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by

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1 *Introduction*

The last three decades have seen an explosion of research in economics inspired by evolutionary thinking. There has been an upsurge in the number of publications addressing themes that have come to be grouped under the heading of 'evolutionary economics', paralleled by the foundation of new journals and new scientific societies devoted to the subject matter. It was a great moment for the science of economics, and for evolutionary economics in particular, when *An Evolutionary Theory of Economic Change* was published, in 1982, by Richard Nelson and Sidney Winter – a work that served as an icebreaker and, arguably, gave the early stages their critical momentum.

In a recent bibliometric account comprising the abstracts of articles published in all economic journals over the past half-century, Sandra Silva and Aurora Teixeira have been documenting the impressive magnitudes and structural dynamic of this trend – a trend that has accelerated tremendously in the last two decades, considering that 90 per cent of this body of research is recorded as having been published since 1990 (Silva and Teixeira, 2009; EconLit database).

The aim of this paper is to present evolutionary economics as a particular *school of thought*. To this end, it is necessary to keep the analysis general enough to highlight the major differences from other schools of thought, but it is also necessary to frame the general exposition in such a way that it allows the main lines of research at present to be accommodated systematically. Inevitably, the choice of general framework can be expected to differ substantially from author to author, and as a consequence any choice of research fields and works is bound to be subjective.

The best approach in the circumstances is to follow the Popperian postulate of falsification and to make the premises upon which the choice of general exposition and of research fields is based as explicit as possible. Specifically, I propose that (evolutionary) economics should be conceived of as *rule-based economics*. Turning to the particular sources used, the discussion about ontological foundations (section 5) draws on Dopfer (2005), as does that about rule taxonomy (section 6) and the architecture of micro–meso–macro, which also draws on Dopfer and Potts (2008) and Dopfer, Foster and Potts (2004). These should provide sufficient disclosed evidence with which to challenge the premises on which the general framework is based and, hence, to obtain a rationale for highlighting the significance of *different* research lines and contributions.

2 *Realism of perception*

It was Thorstein Veblen (1898) who introduced the term 'evolutionary economics' into the discipline, and he did so in recognition of the fundamental fact that the nature of the modern economy may be captured most adequately by referring to its dynamic (1909:621):

> To the modern scientist the phenomena of growth and change are the most obtrusive and most consequential facts observable in economic life. For an understanding of modern economic life the technological advance of the past two centuries – e.g., the growth of the industrial arts – is of the first importance.

Turning to 'neoclassical' economics, as he called it, Veblen continues:

> [B]ut marginal utility theory does not bear on this matter, nor does this matter bear on marginal utility theory.

Although Joseph Schumpeter's theoretical work differed from Veblen's in fundamental ways, the two pioneers of the evolutionary school found themselves in entire agreement when it comes to the recognition that continual change is the hallmark of modern capitalism. As Schumpeter (1942 [1976]: 82) puts it,

> Capitalism ….. is by nature a form or method of economic change and not only never is but never can be stationary.

The engine of the system of 'restless capitalism' (to use Stanley Metcalfe's felicitous phrase) is the energetic-dynamic *entrepreneur*, who carries out new combinations in every province of the economy. Schumpeter designates the entrepreneur as the dynamic alter ego of Vilfredo Pareto's static *Homo oeconomicus*. He portrays the particular functions of this agent in his *Theory of Economic Development* (Schumpeter, 1912 [1934]), and describes their withering away in the managerial large-scale enterprise of late capitalism in his *Capitalism, Socialism and Democracy*, published in 1942. The institutional conditions of the engine of change of modern capitalism have seen a number of metamorphoses, but at no time in its historical course has its engine come to a halt.

There is a distinct difference between the kind of dynamic at work in a traditional system and that in a modern one. Change may well occur in the former on account of altered external factors and data, but this does not represent the evolutionary change that is characteristic of modern capitalism. In the words of Schumpeter (1942 [1976]: 82-83):

> [The] …. evolutionary character of the capitalist process is not merely due to the fact that economic life goes on in a social and natural environment which changes and by its change alters the data of economic action… Nor is this evolutionary character due to a quasi-automatic increase in population and capital or to the vagaries of monetary systems… The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production or

> transportation, the new markets, the new forms of industrial organization that capitalist enterprise creates.

Schumpeter did not consider extant neoclassical theory to be deficient in its treatment of static (non-changing) aspects – in fact, he went so far as to praise Léon Walras's static equilibrium theory as the *magna carta* of the discipline – but, rather, that it lacked a *dynamic* element (Schumpeter, 1908: 182–183; cit. Andersen 2009:5):

> Only Statics has hitherto been somewhat satisfactorily worked up… [but] Dynamics is still in its beginnings…

Schumpeter was well aware that a theoretical programme dealing with dynamic issues would encounter major conceptual and methodological challenges, for which statics could not provide any answers (183):

> Statics and Dynamics are completely different fields; they concern not only different problems but also different methods and different materials.

Considering that dynamics was still in its infancy and that there was little knowledge about 'different methods and different materials' at this time, it is amazing that Schumpeter even dared to embark on the ambitious project of writing a full-blown theory of economic development.

Alfred Marshall, another heroic member of the 'hall of fame' of the evolutionary school, shared Veblen's and Schumpeter's fundamental perceptions about modern capitalism. He too acknowledged the fact that change – continuous, novelty-driven, qualitative and structural change – was the distinctive feature of the modern regime. Arguably, however, he was more reluctant than Schumpeter to make compromises when it came to method and formalisation and, in general, to the use of technique. Schumpeter (1997: 93, 101) emphasises Marshall's pioneering contribution to the understanding of the dynamic nature of modern capitalism:

> Marshall was one of the first economists to realize that economics is an evolutionary science…, in particular that the human nature he professed to deal with is malleable and changing, a function of changing environments. […] His thought ran in terms of evolutionary change – in terms of organic, irreversible process. And something of the flavour of it he imparted to his theorems and concepts and still more to the factual observations with which he presented them.

Marshall emphasises repeatedly in his works the endogenous dynamic of modern capitalism. Like Schumpeter, he considered change not simply as an alteration of quantitative data or of external influences but, rather, as a history-dependent process of organic growth (Marshall, 1898: 42–43):

> 'Progress' or 'evolution', industrial and social, is not mere increase and decrease. It is organic growth, chastened and confined and occasionally reversed by the decay of innumerable factors, each of which influences and is influenced by those around it; and every such mutual influence varies with the stages which the respective factors have already reached in their growth.

To Marshall, the nature of this process was very similar to the ideal found in modern evolutionary biology, eschewing that of classical mechanics – a position well epitomised in the familiar passage in the foreword to the 8th edition of his *Principles* (1920/1972: xii):

> The Mecca of the economist lies in economic biology rather than in economic dynamics.

The only problem was, Marshall could see formidable hurdles in the way of actually undertaking the journey to Mecca. He adds the following to his call to undertake this journey (xii):

> But biological conceptions are more complex than those of mechanics… This fact, combined with the predominant attention paid in the present volume to the normal conditions of life in the modern age, has suggested the notion that its central idea is 'statical', rather than 'dynamical'. But in fact it is concerned throughout with the forces that cause movement: and its key-note is that of dynamics, rather than statics.

The work of Marshall – more than that of any other pioneer of the evolutionary approach – demonstrates the conflicting priorities between realism and method. Schumpeter's (1941) appraisal of Marshall's work is itself a portrayal of this difficult journey, which alternates between statics, in honouring the demands of method, and dynamics, in satisfying those of realism given the ever-changing nature of the system. Thus, Schumpeter (1997: 95) emphasises that '[t]he analytical core or kernel of the *Principles* consists of course in a theory of economic statics', but, at the same time, he also remarks (101) that Marshall's theory, despite its deficiencies, represents ultimately an evolutionary theory:

> I do not think that the theory of evolution…was satisfactory… But still it was a theory of evolution, an important development of Adam Smith's suggestions, and greatly superior to what Ricardo and Mill had to offer on the subject.

This difficult course, alternating between the conflicting demands of method and of realism, has characterised much of the history of theory formulation in evolutionary economics right from its very inception.

Finally, there is Friedrich Hayek's contribution, as the fourth pillar of the exegetically construed edifice of evolutionary economics. He saw the essence of the modern market economy in the distinctive complexity and accelerated evolution of knowledge. For him, the European Enlightenment of the seventeenth and eighteenth centuries had not only changed the meaning and the significance of human knowledge for society at large, it had also altered radically the conditions in which the economy in particular operated. Hayek rejected a deterministic notion of societal or economic development and instead held the view of a future-open development, informed by the vision of what Adam Smith has called 'the Great Society' and Karl Popper 'the Open Society' (Hayek, 1973: 2). All the theoretical concepts that Hayek went on to develop in great detail may be traced back to his realisation of the significance of knowledge. Synchronically, market order shows up as a problem of coordinating divided knowledge; diachronically, economic evolution originates with a process of growth and of complexification of knowledge.

Hayek's emphasis on the role of knowledge in the process of coordination brought him, inevitably and naturally, into opposition to the mainstream doctrine, which largely neglects knowledge (Hayek, 1945: 532):

> Clearly there is here a problem of the division of knowledge, which is quite analogous to, and at least as important as, the problem of the division of labour. But, while the latter has been one of the main subjects of investigation ever since the beginning of our science, the former has been as completely neglected, although it seems to me to be the really central problem of economics as a social science.

The knowledge problem is 'central', embracing not only the particular provinces of price theory but also, more generally, the way in which the different commodities are obtained and used (532):

> [P]rice expectations and even the knowledge of current prices are only a very small section of the problem of knowledge as I see it. The wider aspect of the problem of knowledge…is the knowledge of the basic fact of how the different commodities can be obtained and used and why the subjective data to the different persons correspond to the objective facts.

There is, therefore, a 'narrow' aspect to knowledge, referring to current prices or price expectations, and a 'wider' aspect, referring to knowledge about the generation and use of the knowledge upon which price formation is based. Generally, there is knowledge that pertains to the knowhow required to perform economic operations, on the one hand, and factual knowledge that relates to an understanding of the circumstances of the environment in which operations are performed, on the other hand. The former is called *generic* knowledge and the latter *operant* knowledge – a distinction that is at the heart of the theoretical exposition to be introduced subsequently (section 6).

The evolution of the knowledge that governs economic operations and outcomes works out in a process in which, first, 'knowledge bits' originate in a group and, subsequently, those variants that have a selective advantage are retained. The evolutionary course of knowledge follows the logic of a Darwinian trajectory – specified in biology by the phases of mutation, selection and retention (Hayek, 1973). Hayek joins in the chorus with Veblen, Marshall and other proponents of an evolutionary approach in advocating biology rather than mechanics as the economist's Mecca.

In Hayek's theoretical efforts to specify the notion of knowledge, the concept of the *rule* plays a pivotal role. At the micro level, the term shows up as 'rules of conduct'; at the macro level, it appears as social rules coordinating individual activities under the premise of man-made or spontaneous organisation. The conceptual term 'rule' may carry either a positive or a normative meaning. In a positive mould, a rule is a 'knowledge bit', providing individuals with the potential to carry out operations; here, 'rules…follow from their desires and their insights into relations of cause and effect' (Hayek, 1973: 45). In turn, '[f]or the resulting order to be beneficial, people must also observe some conventional rules…'; here, rules 'are normative and tell them what they ought to or ought not to do' (45).

Although rules may come in different guises, they share a common syllogistic structure. Whether individual, social, positive or normative, they are all anchored in an 'if–then' logic. Given its general format, the rule concept may serve as key device for constructing the overall theoretical framework of evolutionary economics (section 6). On top of this, it is instrumental as a bridging concept, connecting the domain of theorising with that of modelling and computational analysis, in which the concept of the 'rule' is widely used (section 5).

The early pioneers of evolutionary economics perceived the economy as a highly dynamic system. This fundamental perception of reality informed their theorising and their methods substantively. The classical economists before them and the neoclassical economists after them had a different perception, and their ways of theorising and their methods differ accordingly.

3 Evolutionary ontology

Addressing economic change theoretically requires, first of all, identification of the fundamental premises on which the theoretical statements are to be based. A mechanistic world view can provide us with a set of premises that would allow a theory of rest and equilibrium to be constructed, but not one that would explain endogenously continuous change. Ever since its early days, evolutionary economics has been confronting the problem of proper *ontological foundations* to provide guidance for the construction of a theory explaining the phenomenon of change.

Looking for new foundations, as we have seen, Veblen, Marshall and other pioneers considered *biology* to be of primary interest. Recently, philosophers of biology have proposed that Charles Darwin's explanatory principles attain universal significance, suggesting that they may be of scientific interest not only for biologists but for students of other disciplines as well. This persuasive idea has found advocates among economists, who have been proposing that 'universal Darwinism' may inform theory construction in economics in a fundamental way (Hodgson and Knudsen, 2010).

At a more general level, philosophers and biologists have considered *continuity of change* (not one of rest) to be of ontological significance. After he had inspected geological and palaeontological evidence, Gottfried Leibniz proposed a 'principle of continuity' (Öser, 1974); Darwinians such as Thomas Huxley defended their 'continuity theory' against creationists; and Charles Peirce made the 'principle of continuity' a centrepiece of his process philosophy. More recently, the important proposal has been made to premise economic theorising as well on a *continuity thesis*, which views evolution as a *natural history* of increasingly more complex behaviors and production regimes (Witt, 2003). In line with this proposition, a *naturalist* approach to economics has been advocated.

The two strands of discussion have provided valuable insights into various theoretical topics (Darwinian principles explaining the dynamic of institutions, the continuity thesis shedding light on cross-level dependence and transition analysis), but it is fair to say that these endeavours have not yet provided a systematic exposition of what may represent the *ontological foundations* for a theory that deals with change in an economic system.

Exploring the field of ontology further, we arrive at a rich legacy handed down from philosophers of science such as Alfred Whitehead, Charles Peirce and Henri Bergson. Drawing on findings from disciplines such as physics, biology and the social sciences, they have advanced important ontological statements that, together, may be considered to represent an *evolutionary ontology*.

The task facing us in this analysis is not a detailed exegesis of these works but, rather, the crystallising from them of what may be agreed to represent the *essentials of an evolutionary ontology*. Three ontological propositions are submitted. Being ontological, the propositions represent generalisations about reality, and therefore they are subject to falsification. The propositions also represent the premises for the lower, theoretical, level, however, and at this level they are no longer questioned. They are taken to be '*worth*' (Greek *axio*) *not to be questioned*. In the process of theorizing, the ontological propositions thus attain the status of *axioms*. Challenging the axioms means challenging the validity of the evolutionary ontology proposed.

In a nutshell, the three axioms are as follows.

Axiom 1

All existences are *physical actualisations of information* in time and space. There is *bimodality*, meaning that their complete representation requires an acknowledgement of both physical (matter and energy) and non-physical (information) categories of existence.

Axiom 2

Existences have a *propensity to associate*; given (thermodynamic) conditions, they emerge into *structure*.

Axiom 3

Structures unfold as *process*. There are *repeatable* and *non-repeatable* processes. In a regime of repeatable processes, structural characteristics or functional attributes are *retained* (viability); in one of non-repeatable processes, they change (evolvability).

4 Analytical ontology: new concepts of representation

Although adequate ontology is an elementary requirement for theorising, scientific progress also depends crucially on the improvement of formal-analytical weaponry, such as mathematical representation or modelling techniques. Schumpeter and Marshall both deplored the lack of adequate techniques for representing economic dynamics, but there has been a change of wind since the 1980s.

Advances in computing power have opened up entirely new possibilities for dealing with masses of data and information, and the computational sciences have provided an arsenal of new methods for analysing or modelling the complex phenomenon of economic change. The radical novelty of these developments lies not in the improvement of the received tools such as calculus, topology or descriptive statistics (which are all suitable for the purposes of an analysis cast in a mechanistic mould) but, rather, in furnishing entirely *new analytical tools and modelling techniques* in accordance with the requirements of an *evolutionary ontology*.

The radical turn in analytical representation is well demonstrated by the fact that, in the computational sciences, this development is considered as being *ontological*, and in fact the term *computational ontology* is widely used nowadays. Various ontological issues have been surfacing in many of the works on analytical representation inspired by the digital age: e-science tools, computational automation and cyber-infrastructures (Kishore, Shanan and Ramesh, 2004). Given the significance that ontology attains in this domain, we may assemble studies addressing computational and other kinds of analytical representation under the umbrella of *analytical ontology*.

This new kind of analytical ontology can be distinguished from the one handed down from philosophy, which deals with the ultimate status or 'content' of reality. We may call the received philosophical kind of ontology *semantic ontology*. Using Ferdinand de Saussure's seminal distinction between *signifiant* and *signifie*, analytical ontology relates to the former of the linguistic categories, its semantic cousin to the latter.

Thus we have two branches in contemporary ontology:

1	*semantic ontology:*	content
2	*analytical ontology:*	representation

Important scientific advances in evolutionary economics have been forthcoming in the domain of *analytical* ontology. It is indicative of the close nexus between the two branches that the terms *rule* and *carrier* represent key concepts not only in evolutionary ontology but also in computational ontology. This fact is significant considering that it has been *common language* – bridging the theoretical (*signifie*) and analytical (*signifiant*) levels – that has accounted for much of the neoclassical success story.

Theoretical developments concurring with advances in analytical ontology abound. Multi-agent models have become standard for numerous special theoretical models (Grebel and Pyka, 2006; Tefsatsion, 2002). An array of network models connects with multi-agent and related models highlighting the connective complexity (Potts, 2000). Models featuring multidimensional fitness landscapes allow for the dynamic of differential adaptation and selection, as in Stuart Kauffman's NK models (Kauffman, 1989). Percolation models have been designed to capture the logic of innovation and diffusion in complex technology spaces (Silverberg and Verspagen, 2005b), Polya models have been created to address 'chaotic' probability followed by path dependence and lock-in given initially competing technologies (Arthur, 2009) and path-dependent models have been posited in network structures to highlight the interconnectivities of non-ergodic paths (David, 2005).

Models applying the (physics) synergy master equation have been introduced to give analytical precision to Veblen's venerable proposition that there is circular causality between individual and social behavior (Weidlich, 2000). Models featuring kernel density distribution methods have shed new light on the structure of income distribution given dynamic knowledge differentials (Cantner et al., 2001).

Complexity economics has re-emerged from the 1950s as a general branch featuring new forms of analytical exposition, new tools and new modelling techniques (Harper and Lewis, 2012; Colander, Holt and Rosser, 2010; Rosser, 2010; Arthur, Durlauf and Lane, 1997; section 6). Many of the analytical approaches have been producing offspring in the form of more special models, and have been further specified by referring to particular theoretical problems (Safarzyńska, Frenken and van den Bergh, 2012; Safarzyńska and van den Bergh, 2010; Kwasnicka and Kwasnicki, 2006).

The theoretical concept of the *rule* (sections 5 and 6) has been specified analytically as requiring a *deductive* format. For any rule R_j it holds that, 'if condition C_j obtains, then operations Op_j' occur/are possible (Holland, 1986). While syllogism also applies to 'laws' (as *nomological* rules), a rule in, for example, a *classifier system* has *generic* characteristics expounding *variety*, *plasticity* and *evolvability*. A special category inspired by biology deals with rules as genetic algorithms, adaptive genetic algorithms or hybrid genetic algorithms, paralleled by its sister branch of genetic programming.

Taking an overview, the contours of a unified programme may be seen to emerge in which analytical and semantic ontology combine – epitomised in the view of '*evolution as a form of computation*' (Beinhocker, 2011; see also Kakarot-Handtke, 2012).

5 Rule taxonomy

The main branches of modern biology, such as genetics and epigenetics, investigate the nature of *biological rules*. Many of the recent scientific advances in biology have occurred in these branches. In economics, however, unlike biology, there does not yet exist any corresponding *general research area* to deal with *economic rules*.

Although this implies a deficiency in general in economics, the concept of the rule has at least been applied in various specialised areas. They have made their appearance, for instance, in the guise of social rules, technical rules, behavioral rules and cognitive rules. The following analysis brings together some of these diverse research pieces with a view to combining them into a *unified rule taxonomy*.

The broad distinction between *biological* and *cultural* rules is critical for drawing the *boundaries* of the discipline. Economics belongs to the *cultural* level of the evolved hierarchy of natural history. Its subject matter is neither the analysis of the structure and evolution of biological rules nor the more narrowly conceived analysis of the coevolution of biological and cultural rules.

The rules of the cultural level – *cultural rules* – may be used for both *economic* and *non-economic* operations. Differentiation on the basis of the kind of operation sets economics apart from other social sciences. Thus we arrive at the definition: *economics is the study of cultural rules for economic operations*. Economic operations include production, transaction and consumption.

Biological rules describe the innate capacity of *Homo sapiens* (HS) *to make and to use rules*. Our focus being on rules for *economic* operations, we are interested specifically in

Homo sapiens oeconomicus (HSO)

The neoclassical *Homo oeconomicus* is a particular 'species' of HS equipped with a *single invariant rule* stated in terms of the maximisation of expected utility under constraints. This HS rule represents a universal 'law' (not subject to further scrutiny), and the subject matter of neoclassical analysis is economic operations under the sovereignty of this law. In contrast, evolutionary economics highlights HSO: explaining economic operations on the basis of a scientific understanding of the *structure and evolution of cultural rules.*

Analytically, we have two levels of investigation:

1 *generic level:* rules for economic operations

2 *operant level:* economic operations based on these rules

To summarise, therefore, neoclassical economics occupies the operant story in this analytical edifice, evolutionary economics the generic one, putting centre stage investigations into the rule knowledge that enables economic operations.

Homo sapiens generates *cultural artefacts.* Economics deals with cultural artefacts under the special premise of scarcity. Looking for the constituent characteristics of the two prime categories – HSO and economic artefacts – there should be little in the way of objection if we associate the former with the concept of *subject* and the latter with that of *object.* Introducing the general concept of the *carrier*, we get HSO as the carrier of *subject rules* and economic artefacts as the carriers of *object rules*.

The validity of economic theory depends crucially on the giving of proper emphasis to 'subjective' (subject-related) and 'objective' (object-related) factors. Evolutionary economics eschews monist interpretations and views change in/of the economy generally as a process of *coevolution between subject rules and object rules*. A good example of a monist position that relates to 'subjectivism' is radical Austrian economics, and one that relates to 'objectivism' is radical Marxian economics.

The usefulness of a rule taxonomy depends largely on its ability to delineate a scope wide enough to embrace all the relevant rule categories and pinpoint them in a way that they may be used as building blocks for theorising. To this end, *subject* rules may be subdivided into *cognitive/mental rules* and *behavioural rules*, on the one side, and *object* rules may be differentiated into *social rules* (for organizing subjects) and *technical rules* (for organizing physical artefacts), on the other side. Evolutionary (or generic, rule-based) economics is, then, the study of the structure and evolution of the economy in terms of these rules.

Generic rules			
Subject rules		Object rules	
Cognitive rules	Behavioural rules	Social rules	Technical rules
e.g. mental models & schema	*e.g. behavioural heuristics*	*e.g. organization of a firm, rules of a market*	*e.g. technologies*

The four rule categories correspond to major research areas and are represented by large bodies of publications. Although this is, in general, a sign of scientific progress, the further task is to investigate the specific aspects that are relevant for explaining the structure and evolution of the economy. This immediately brings back into focus the economic agent as a *rule maker and rule user*. At the level of micro-foundations, the evolutionary programme calls essentially for a reconstruction of the *economic agent as HSO* (Davis, 2010; Gerschlager 2012, Witt, 2009).

The generic programme of cognitive and behavioural economics deals specifically with aspects of rule processes. Topics covered by the two broad agendas include the creation of novel rules, selective adoption, generic learning, the adaptive accommodation of novel rules in the extant knowledge base and retaining them in a meta-stable process for recurrent operations (Blind, 2012; Herrmann-Pillath, 2012; Hodgson 2006; Dosi, Marengo and Fagiolo, 2005; Witt, 2003).

The nature of *object rules* may be highlighted by making reference to four rule categories: rules expressing product characteristics; industry or manufacturing rules; Nelson–Winter (N–W) organisational routines; and Ostrom social rules. While these rules may relate to quite different kinds of operations, as object rules they all share the feature of being rules for *organising* entities of the *external world*.

Traditionally, a product (or commodity, good) is defined in quantitative terms (section 7). There are no rules that would '*inform*' the product of its *qualitative* characteristics. In the 1970s Kelvin Lancaster initiated a discussion by proposing to augment the neoclassical utility function with factorials of product attributes. This was a major step forward, and a generic approach has now been employed in evolutionary economics by defining Lancaster's characteristics as rules that expound plasticity and evolvability (Saviotti and Pyka, 2004; Saviotti and Metcalfe, 1984).

At a global scale, a taxonomy of object rules has been developed for manufacturing systems and industrial sectors. Traditionally, classifications such as the Standard Industrial Classification (SIC) have followed the template of Carolus Linnaeus, who assumed morphological characteristics to be immutable and who posited them in a grand classificatory schema on the basis of their similarity.

This kind of taxonomy may prove helpful for making statements about structure. The rules of biology and of economics are in a continual state of flux, however, which calls for a taxonomy that accounts for this fact. Based on Darwinism, *cladistics* and similar taxonomies have been devised to reckon with the phenomenon of *change*. They integrate aspects of the genealogy of rules with morphological attributes reconciling the demands of structure and of change when charting empirical data (McCarthy, 2005). Cladistic taxonomy has inspired novel taxonomies in evolutionary economics, as in the form of *cladograms* for manufacturing systems or phylogenetic trees for industrial sectors (Peneder, 2010; Andersen, 2003; McCarthy et al., 2000), or particular aspects of evolutionary taxonomy such as classifying technology policy (Cantner and Pyka, 2001).

Up until this point, the focus has been on object rules for organising physical entities. In contradistinction, Nelson–Winter routines and Ostrom social rules are *for organising agents* – subjects, not physical entities. N–W *organisational routines* are especially interesting from a conceptual point of view, since they combine the concept of *rule* with that of *actualisation*.

Generally, a *routine* is a *rule* that has passed through a process of *routinisation*. An N–W routine is a rule that has attained the specific informational content of a *social organisational rule*. Other rules, not related to the process of organizing, may also be subject of routinisation.

The process of routinisation is part of an overall process of rule actualisation. The *entire process of rule actualisation* involves the generation, adoption and retention of a rule. These may be conceived of as constituting three distinct phases of a *micro-trajectory* of rule actualisation:

phase 1	*generation* of novel rule
phase 2	*adoption* of rule by carrier
phase 3	*retention* of rule for recurrent operations

The routinisation process relates to the second and third phases of the trajectory. Routinisation presupposes a rule.

Routinisation – being a mental process – takes place at the locus of an *individual*. Veblen has called this process *habituation* and its outcome *habit* (Brette and Mehier, 2008). Individual routines and habits may therefore be taken to be identical. An individual Nelson–Winter routine is an *organisational habit* of an individual agent as a member of a firm.

An *institution* may be defined as habits shared by *many agents* of a group. Frequently – though, evidently, not in all cases – institutions involve organisational rules. If agents of a group have adopted an organisational rule (such as an N–W rule), the institution may be said to be *structured*; if they have adopted another type of rule, it is *unstructured*. It is impractical to make the criterion of 'structure' a general definiens of institution (as with Hodgson, 2006), since it excludes the latter class of institutions. Institutions are always a component part of the structure of the *macro*-institution of the economy, however, irrespective of whether they are structured as *micro*-institutions. It may therefore be useful to make a distinction between being a structure and being a component part of a structure.

The Nelson–Winter concept of routine has led to various discussions, which have furnished valuable building blocks for reconstructing the evolutionary micro-foundations of economics, and in turn they have stimulated discussions in the management sciences (Lazaric and Oltra, 2012; Becker, 2008; section 7).

The work of Elinor Ostrom and her collaborators represents a milestone in the construction of a taxonomy of social rules (Ostrom, 2005). On the basis of dozens of empirical studies and having inspected about 100 empirically recorded social rules, she has devised a 'universal' rule taxonomy. This general result is particularly interesting, as Ostrom links it up with major theoretical approaches, thereby demonstrating its great usefulness for theory making. She connects the rule categories of choice rules, pay-off rules or scope rules with game theory and those of positional rules, entry rules or boundary rules with the organisation theory featured in the concept of Nelson–Winter routines. It may also be indicative of the fruitfulness of her approach that she foresees theoretical advances in integrating her approach with the rule-based approach advocated in this paper (Ostrom and Basurto, 2011).

6 Theoretical architecture: the significance of meso

The subject matter of evolutionary economics is the *economy as an evolving system*. The central scientific focus of this approach lies in investigating the theoretical nature of the *system* and that of *evolutionary dynamics*. From the perspective of extant science programmes, economics may thus be seen as being built on two pillars. These are:

1. *system science*
2. *evolutionary science*

Early pioneers of modern evolutionary economics, such as Nicholas Georgescu-Roegen (1972) and Kenneth Boulding (1980), featured expressly an *evolutionary system approach*. There are surprisingly few references to these pioneers in evolutionary economics today, which may reflect the fact that the systemic aspect of evolutionary analysis has been generally neglected in the community. There has been some renaissance since the 1990s, however, brought about by contributions that can be grouped together under the umbrella of *complexity economics* (section 4).

The archetypical domain to start with is a *network*, defined as an ensemble of many elements and connections (Potts, 2000). A *system* is a network (or, alternatively, a network is said to have systemic properties) if all or some of the elements have functional or similar systemic attributes connecting into a whole. The systemic distribution of the elements represents a *structure* brought about by their *coordination*. A system *changes* when one or several of the component parts of the structure change and, as a consequence, the *structure of their connections changes*. The theoretical key issue is to define the *basic analytical unit* that allows us to cope theoretically with the phenomena of structure and of change in an economic system.

The analytical concept dealing with structure – the *structure component* – is well exemplified in Adam Smith's famous case of the division of labour in needle production. The whole process of producing a needle is divided into structure components stated in terms of special (and possibly specialised) production steps of the total production sequence. This example is important, as it highlights the power of scale economies, but it is not the only kind of structure component characteristic of a product and its production. For instance, for a car to qualify as such it is necessary for it to be composed of various component parts independent of whether or not their production involves Smithian division of labour or scale economies. The constituent criterion in this case is the *complementarity* of the component parts. The relative importance of this kind of division of labour will increase as the number of new consumer products increases or as factorial inputs (as structured wholes) are substituted increasingly by new ones. In this way, there are derived, ex-post (Smith type), and original, ex-ante (non-Smith type), kinds of complementarity defining the division of labour.

How does *change* occur in the economy? Enquiring into this issue, it is helpful to return to evolutionary ontology, which proposes that information changes continuously. This has led to a bimodal representation of existences distinguishing between information content or rule and its physical actualisation in historical time and space (axiom 1). Structure and change (*rest* representing temporary *non*-change) are defined with respect to these two existential categories.

At the *information* level, we have rules as component parts of a *rule structure*. The subject of analysis at this level is the nature of the complementarities, which calls for the methods of *mereology* and *hermeneutic*s. Both are analytical branches that are hardly touched upon in economics. Information being *invisible*, we may conceive of the rule level as the '*deep*' level of the economic system.

In turn, *rule actualisation* occurs as a *process*. Being physical instantiations, rule actualisations are *observable*. They may be interpreted as representing a '*surface*' level of the economic system. Thus we have:

deep level	structure
surface level	process

Activities at the *operant* level – the level at which rules are assumed to be given – are also observable; as a result, dealing with particular topics in economic analysis may suggest a need to distinguish between the *generic* and the *operant* surface level. In what follows I deal only with the former.

Evolutionary change occurs as *change in the rules* at both the *deep* and the *surface* levels. While this exposition excludes some interpretations it still leaves much room for competing propositions as to how change occurs, or what its causes and systemic consequences are. In Smith's model, change occurs in the course of an increase of production steps and specialisation in a particular kind of product. The crucial point with this interpretation of change is that the novelty-generating engine comes to a halt once the optimal regime of decomposition has been reached and the benefits from economies of scale have become exhausted. Smith's model is reminiscent of that of Jean-Baptiste Lamarck. Lamarck proposed that organisms adapt to their environment and that the characteristics acquired by an organism during its lifetime can be inherited by future generations. Once the organism is perfectly adapted to its environment, evolution comes to a halt (ignoring Lamarck's spontaneous procreation of novel variants).

Darwin, by contrast, proposed that change comes about in the process of sexual reproduction, suggesting a *continuity of change*, which therefore did not require Lamarckian 'learning' (though Darwin did appreciate Lamarck's views). Various mechanisms, such as recombination, mutation and others, incessantly generate novel generic variants (today we talk of genes or genomes). The various organisms produce offspring, leading to a *variety* of organisms in a *population*. Learning from Thomas Malthus that resources are scarce, Darwin conjectured that only those organisms would survive – and *retain* temporarily their heritable information – that could cope with environmental constraints through *adaptation*. He argued that nature '*selects*' much more powerfully than humans do when practising artificial selection, and thus he used for the proposed mechanism the metaphor '*natural selection*'.

The micro-trajectory introduced earlier (section 5) is reminiscent of Darwin's trajectory, with the crucial difference that a Darwinian trajectory features in the second (selection) phase and the third (retention) phase the concept of *population*. Darwin's notion of population represents an entirely new concept. There was, of course, the concept of species defined by a genus and a population, as with the taxon in Linnaeus's taxonomy, but in that concept the genus was assumed to be pre-given and fixed. In Darwin's model, a population is assumed *to come into existence* only if *new information* is generated. Linnaeus's taxa of species featured 'typological thinking', Darwin's '*population thinking*' (Metcalfe, 2001).

From the viewpoint of the present analysis, it is essential to acknowledge not only that a population is an ensemble of many members but also that it represents a *process of rule actualisation* along a *trajectory of origination, selection and retention*. We take the concept of *population trajectory* to represent the *analytical process unit* of an economic theory of evolutionary change.

How shall we posit the analytical unit in an architecture that, traditionally, is composed of micro and macro? The unit is neither micro (organism, agents) nor macro (nature, economy) but, rather, assumes an *intermediate* position. In acknowledgement of this, I use the term *meso*.

We get thus a *theoretical architecture* with the levels of

micro–meso–macro

The concept of rule structure exemplified by Smith's division of labour lacks a Darwinian type of trajectory that would drive endogenously a self-generating and self-destructive evolutionary dynamic. Smith's model is *proto-evolutionary*; to allow for a theoretical statement about the evolution of economic structure, we require Darwin.

The question is whether or in what way a Darwinian approach may help us in the task of connecting the process units into a structure in order to explain the evolution of the economy as a change in its structure. We have defined structure by its *complementarities*, such as heterogeneous agents performing complementary production tasks. The structure of knowledge and labour in an economy is generally based on complementarities.

It is quite clear that, in nature, nothing like a Smithian kind of division of labour exists. In nature there are, of course, hunter–prey relationships, co-variation among species and interdependences between them in the use of resources and so on, but there is no structure in a sense of complementary tasks or functional assignments aimed at common ends. Not only have we never seen a dog exchanging bones with another but also has there been no empirical indication that dogs would cooperate on the basis of assigned tasks for a common result. The evidence becomes much more robust as we extend the observation to the whole of nature, considering cooperation among various species, say dogs, cats and chimpanzees. While Smith cannot explain process, Darwin cannot explain structure. The most challenging task for evolutionary economics lies in integrating Smith and Darwin.

Analytically, we have a *structure component* (Smith) and a *process component* (Darwin). The structure component is a single rule (or rule composite) that relates to other rules as part of a structure. The process component is a trajectory that tells the 'life story' of that rule as a process of physical actualisation in an agent population. Both *combined* represent the basic analytical unit, which, as posited in the theoretical architecture, is *meso*.

To ease the process of falsification with respect to the theory, let us state the conclusion explicitly: *without meso neither structure nor process can be explained endogenously*. Neoclassical economics is a most obvious case in point.

7 Rule-based microeconomics

Conventionally, microeconomics is the study of the individual decisions made in the market. In it, producers and consumers exchange a certain quantity of a product at an equilibrium price. When referring to a single market, the study is usually called *partial* equilibrium analysis. Further, demand and supply functions may in their entirety be represented as a system of simultaneous equations. The study of the totality of all markets is usually called *general* equilibrium analysis. In this case, we have a model that contains *all* producers, *all* consumers, *all* products, *all* quantities supplied, *all* quantities demanded and *all* exchange prices. We are dealing with the total produce on an economy stated in terms of many individually allocated resources. Having included everything that constitutes a market economy, one might expect that this ought to make for macroeconomics, but still it is called microeconomics.

The obvious misnomer can be explained only by considering its intellectual history. John Maynard Keynes suggested not looking at the relative allocation but, instead, at the aggregates of all production and of all consumption, and relating these to other aggregates such as investment, money volume and employment. The decision making of individual agents now does not refer to the relative choice in a commodity space but, rather, involves choices (translated into propensities) referring to the variables of the macro model. This alternative position led to the divide into micro and macro after World War II.

The 'new macroeconomics' argues that better results may be obtained on the basis of microeconomics, for instance by considering the individuals' relative choice between more employment or more leisure – suggesting that properly understood macroeconomics can be interpreted as 'applied' microeconomics. What remains as a distinguishing criterion for macroeconomics today is the money side, namely the variables of money volume, price level, circulation velocity and related variables. The entire real side of the economy is left to the received canon of microeconomics, leaving in limbo the important questions of its endogenous structure and its endogenous change. Post-Keynesian economics has identified major weak spots in the treatment of the money side, but it is not unfair to say that it has largely failed to furnish a theoretical exposition that would allow us to dealing with structure and change.

Evolutionary rule-based economics aims to construct 'micro-foundations' that will enable us to explain endogenously structure and change in the economy. In the following I adopt the term 'microeconomics' from mainstream economics for ease of communication. I also retain the proposition of *bimodality* in the interpretation of microeconomics, however. We have thus a rule (or rule composite), on the one side, and its carrier and a population of carriers that have adopted this rule, on the other side. This means that microeconomics is not given the meaning attached to it in general equilibrium theory, as it deals only with a single market.

This stance may be identified as typically *Marshallian*. Marshall saw the single market, or industry as a single unit comprising several integrated markets of a kind, as the *major building block* for constructing the *macro* of the economy. His building block was designed as a component part of the economy's structure and as a process unit for explaining how it changed over time and, concomitantly, the structure it was part of. In the dichotomy between Keynesianism and neoclassicism, this central aspect of Marshall's work got lost entirely.

This aspect has previously been captured with the notion of *meso*, distinguishing it from micro, as the single agent or socially organised micro-entity such as the firm, and macro, as the domain of the whole economy. The term *microeconomics* is redefined in this way, allowing us to address structure and change – in both the agent and the population. *Evolutionary microeconomics* is composed of a *micro-unit* (agent, firm, household) and a *meso-unit* (population, industry, institutional setup).

Drawing on the concepts of rule trajectory and rule taxonomy, as introduced earlier, an exposition of the theoretical building block that captures the features of a single market can be attempted. At its simplest, we have supply and demand for a product in a market. The magnitudes of these depend on the demand and supply behaviour of the agents. All operant behaviour is rule-based; specifically, demand behaviour depends on *demand rules*, and supply behaviour depends on *supply rules*. After a time rules become stabilised as institutions, facilitating the efficient performance of operations. The operant base of a market in this way may be said to represent an *institution composed of supply rules and demand rules*.

The market is the locus where demand and supply meet, but the way this happens depends on the *organisational rules* of the market. Until the breakdown of the centrally planned Soviet system prevailing in eastern European countries, the question of market organisation was part of the broader issue of centralisation versus decentralisation for all economic activities. Today the issue is more narrowly construed, with the focus on rules for organising capitalist markets. In this context, various types of market organisational rules have been discussed (Storbacka and Nenonen, 2011; Roth 2007: Mirowski, 2007; Lusch and Vargo, 2006).

An overview of a rule-based market model is provided in figure 1.

Figure 1 Demand and supply, rule-based market model

	Supply		Market		Demand
Rules	**Supply rules**	→	**Market organisation rules**	←	**Demand rules**

The object of exchange is a *product*. It may be a *money* product or a *real sector* product. Demand and supply in real (sector) product markets relate, contrary to money markets, to producers and to consumers (of real products). Therefore, supply and demand operations depend on *producer rules* and *consumer rules*. The real product itself is not homogeneous, like money (standard commodity), but it does have particular characteristics. To allow for the heterogeneity of product rules, it is necessary to specify products in terms of *product rules*.

The example par excellence for producer rules is Nelson–Winter organisational routines, but they run through the whole gamut of rules assembled in the rule taxonomy (section 5). Consumer rules relate to new ways of consuming, to learning to consume and to retaining them as habits and institutions for recurrent consumptive operations (Lazaric and Oltra, 2012; Nelson and Consoli, 2010; Potts et al., 2008; Witt, 2001; Bianchi, 1998).

At an equilibrium price, supply equals demand, leading to market clearing. The operations of supply and demand depend on producer and consumer rules, however, and reallocation at the operant level can take place only within a domain determined by the matching of producer rules and consumer rules. Thus, for market clearing, besides the equilibrium condition at the operant level we have the condition of *rule correspondence* at the generic level. The domain of the rule correspondence is not defined by the Jevon's '*quantil*' (number of units times price) of the product exchanged but, instead, by particular rule-defined product characteristics. It is not the operant but, rather, the *generic intersection point* (or domain) that determines the exchange value and quantity of a product at the 'deep' level.

The *duality* (producer versus consumer) of the generic characteristics of a product has been discussed in terms of *technical rules* (producer) and *service rules* (consumer) as a condition for establishing the afore-mentioned rule correspondence (Windrum, Diaz and Filiou, 2009; Saviotti and Pyka, 2004; Saviotti and Metcalfe, 1984).

An exposition of a generic market model in which producer (firm) rules and consumer (household) rules are in a state of rule correspondence, thus yielding the product rule, is provided in figure 2.

Figure 2 Firm and household rules map into product rule

Carriers	Producers Firms		Product		Consumers Households
Rules by carrier categories	**Producer rules** **Firm rules**	→	**Product rule**	←	**Consumer rules** **Household rules**
Rule types	*Nelson–Winter*		*Saviotti–Metcalfe–Pyka*		*Nelson–Consoli–Witt*
Examples	Firm routines		Product characteristics		Consumer routines

The dynamics of markets is the process of the coevolution of the rule categories stated.

8 Rule-based macroeconomics

Students of evolutionary economics have traditionally dealt with microeconomic issues, and it is only recently that macroeconomic issues have received particular attention. The general aim of the models is to integrate evolutionary behavioural assumptions with approaches that emphasise structural economic dynamics.

In some models, the theoretical arguments have been developed along a Marshall–Kaldor–Fabricant–Pasinetti trajectory and related lines, highlighting the evolutionary relationships between production, productivity and consumption structures (Metcalfe, Foster and Ramlogan, 2006, Wagner 2012). In another strand, Lotka–Volterra, selection, percolation and related models have been utilised to explain the evolutionary nature of economic growth (Silverberg and Verspagen, 2005a). Along Keynesian lines, attempts have been made to substantiate the Keynesian money and real aggregates by integrating the novelty-driven dynamic, with its effect on changing income distribution and structures, into output, investment, consumption and employment aggregates (Verspagen, 2002).

The basic aim of *evolutionary economic policy* may be approximated by considering the works on the concept of the '*national system*'. Traditionally, the economy has been a domain defined by micro- and macroeconomics, with a linkage to governmental policy informed by these. In contrast, evolutionary economic policy views the national system of the economy in its distinct evolutionary characteristics, and designs economic policies in consideration of these. Appreciating the national system as a *complex evolving system*, various suggestions have been put forward with a view to reconfiguring economic policy along evolutionary lines, such as highlighting the national economy (or analogous politico-economic unit) as a 'national system of innovation', a 'national knowledge system', a 'national R&D [research and development] system' or a 'national learning system' (Freeman, 2002; Nelson, 1993; Lundvall, 1992).

9 Outlook

The modern economy has been called – with much justification – a *knowledge economy*. This may be misleading, however, as knowledge is required in a traditional economy as well to perform operations for solving the scarcity problem. What the statement means is that, at the present and in the future, it may not be possible to acquire an adequate understanding of economic phenomena without due recognition of the significance of knowledge.

Central to our analysis has been the recognition that *knowledge enables economic operations*. Simple as it is, this tenet allows an important distinction to be drawn between two major levels of economic enquiry. One is the level of knowledge for economic operations, the other that of operations under the assumption of given knowledge. Evolutionary economics deals with the former, neoclassical mainstream economics with the latter.

Analysing the structure and change of economic knowledge calls for the adoption of an evolutionary ontology; in turn, theoretical enquiry into the phenomena of the operant level may be conducted validly on the basis of mechanistic ontology (constant knowledge may attain the status of immutable 'law'). Evolutionary economics considers the problem of economic knowledge to be centre stage, and it aims to reconstruct economic theory on the basis of – semantic and analytical – evolutionary ontology.

By addressing the knowledge level, evolutionary economics opens up the problem space required to identify and – possibly – solve the most important problems of a modern economy. In its grand theoretical design, it is heading towards an *integration of Smith (structure) and Darwin (process).*

These considerations may be taken as implying a forecast about the future direction of economics, but a commitment to evolutionary thinking would seem to rule out actually engaging in predictions.

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