasis on the analysis of the whole and on the dynamic interrelation of its constituent parts. In each case, the focus falls less on the substantive properties of the elements themselves than on their organisational configuration – a concern that is likewise central to Marx's critique of political economy. Moreover, within both structuralist and systems-theoretical frameworks, each component of the whole conditions the 'meaning' of the others, that is, their functional role within the operation and development of the system as a whole (Nalbone 1974).

By contrast, the traditional reductionism characteristic of mainstream economics tends to construe the elements of a system as self-contained monads, independently determined and interacting solely on the basis of their intrinsic and pre-given properties.

From Marx's standpoint, such elements are conceived in an unduly metaphysical manner, rather than being derived through abstraction from empirical reality. For Max Weber, in fact, they are best understood as *ideal types*: not descriptions of how things are, but *heuristic constructs* designed to facilitate the interpretation and comparison of real-world phenomena with their simplified and stylised counterparts (Weber 1978 [1921]; 2012 [1904]).

However, Marx's dialectical perspective continues to point towards an aspect of the scientific understanding of reality that even systems theory has yet fully to assimilate (Levins 1998). Systems theory, for example, proves ill-equipped to address the relation between continuity and discontinuity within processes – a relation that, by contrast, lies at the very heart of Marx's dialectical method (Levins 1998).

Accordingly, while systems theory is well suited to the analysis of complexity, interconnection, and process, it remains, in important respects, bound to a reductionist framework. As such, it is unable adequately to account for 'the richness of dialectical contingency, contradiction or historicity', nor does it fully apprehend the subtleties of dialectical 'mediation' (Levins 1998).

The standing of *General Systems Theory* within the scientific community is no longer as favourable as it was in the 1970s. Many scholars now contend that no such unified theory can, in fact, exist, on the grounds that there are no general propositions capable of applying across all possible systems.

According to Ted Goertzel (1994), however, after roughly two decades of development, *General Systems Theory* effectively collapsed under the weight of its own ambitions. It was not so much refuted as it was exhausted: having articulated its central insights, it gradually declined as a distinct field of scientific inquiry.

Nevertheless, it would be misleading to regard *General Systems Theory* as an outright failure. On the contrary, it has yielded a number of enduring contributions, notably in the field of *cybernetics* through the work of W. Ross Ashby, as well as in various developments within *operations research*. Moreover, it bears a profound affinity with contemporary *theories of complexity* and *self-organising systems*, a connection that continues to inform current lines of research (Goertzel 1994).

Cybernetics, in particular, developed as the science of *control systems*, emerging from the same technological advances that gave rise to increasingly complex artefacts and which likewise informed the development of *systems theory*. In this respect, it shares a substantial body of mathematical techniques with the latter (Ashby 1956; Pask 1968).

One of the most significant outgrowths of cybernetics is *Viable Systems Theory*, which is concerned with the control processes governing the evolution of dynamical systems – such as living organisms – that are adaptive and capable of maintaining themselves far from thermodynamic equilibrium within a given range of environmental conditions (Aubin 1991). Such systems are characterised, above all, by their capacity to preserve the stability of key *state variables* through processes of adaptation and responsive adjustment to changing environments.

In its formal articulation, this theoretical framework is closely aligned with systems theory and furnishes a mathematically grounded approach to the analysis of the *dynamics of complex systems*.

Leo Apostel (1960) argued that cybernetics might furnish the most adequate formalisation of a genuinely dialectical process. A similar position was advanced by Oskar Lange (1965), who maintained that cybernetics provides a conceptual and

methodological apparatus well suited to the analysis of systemic evolution in terms consonant with dialectical materialism.

On this view, *contradictions* within a system – understood as the absence of equilibrium among the values of its variables – generate adjustments that tend towards configurations in which such contradictions are provisionally resolved. This dynamic corresponds, in essence, to the characteristic cybernetic mechanism of *negative feedback*. The resolution thus attained, however, is never final: it gives rise to new contradictions, which in turn precipitate further transformations. Systems, accordingly, do not persist in a state of equilibrium but are subject to continuous change.

Such change, moreover, typically assumes the form of development, insofar as it unfolds along determinate trajectories. Simpler systems tend, over time, to combine into more complex configurations, exhibiting *emergent properties* and novel *modes of action* – that is, *new forms* of behaviour.

Oskar Lange operationalised his cybernetic approach to economics by drawing upon conceptual frameworks derived from systems analysis and by constructing linear algebraic models based on 'black box' networks. In so doing, he demonstrated that the mode of action of a system – conceived as a set of *coupled active elements* – depends both on **T**, the matrix representing the modes of action of the individual elements, and on the system's *structure matrix* **S**, whose appropriately ordered elements comprise the set of *coupling matrices* that define the interactions between each pair of active elements.

This result is entirely consistent with the formulation advanced by von Bertalanffy, according to which a system may be understood as an ordered pair consisting of the set of its variables and the set of relations obtaining between them.

On the basis of his cybernetic approach, Lange interpreted and analysed Marx's schemes of reproduction – both simple and on an extended scale – as *viability* schemes (Lange 1970: 49–62).

Prior to this, and in conjunction with Marx's prices of production, these schemes had often been construed as early formulations of general equilibrium analysis (Samuelson 1957, 1959a, 1959b; Arrow 1968). Yet such an interpretation is, in important respects, misleading. Not only were these schemes originally formulated in terms of labour values rather than prices and quantities, but they were explicitly intended to delineate the manner in which a competitive capitalist system reproduces its socio-economic structure over time. In this sense, they are more appropriately understood – much like Quesnay's *Tableau économique* – as viability schemes, as Lange himself emphasised.

To be sure, the schemes of reproduction can be construed as representing hypothetical dynamic equilibria. Marx's original treatment of them, however, while undoubtedly insightful, does not amount to a fully-fledged dynamic analysis in the modern sense.

Marx elaborated a series of numerical examples designed to demonstrate that schemes of extended reproduction presuppose proportions between the production of capital goods and that of consumer goods markedly different from those obtaining under conditions of simple reproduction (Marx 1992 [1885]: 586–595). In his account, the requirements of sustained extended reproduction necessitate a reconfiguration of the composition of the social product in favour of the capital goods sector, which serves as the principal driver of accumulation. At the same time, the consumer goods sector must experience an expansion of the capital employed within it, so as to support the growth of variable capital in the capital goods department.

Such a configuration presupposes, of course, the availability of an adequate 'industrial reserve army', yet it also indicates the theoretical possibility of an absence of any structural deficiency in effective demand. Marx, it should be noted, did not posit the existence of any automatic coordinating mechanism capable of securing the proportions between the various departments of social production required for the smooth progression of accumulation. In more contemporary terms, while a form of dynamic equilibrium may be said to obtain under conditions of extended reproduction, it remains inherently unstable under the anarchic conditions of the market (Scarano 2025).

Marxian reproduction schemes, therefore, serve to illuminate the enduring problem confronting private capital, namely its incessant need to secure new outlets for realisation. Marx himself maintained that disproportionalities between investment and consumption could give rise to recurrent crises. More generally, he conceived the capitalist process of production as characterised by a persistent state of disequilibrium, generated by the essentially anarchic nature of production under private capital.

4. Dialectic view and complex systems *far-from-equilibrium*

For Marx, as for Hegel before him, primary reality is not *being-in-act* but *becoming*. It is in this form that the 'negation of the negation' – that is to say, the synthesis which preserves both the original affirmation and its partial negation – is realised in both thought and reality. From this standpoint, it is the *totality* that renders intelligible the meaning of the parts and the role they fulfil within it.

By contrast, neoclassical economics developed under the strong influence of *classical physics*, which was dominated by a mechanistic worldview in which reality presents itself as a kind of automaton. Within this framework, the fundamental processes of nature are conceived as deterministic and reversible, with emphasis placed upon time-independent laws, elevated to the status of axioms through the generalisation of observed regularities. It follows that, once the state of a system has been specified in quantitative terms, these reversible laws are taken to determine both its future trajectory and its past evolution.

To be sure, a wide range of phenomena present themselves in precisely such a manner: they exhibit no privileged direction of time and can be adequately described within a mechanistic framework. Yet we are equally familiar with numerous irreversible processes – in both chemistry and biology – that presuppose a definite *arrow of time*. Moreover, many processes, including biological evolution and the development of social systems, are marked by an irreducible element of contingency. It is hardly surprising, therefore, that since the closing decades of the twentieth century the scientific conception of nature has undergone a profound transformation, characterised by an increasing emphasis on temporality and complexity.

However, increasing complexity tends to amplify the role of history (Jacob 1981). To conceive of a social system as a 'historical structure' is, in effect, to pose simultaneously the question of its functioning and that of its genesis, and to seek to address them in tandem – in other words, to aim at once for a genetic and a structural explanation. The methods of classical physics, however, are ill-suited to this task, given the limitations inherent in their characteristic modes of modelling.

As noted above, Marx's engagement with classical political economy stemmed directly from his materialist conception of history, according to which every mode of

production constitutes but a transitory phase in the historical development of humankind (McLellan 1973). It follows that the capitalist mode of production itself must have a determinate trajectory – encompassing its origin, ascent, development, decline, and eventual dissolution (Mandel 1990).

Marx was therefore not in search of universal laws governing the operation of economic systems, in the manner of the classical economists. Rather, his principal aim was to uncover and analyse the *laws of motion* specific to the dominant mode of production of his time, with a view to anticipating the principal turning points in its historical trajectory and, ultimately, its likely demise.

All complex entities are the outcome of evolutionary processes in which two distinct classes of factors come into play: on the one hand, constraints that define the rules of operation and delimit the bounds of the possible; on the other, a succession of contingencies that shape the historical unfolding of events. The latter, while not necessary in a general sense, constitute the necessary moments of a particular historical trajectory, thereby revealing the path-dependent character of real phenomena (Jacob 1981).

From this perspective, purely mechanical systems tend to be governed more by constraints than by their history. Thermodynamic systems, by contrast, are structured by the irreversibility implied by the arrow of time. Biological and social systems, ultimately, are best understood as the outcome of an intrinsically 'historical process' (Jacob 1981).

In the case of Marx, a reference to thermodynamics is by no means without significance. As Michio Morishima (1973) has argued, Marx may in fact be regarded as the first macroeconomist in the history of economic thought prior to John Maynard Keynes, insofar as he was the first to engage systematically with *macroeconomic aggregates* and their *laws of motion*. Accordingly, his primary concern lay in the analysis of the historical dynamics of the principal aggregates that characterise such systems, and his central objective was, beyond doubt, to elucidate the movement of their aggregate magnitudes over time.

Macroeconomics shares a number of salient features with thermodynamics. Both are concerned with aggregate magnitudes, abstracting from the behaviour of individual components, and seek to identify mathematical regularities governing their average properties. Marx, for his part, frequently refers to *average prices*, *average techniques*, and the like, while it is precisely average magnitudes that constitute the principal object of thermodynamic analysis.

More fundamentally, Marx accounts for the dynamics of economic systems in terms of *value* – understood as incorporated abstract social labour – which may be interpreted as a *state function* of those systems. In this sense, the concept of *labour value* can be regarded as an *emergent aggregate property* of economic systems characterised by an unplanned and largely unconscious social division of labour. Accordingly, Marx's *law of value* – according to which the sum of outputs, evaluated at their production prices, must equal the total value produced – may be seen as a general constraint that confers substantive meaning upon the *determined abstractions* he deploys in his analysis of capitalist dynamics. Within the aggregate economic system, it thus assumes a role closely analogous to that of *conservation laws* in conservative systems in thermodynamics and mechanics (Scarano 2021).

Traditionally, mechanics and thermodynamics have offered markedly different conceptualisations of the conditions of *possibility of history* – that is, of time itself. The

evolutionary paradigm, which emerged within the physical sciences from attempts to reconcile dynamics with thermodynamics, has achieved only a partial synthesis, and has done so by foregrounding the *emergence*, within complex dynamical systems, of particular 'structures' arising from *non-equilibrium processes*.

According to Arthur Eddington (1929), nature is governed by both primary and secondary laws. The former regulate the behaviour of individual particles, whereas the latter pertain to aggregates or collections of elements. In the latter case, an account of elementary behaviours, taken in isolation, proves insufficient to grasp the functioning of the system as a whole. A paradigmatic instance of a secondary law is the *second law of thermodynamics*, which introduces into physics the notion of an 'arrow of time'. This law, in turn, brings with it the concept of entropy as an intrinsic property of thermodynamic systems, driving them – when isolated – towards increasing disorder and disorganisation.

Within the framework of the *thermodynamics of systems far from equilibrium*, however, irreversible processes are understood as sources of order rather than mere agents of decay. Order and organisation may arise 'spontaneously' out of disorder and chaos through processes of *self-organisation*. Entropy, on this view, is not simply synonymous with an inexorable drift towards disorganisation; under specific conditions, it may instead serve as the very wellspring of order (Prigogine & Stengers 1984).

From this standpoint, it becomes necessary to distinguish between systems *in equilibrium*, those *near equilibrium*, and those *far from equilibrium* (Toffler 1984). Systems *far from equilibrium* invariably comprise subsystems subject to continual *fluctuation*. On occasion, individual fluctuations – or particular combinations thereof – may be amplified through *positive feedback*, to the point of destabilising the pre-existing organisation. Such 'singular moments', or 'bifurcation points', constitute genuinely 'revolutionary moments': their trajectories cannot be determined ex ante, rendering it impossible to predict whether the system will collapse into chaos or instead transition to a higher level of organisation. These *emergent forms* are termed 'dissipative structures', because they require a greater throughput of energy to be sustained than the simpler configurations they supersede (Prigogine & Stengers 1984).

Such chemical and physical concepts readily lend themselves to illuminating analogies with quintessentially economic phenomena – such as *economic crises* and *technological upheavals* – upon which Marx placed considerable emphasis, but which neoclassical economics has often struggled to accommodate within its analytical framework. The disequilibrium phenomena examined by Marx may thus be plausibly interpreted in terms of *fluctuations*, *feedback amplification*, *bifurcations*, and the *emergence of dissipative structures* within dynamic economic systems.

Thermodynamics, in turn, demonstrates that, under conditions *far from equilibrium*, novel forms of organisation may arise spontaneously. As a dynamical system is driven away from equilibrium, its behaviour shifts from what Isaiah Berlin (2013 [1977]) termed the 'repetitive and universal' – the proper domain of reductionist abstraction – towards the 'specific and unique', which is the hallmark of historical processes. Within such dynamics, processes of self-organisation may unfold, giving rise to unexpected and non-homogeneous configurations – namely, *dissipative structures*. In these far-from-equilibrium conditions, therefore, transformations from disorder to order become possible, and new dynamical states may emerge as a consequence of the ongoing interaction between the system and its environment.

Near-bifurcations systems typically exhibit pronounced fluctuations. Under such conditions, they appear, as it were, to 'hesitate' among a plurality of possible evolutionary trajectories, and the *law of large numbers*, in its conventional sense, ceases to hold. A seemingly negligible fluctuation may thus precipitate an entirely new course of development, radically altering the macroscopic behaviour of the system as a whole.

Fluctuations that drive a system far from equilibrium generally give rise to a *critical moment* or *bifurcation point* (Toffler 1984). At such a point, it is intrinsically impossible to determine ex ante the system's subsequent state, and *contingency* assumes a decisive role in directing its evolution along a particular path. Once this trajectory has been 'chosen', however, deterministic dynamics reassert themselves, at least until the system approaches a further bifurcation point.

The thermodynamics of non-linear systems far from equilibrium thus reveals that *chance* and *necessity* are equally indispensable to any adequate account of such systems. Far from constituting irreconcilable opposites, they operate in tandem, jointly shaping the evolutionary course of systems over time.

Once again, the analogy with the social phenomena and historical processes analysed by Marx – through the lens of dialectical contradictions and the transformation of quantity into quality – appears unmistakable.

Marx, and subsequently Joseph Schumpeter, conceived capitalist development as an inherently dynamic process that, by its very nature, precludes any notion of equilibrium understood as a *state of rest* or of *uniform linear motion*. Capitalism is thus viewed as intrinsically contradictory and perpetually self-destabilising. In this perspective, economic movements, as social phenomena, are marked by incessant change, structural asymmetries, and uneven development, and are punctuated by crises and disruptive upheavals that are not *exogenous shocks* but rather arise from the system's own immanent laws of motion.

Within this perspective, disequilibria and crises constitute the norm in a system that is intrinsically anarchic. Disequilibrium conditions continually generate forces that tend to transform the prevailing state. Indeed, several phenomena analysed by Marx – such as the concentration and centralisation of capital – may be fruitfully interpreted as 'dissipative structures' emerging from non-equilibrium processes.

Even when dynamic forces are persistently out of equilibrium, their behaviour may still be rendered intelligible through the notion of *attractors*, as demonstrated by modern theories of *deterministic chaos*, which can play a pivotal role in accounting for the evolution of complex systems (Medio & Gallo 1992).

Attractors are, strictly speaking, abstract constructs pertaining to the models we devise, rather than to the empirical systems under investigation (Bertuglia & Vaio 2005). They may be understood as configurations of variables endowed with a basin of attraction that confers upon them a degree of stability.

Many phenomena whose observable manifestations are marked by a high degree of unpredictability – such as fluctuations in market prices, particularly in financial markets – may, in fact, be 'controlled' by chaotic attractors that effectively 'contain' their dynamics within a stable basin of attraction, provided that external perturbations remain within certain bounds.

From this perspective, chaotic phenomena may be regarded as 'robust', insofar as a *strange attractor* continually draws them back into a state of dynamic stability. This remains the case until an exogenous disturbance of sufficient magnitude dislodges the system from its original basin of attraction, thereby propelling it into that of another

attractor. If this interpretation holds, then the identification of the relevant attractor would suffice, in principle, to render intelligible the dynamics of processes that might otherwise appear irreducibly erratic (Bertuglia & Vaio 2005).

The differential equations underpinning a model – those that define what is commonly taken to be the 'law' governing the real process under consideration – are typically non-linear and may give rise to deterministic chaos, which often provides a plausible representation of observed fluctuations. Such chaos, however, is of a purely mathematical kind – that is, a construct of the human intellect – and thus raises the perennial question of its correspondence with the empirically observed and intrinsically unpredictable variability of real-world phenomena (Bertuglia & Vaio 2005).

Once again, the concept of the attractor admits of suggestive parallels with Marx's thought. The *schemes of reproduction*, for instance, may be interpreted as dynamic attractors that can only be realised contingently under the anarchic conditions of capitalist markets. Likewise, *prices of production* and *labour values* themselves may be understood not as equilibrium points in any strict sense, but rather as attractors. In other words, they function as analytical constructs that serve to identify the forces continually set in motion by the persistent imbalances characteristic of such markets.

An attractor, moreover, need not correspond to a specific point along the trajectory of a variable describable as a function of time. Nor does its significance necessarily reside in its own numerical value; rather, it lies in the manner in which it conditions and organises the behaviour of other magnitudes. From this standpoint, the proper object of analysis is the *gravitational process* itself, rather than the attractor taken in isolation. That said, the determinants of the attractor's value are by no means inconsequential, since the vectorial properties of the underlying 'gravitational' forces ultimately depend upon it.

5. Conclusion

Karl Marx's philosophical formation rendered him a singular figure within the discipline of economics, endowing his work with a wealth of original interpretations, concepts, and insights which – broadly in line with Thomas Kuhn's account of *scientific revolutions* (1996) – may be said to have inaugurated a distinct *paradigm* within political economy. Although many of his analytical categories were inherited from the tradition of classical political economy, Marx sought to establish a new science through a radical critique of his predecessors, grounded in his dialectical method and worldview.

From the perspective of *catastrophe theory*, the disintegration of the *Ricardian schoo*l may be construed as a 'critical point' in the evolution of economic thought, giving rise to a cultural 'bifurcation' from which two divergent trajectories emerged: the Marxian approach on the one hand, and the neoclassical on the other.

The persistent historical underestimation of Marx's political economy by the mainstream of the discipline may be attributed, above all, to the disquieting political implications of his analysis. As Marx's ideas came to serve as a touchstone for a wide range of radical political movements, according intellectual legitimacy to his economic theories risked lending credence to their broader political programmes – a prospect unlikely to commend itself to the principal apologists of the prevailing economic order.

At the same time, many of Marx's insights struggled to gain wider currency within an intellectual climate dominated by positivism, not least because of their ostensibly

metaphysical character. Yet, with the benefit of hindsight, a number of these insights appear strikingly consonant with more recent scientific developments, which have themselves been compelled to move beyond the conceptual confines of classical physics.

Marx analyses social reality as ‘a process that evolves in response to its own internal contradictions’ (Foley 1986). The relations he examines are in a continual state of transformation and ‘cannot be understood independently of the history that produced them’ (Foley 1986).

This perspective stands in marked contrast to the static conception of equilibrium that characterises neoclassical economics. It nevertheless represents but one mode of inquiry among others, and may be regarded as both an alternative and a complement to different analytical approaches. Indeed, much as in physics – where the same phenomenon may be examined concurrently from classical, relativistic, and quantum standpoints – so too in economics it ought to be possible to analyse a given phenomenon from a plurality of perspectives, each rooted in a distinct scientific paradigm.

In his analysis of economic dynamics, Marx incorporates phenomena that contemporary mainstream economics frequently relegates to the status of exogenous shocks, largely because they elude prediction within its deterministic analytical framework.

Marxian political economy, by contrast, places the specification of the organisational and social features of the economic system at the very heart of its analysis, thereby offering a theory of economic evolution rather than one confined to equilibrium states. Above all, Marx underscores that the purportedly automatic self-regulating mechanisms of capitalism are, in reality, but moments within a broader dialectical process of development – one that engenders progressively intensifying internal contradictions within the system itself.

From this vantage point, the present ‘age of turbulence’ (Greenspan 2007), marked by profound structural change and intensifying domestic and international tensions, provides a compelling rationale for revisiting and reassessing key elements of Marx’s political economy.

Moreover, concerns regarding the scientific robustness of Marx’s approach may be, at least in part, addressed through the application of mathematical tools drawn from dynamical systems theory, chaos theory, and statistical physics. Such frameworks have the potential to render the ideas of a thinker writing a century and a half ago more tractable, and more readily aligned with the analytical sensibilities of contemporary economists and financial analysts.

However, the richness and depth of Marx’s work admit of interpretation from a plurality of philosophical, historical, sociological, and economic standpoints, and any single perspective risks doing a degree of injustice to the others. In this light, even the present attempt to discern within his thought themes of complexity and dynamic systems may inadvertently circumscribe it within boundaries that are unduly restrictive when set against the breadth of his original vision.

That said, the purpose of this exercise is to bring to the fore certain epistemological dimensions of Marx’s political economy which, in their original formulation, might otherwise be dismissed as excessively metaphysical and of limited relevance to contemporary economic discourse. Yet, once recast within more modern epistemological frameworks, these same elements may prove to be of considerable

value in addressing some of the limitations of mainstream economics in grappling with complex and continuously evolving systems. Such an endeavour necessarily entails a willingness, where appropriate, to move beyond Marx himself.

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ROMA TRE
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