In order to stand up you must keep cycling: Change and coordination in complex evolving economies

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\textbf{A R T I C L E I N F O}

Article history:
Received 23 January 2017
Accepted 14 June 2017
Available online xxx

\textbf{JEL classification:}
O1
O3
P1

Keywords:
Change
Coordination
Evolutionary Economics
Socio-economic systems

\textbf{A B S T R A C T}

In this work we discuss the main building blocks, achievements and challenges of an evolutionary interpretation of the relation between mechanisms of coordination and drivers of change in modern economies, seen as complex evolving systems. It is an evident stylised fact of modern economic systems that there are forces at work which keep them together and make them grow despite rapid and profound modifications of their industrial structures, social relations, techniques of production, patterns of consumption. We suggest that a fruitful interpretation of the two processes rests in what we call the "bicycle conjecture": in order to stand up you must keep cycling. However, changes and transformation are by nature "disequilibrating" forces. Thus there must be other factors which maintain relatively ordered configurations of the system and allow a broad consistency between the conditions of material reproduction (including income distributions, accumulation, available techniques) and the thread of social relations.

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1. Change and coordination: an introduction

In this work we discuss the main building blocks, achievements and challenges of an evolutionary interpretation of the relation between mechanisms of coordination and drivers of change in economies seen as complex evolving systems. Certainly, in economic systems there are forces at work which keep them together and make them grow in relatively ordered manners (often but not always) despite rapid and profound modifications of their industrial structures, social relations, techniques of production, patterns of consumption, which as such, are "disequilibrating" forces. Thus, there must be factors which maintain relatively ordered configurations of the system and allow a broad consistency between the conditions of material reproduction (including income distributions, accumulation, available techniques) and the thread of social relations.

Very daringly, indeed, the article attempts to address the two basic questions at the core of the whole economic discipline since its inception which regard, first, the drivers and patterns of change of the capitalist machine of production and innovation and, second, the mechanisms of coordination among a multitude of self-seeking economic agents often characterized by conflicting interests. Of course, of crucial importance are the answers which diverse theories offer to these two questions, but equally important, the relations purported between the two.

The interplay between change and coordination, well before Evolutionary Economics, has been at the core of the analyses of Adam Smith and later Marx and Schumpeter. Change and transformation of technologies, industrial structures, organizations and social relations shape the evolution of the capitalist system which is characterized by processes of endogenous self-sustained growth, punctuated by small and big crises. The process of economic growth is all but steady:

Industrial mutation – if I may use the biological term – that incessantly revolutionises the economic structure from within, incessantly destroying the old one, incessantly creating a new one. This process of Creative Destruction is the essential fact about capitalism. \textsuperscript{[Schumpeter (1947), p. 83]}

Interestingly, Adam Smith begins his Wealth of Nations with a detailed analysis of the drivers of change – in particular the positive feedbacks between division of labour, mechanisation, productivity growth and demand growth, while issues of coordination are discussed much later, building on such a dynamic background. Much later and from a quite different angle, Keynes too never dreamt
of separating “what keeps the system together” from “what keeps it going”: in fact, the properties of shorter term coordination were derived from the properties of capital accumulation and the animal spirits driving it.

As well known, the current dominant theoretical creed is very much on the analytical opposite to Smith and Keynes. It builds on the separation between “coordination” and “dynamics”, starting from the former, and assuming away the latter in a first approximation. The “coordination research program”, soon culminated into the Arrow-Debreu-Mckenzie General Equilibrium model, has been indeed an elegant and institutionally very parsimonious demonstration of the possibility of equilibrium coordination amongst decentralised agents. However, subsequent, basically negative, results have shown the general impossibility of moving from existence theorems to that sort of implicit dynamics captured by proofs of global or local stability – loosely speaking, the property of the system, when scrambled, to get back to its equilibrium state. Quite the contrary, even empirically far-fetched processes such as tâtonnements (with the omniscient Walrasian auctioneer proclaiming equilibrium vs transaction when he sees them) in general do not converge. Even more powerfully, some of the founding fathers of GE themselves have shown that existence does not bear any implication in terms of the shape of excess demand functions (this is what the Sonnenschein-Mantel-Debreu theorem implies). Putting it shortly, in general even forget local stability! Conversely, any careful look at the toll requirements which sheer existence entails – in terms of information and rationality – highlights the extent to which GE is a beautiful but extremely fragile creature, certainly unable to withhold the weight of any account of the coordination processes of the economy as a whole and even less so, to offer any serious micro-foundation to transforming economies undergoing various forms of innovation. In fact, if the conditions – in term of rationality, characteristics of the exchange, etc. – required in reality were even vaguely as stringent as those required in GE models, probably no one would be ever observed in the real world!

Here, we propose to revert to the old Smithian style of interpretation, beginning with the understanding of the drivers of change and only next try to understand the (imperfect) coordinating properties of the economic systems. It is what we call the bicycle conjecture: in order to stand up you must keep cycling. However, in order to operationalize the conjecture, very tall tasks concern, first, the identification of “what is there to be explained” – that is the empirical and historical stylized facts at different level of aggregation and different time scales – and, second, explore how we theoretically account for them.

In contemporary economies one observes that technological knowledge is to a good extent incorporated into corporate organizations, in the form of shared cognitive frames and organizational routines, evolving over time as a result of learning, innovation, and adaptation. In turn, such (heterogeneous) firms operate in competitive environments which contribute to determine their revealed performances – in terms of growth, profitability and survival probabilities – and collectively the evolution of the whole industry to which they belong. Indeed, the evolution of diverse industries driven by technological and organizational learning is also at the heart of the process of development and macroeconomic growth.

How does the theory accounts for the foregoing historical patterns and stylised facts? Under the prevailing paradigm, it does that to trying to rationalise each empirical regularity with “the combined assumptions of maximizing behaviour, market equilibrium and stable preferences, used relentlessly and consistently” (Becker, 1976). Here, we propose an alternative view largely based on opposite building blocks, aimed at understanding the economy as a complex evolving system. In a nutshell, such a perspective attempts to understand a wide set of economic phenomena – ranging from microeconomic behaviours to the features of industrial structures and dynamics, all the way to the properties of aggregate growth and development – as outcomes of far-from-equilibrium interactions among heterogeneous agents, characterized by endogenous preferences, most “often boundedly rational” but always capable of learning, adapting and innovating with respect to their understandings of the world in which they operate, the technologies they master, their organizational forms and their behavioural repertoires. In the following we shall discuss the building blocks of such a perspective (Section 2), some of its domain of applications (Section 3), concluding with some challenges ahead (Section 4).

2. The economy as a complex evolving system

Start with the most minimalist notion of complexity: it stands at the very least for the fact that the economy is composed by multiple interacting agents. As H. Simon, also cited in Kirman (2016), puts it:

Roughly by a complex system I mean one made up of a large number of parts that interact in a non-simple way. In such systems the whole is more than the sum of its parts, in an ultimate metaphysical sense, but in the important pragmatic sense that, given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole. [Simon (1969), p. 267]

Indeed, the properties of the whole are generally emergent properties, that is collective properties stemming from the local interaction among multiple agents, which however cannot be attributed to the intentional property of any agents or collection of them (more in Lane, 1993; Nicolis and Prigogine, 1977; Camazine et al., 2001). Note that complexity and emergence do not prevent at all the search for possible laws of motion of any system, but they do rule out any “anthropomorphization” of the interpretation of whatever dynamics, so familiar in contemporary theory. Moreover, evolution entails that any assumption of “given fundamentals” (including technologies and preferences) in most circumstances implies a significant violence to the object of study. Of course for any analysis of a complex and evolving economy one has to go well beyond the Schumpeter/Samuelsen separation between coordination and change. The (imperfect) coordinating features of the system are fundamentally shaped by its evolving nature. The relatively orderly properties of capitalist economies derive from its being in motion. This is the relative order of “restless capitalism” (Metcalfe, 1998). So for example, prices move roughly in line with the average costs of production which in turn depend on the underlying (technology-specific and sector-specific) rates of process innovation. Demand patterns are shaped by the ensuing prices and, possibly even more importantly, by the trajectories in product innovation. Gross and net labour demand are affected by the double nature of technical progress as a “labour saver” and as a “demand creator”. Among many others, these are all features of imperfect coordination in evolving systems. And so are the distributional properties of whatever statistics on economic variables which stem precisely from the fact that the system is changing all the time in its process and product innovations, consumption patterns, organizational forms.

2.1. Routines, rules of thumb, heuristics

The first question one needs to address is: how do agents behave? In the tradition of Evolutionary Economics, routines, rules of thumb and heuristics are the core pillars describing the behaviour of agents.

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1 Complementary discussions are Shaikh (2016), Pianta (2017) and several contributions in the prospective of structural change and a theoretical essay on the dynamics of the wealth of nations (Pasinetti, 1981; Scanzieri, 2017).
In Cohen et al. (1996), S. Winter provides a conceptual classification of the three latter categories: (i) routines are automated, repetitive and unconscious behaviours which however require a high level of information processing (e.g. working in an assembly line, making airline reservation or bank transactions); (ii) rules of thumb are relatively simple decision rules which require lower levels of information processing involve some quantitative decisions (e.g. the share of R&D over total sales, the fixed mark-up); (iii) heuristics are guidelines and behavioural orientations adopted to face problem solving which do not provide any ready-to-use solution, but only broad strategies (e.g. in decision making, “Do what we did the last time a similar problem came up”, in bargaining, “Ask always more than what you desire”, in technology, “Make it smaller/Make it faster”).

These three elements are the traits of organizations and they entail both (i) problem-solving action patterns and (ii) mechanisms of control and governance. The conflicting nature of interests, knowledge, and preferences inside organizations, like firms, is well summarized in March (1962): rather than maximizing units, firms are better represented in terms of political structures displaying (i) the tolerance of inconsistencies in both goals and decisions over time and inside the organization, (ii) decentralised goals and decisions with loose cross-connections, (iii) slowly shifts over time in response to shifts in the coalition But given such a nature of the firm how can we model its behaviour?

Conversely, in the recent years, the introduction of the computer and the computer program model to the repertoire of the theorist has changed dramatically the theoretical potential of process description models of conflict systems. Complex process description models of organizational behaviour permit a development of a micro-economic theory of the firm. [March (1962) pp. 674–675] In tracing the Agenda for Evolutionary Economics, Winter (2017) emphasizes how the use of the maximization procedure is intrinsically inappropriate to study the behaviour of the firms. March (1962) shared long ago the same concern:

Generally speaking, profit maximization can be made perfectly meaningful (with some qualifications); but when made meaningful, it usually turns out to be invalid as a description of firm behaviour. [...] With few exceptions, modern observers of actual firm behaviour report persistent and significant contradictions between firm behaviour and the classical assumptions. [March (1962) p. 670]

The profit-seeking maximizing behaviour of firms is carefully debunked in Winter (1964) who points at two lines of criticism: first, even though it is reasonable to conceive firms as having goals, is not appropriate to assume that the operational goal is profit maximization. Rather, organizations try to satisfy some objectives operationally different from profit maximization. Second, in a world characterized by continuous change it is impossible to pursue any profit maximization for the lack of any thorough understanding of the detailed structures of ever-changing worlds.

In his Nobel Memorial Lecture Simon (1979) stresses how the failure of omniscience are “failures of knowing all of the possible alternatives, uncertainty about exogenous events, and inability to calculate consequences” (p. 502). Results from a vast literature in experimental economics show that:

it is not that people do not go through the calculations that would be required by the subjective expected utility decision – neoclassical thought has never claimed that they did. What has been shown is that they do not even behave as if they have carried out those calculations, and that result is a direct refutation of the neoclassical assumptions. [Simon (1979), p. 507]

There are good reasons why agents in such evolutionary environment adopt robust and rather information-independent heuristics, which

[i] is a strategy that ignores part of the information, with the goal of making decisions more quickly, frugally, and/or accurately than more complex methods. [Gigerenzer and Gaissmaier (2011), p. 454]

Note that, heuristics are not “biases” yielding sub-optimal behaviours (as one would gather from Kahneman, 2002, or from the bulk of behavioural economics), but might be “locally ex-post optimal strategies” that outperform purportedly “rational” choices in large worlds characterized by substantive and procedural uncertainty (Dosi and Egid, 1991), as well as drivers of major contagion-fuelled disasters.

A clearcut example of the use of heuristics in trading behaviours is highlighted in finance. As DeMiguel et al. (2009) show, over a sample of seven datasets, the simple 1/N rule outperforms the Markowitz Portfolio strategy in fourteen alternative portfolio specifications. “Rational” allocation strategies yield very high estimation errors in the variance-covariance matrices. In fact, in changing and distributional variant worlds, the simple 1/N strategy happens to be much more robust and less error prone.

2.2. Coordination vis-à-vis equilibrium

The term Evolutionary recalls the field of Biology wherein the processes of mutation and selection among species are at the core of evolution. Already in the Marshallian definition of Economics, the latter was conceived to be much more closer to Biology rather than Mechanical Physics:

The Mecca of the economist lies in economic biology rather than in economic dynamics. But biological conceptions are more complex than those of mechanics; a volume on Foundations must therefore give a relatively large place to mechanical analogies; and frequent use is made of the term “equilibrium,” which suggests something of statical analogy. 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. [Marshall (1890), vol. 1, p. xiv]

Nonetheless, the goal of neoclassical economic analysis has been confined to study market coordination as an equilibrium outcome. Coordination is not an easy task: after all the economic processes are the results of individual decisions making characterized by ex-ante possible inconsistencies. But, economic agents coordinate themselves inside organizations, institutions, societies. Why do we observe such emergence of order (where the meaning of order should be accurately distinguished from the notion of equilibrium)?

As well known, the neoclassical response to the problem of coordination has been by means of prices: exchange among decentralized agents, who are pursuing their own utility maximizing transactions, are supposed to yield equilibrium outcomes (that is an equilibrium system of prices and quantities); markets clear after all desired transactions have occurred, so that nobody desires more than what she obtained after the exchange. Apart from the easy criticism on the realism of this approach, and particularly on the validity of the assumptions of perfect competition and rational expectations, which have also been taken up in the neoclassical analysis itself (taking on board, to varying degrees, imperfect competition and asymmetric information), the processes of interactions and evolution of behaviours is remarkably neglected.
If dynamics and interactions count, the concept equilibrium ought to be re-thought and substituted by some notion of coordination patterns (more in Dosi and Orsenigo, 1988). In fact, the usual concern for equilibrium does not find much place inside the evolutionary theorizing. Without postulating any ex-ante market clearing condition, necessary to endogenously determine a closed solution for the unknown variables (e.g. prices and quantities), evolutionary economic models are meant at understanding the coordination patterns that result out of the interaction of heterogeneous agents. The analysis is not interested in finding any deductive equilibrium solution, but rather in identifying emergent properties. According to Lane (1993), emergent properties are:

[...] a feature of a history that (i) can be described in terms of aggregate-level constructs, without reference to the attributes of specific MEs (Microlevel Entities); (ii) persists for time periods much greater than the time scale appropriate for describing the underlying micro-interactions; and (iii) defies explanation by reduction to the superposition of “built-in” micro-properties of the AW [Artificial Worlds]. [Lane (1993), pp. 90–91]

So, for example, in The ‘Schumpeter meeting Keynes’ models (building on Dosi et al., 2010), we build an artificial world populated by machine-producers who make new capital goods and machine-buyers who order the latter to produce homogeneous good sold to the workers. The dynamics of aggregate output, consumption and investment which typically exhibit sustained long run growth and fluctuations are emergent properties not directly linked to the attributes of the microlevel entities.

The emergent properties are conceived to be meta-stable and not unique or stable equilibrium whenever attributes at the microlevel are changed also the emergent properties can be fairly different. Artificial economies are mainly high-dimensional stochastic models, hardly treatable analytically. Then, asymptotic convergence some steady-state stability are generally impossible to obtain. Rather, the conditions under which ordered patterns or trajectories emerge are the relevant questions addressed by the analysis.

2.3. Heterogeneity and interaction

Heterogeneity is a general feature of complex evolving economies in all domains of observation. It concerns productivity dispersions at all levels of aggregation, organizational forms, personal and functional income distributions.

In turn, these heterogeneous agents interact, contrary to the standard models where there is no sign of such interactions. The absence of any explicit coordination process in the latter models is discussed in Kirman (1992), in his devastating critique of the representative agent (RA):

Paradoxically, the sort of macroeconomic models which claim to give a picture of economic reality (albeit a simplified picture) have almost no activity which needs such coordination. This is because typically they assume that the choices of all the diverse agents in one sector consumers for example can be considered as the choices of one “representative” standard utility maximizing individual whose choices coincide with the aggregate choices of the heterogeneous individuals. [Kirman (1992), p. 117]

As Kirman (1992) shows, the RA apparatus is not simply unrealistic but wrong because not well-suited to study problems of emergence and particularly of lack of coordination like unemployment, income inequality, and in general aggregate demand externalities. Related, intrinsic, theoretical flaws of the representative agent concern (i) the symmetry of behaviour between individual and aggregates rationality; (ii) the reaction of the RA to policy changes maybe quite different from the aggregate reaction of the individuals; (iii) the ordered of choices of the RA may not guarantee the individual preference ranking orders; (iv) whenever one does hypothesis testing, trying to compare the model with the data, the modeller does not know if, in case of rejection, one has to reject specifically the RA or some other behavioural hypotheses.

If the objective of the neoclassical modeller is to reach the exact microfoundations, ensured by the optimization procedure performed by the RA, the latter procedure intrinsically contradicts the inner meaning of microfoundation. All in all, a direct consequence of the RA is that the trade conundrum, according to which no exchange should persistently occur in equilibrium. Transactions are only mild turbulences around the equilibrium point.

Results from the General Equilibrium scholars themselves highlighted by the Sonnenschein–Mantel–Debreu theorems show that assumed micro properties, like transitivity of preferences, which if violated could lead to multiplicity of equilibria, are not guaranteed by the aggregation process (unless further restrictions such as homothetic utility functions etc. of all micro agents are postulated). The only viable set-up explored in the neoclassical models to overcome the aggregation problem has been reducing the dimensionality from n potentially heterogeneous individuals (at least two in the original General Equilibrium program) to one. In this latter case, the excess demand function will obviously satisfy all the regularity conditions required to get uniqueness and stability of the equilibrium.

In an alternative perspective, Kirman (1992) discusses under which circumstances aggregation among heterogeneous agents is sufficient to have a well behaved aggregate demand function:

Once one allows for different micro-behavior and for the fact that different agents face differing and independent micro-variables then [...] complex aggregate dynamics may arise from simple, [...], individual behavior. [Kirman (1992) p. 127]

Becker (1962) in the early sixties already emphasized how “the law of demand” may be just the effect that price changes exert on the budget constraint, and not be related to any decision rules: the negative demand slope is independent from the rational or irrational content of the decision rules. A similar theoretical discussion is in Grandmont (1991), who shows the relatively unimportance of the maximization of a utility function, and conversely the relevance of the simple satisfaction of the budget constraint to obtain well-behaved aggregate demand functions. The conditions under which aggregation yields “well behaved” aggregate demand functions independently of the fine specification of micro behaviours are showed in Hildenbrand (1994).

More generally, the interaction among heterogeneous agents, by itself, allows for the emergence of dynamics such as endogenous cycles and fluctuations, without the need of external shocks hitting the system (see Dosi et al., 2010 among others).

2.4. Innovation and growth

The process of economic change as been at the core of the “Grand Evolutionary Project” at least since the seminal work by Nelson and Winter (1982). The early growth neoclassical models have been identifying in the so called Solow residual or, using the felicitous expression by Abramovitz (1956), the measure of our ignorance, the unaccounted source of economic growth. Rather surprisingly, the early scholars of growth theory decided to shelve the enquiry exactly on the source of economic growth, treating “technological change as a residual neutrino”.

The neutrino is a famous example in physics of a labelling of an error term that proved fruitful. Physicists ultimately found neutrinos, and the properties they turned out to have were con-
sistent with preservation of the basic theory as amended by
acknowledgement of the existence of neutrinos. A major por-
tion of the research by economists on processes of economic
growth since the late 1950s has been concerned with more ac-
curately identifying and measuring the residual called technical
change, and better specifying how phenomena related to tech-
ival advance fit into growth theory more generally. [Nelson and
Winter (1982), p. 198]

After the early growth models of exogenous technical change à
la Solow, the 1990s saw the flourishing of the so called “endogenous
growth theory” attempting to incorporate inherently Schumpet-
rian themes into mainstream models. Nonetheless, endogenous
growth models do not seem able to account for some elements
typically characterizing the processes of innovation and growth.

As one of the early evolutionary models of technological change
(Silverberg and Verspagen, 1994) puts it, requirements needed
to genuinely model endogenous growth are (i) coexistence of
many technologies and techniques of production at any given time
period; (ii) no unique production function (coexistence of mul-
ple techniques of production even at the frontier); (iii) dependence
of the aggregate rate of technical change on diffusion of innova-
tion, not simply on the instantaneous innovation rate; (iv) if the
innovative effort is represented by a stochastic draw from proba-
bility distributions, the parameters of the distributions have to be
unknown to the agents.

In fact, such requirements appropriately map into a series of
attributes of technology (see also below): search and discovery of
innovation are processes intrinsically characterized by Knighthan
uncertainty wherein there is no exact correspondence between ex-
ante effort and ex-post performance; there is no convergence
toward an optimal capital/labour ratio which defines the unique
technique adopted by the users, but rather a constellations of tech-
niques of production are employed by different firms.

In our evolutionary perspective it is the contribution of
knowledge, transferred into the innovative activities which is
“responsible” for the neutrino. And knowledge is a very special
entity which is not characterized by scarcity and by diminishing
returns, overturning the old perception of economics as the sci-
cence of allocation of scarce resources. If knowledge and innovation
become the main determinants of economic growth, then abun-
dance and dynamic increasing returns are the rule and not the
exception: worlds with endogenous innovation are ubiquitously
characterized by dynamic increasing returns. If anything, innova-
tion and knowledge accumulation are precisely the domains where
the dismal principles of scarcity and conservation are massively
violated: one can systematically get more out of less, and increas-
ing returns are the general rule. The theoretical consequences are
far-reaching.

The known properties of information (its non-rival use, non-
perishability, scale-freeness in its application etc.), when taken
seriously, imply that the usual General Equilibrium properties
can be ruled out. In fact as discussed in Radner and Stiglitz (1984), it
is sufficient to assume nonconvexities in the production function,
due e.g. to the fixed cost of acquiring information. Given such non-
convexities, the existence of equilibrium is not guaranteed (see
Rothschild and Stiglitz, 1976 and its manual-level acknowledge-
ment in Mas-Colell et al., 1995). Under nonconvex technologies, the
supply curve is not equivalent to the marginal cost function and the
intersection with the demand curve is not ensured. Arrow (1996) puts it bluntly:

[...]competitive equilibrium is viable only if production possi-
ilities are convex sets, that is do not display increasing return
[...] with information constant returns are impossible. [...]The
same information [can be] used regardless of the scale of pro-
duction. Hence there is an extreme form of increasing returns.

In fact, the existence of a conventional General Equilibrium is
undermined in existence of innovation even neglecting the increas-
ing returns properties of innovation itself; see Winter (1971). In
turn, increasing returns are likely to display as a norm, divergence
in e.g. technological capabilities and incomes.

2.5. History

History and path dependency are at the center stage in evo-
lutionary theorizing. So, for example, in order to understand the
process of evolution of a given technology, it is fundamental to
understand its historical origin. David (1985) in his seminal con-
tribution emphasis the importance of the sequence of past events
to interpret economics as an evolutionary process:

Cicero demands of historians, first, that we tell true stories. I
intend fully to perform my duty on this occasion, by giving you a
homely piece of narrative economic history in which “one damn
thing follows another”. The main point of the story will become
plain enough: it is sometimes not possible to uncover the logic
(or illogic) of the world around us except by understanding how
it got that way. A path-dependent sequence of economic changes
is one of which important influences upon the eventual outcome
can be exerted by temporarily remote events, including
happenings dominated by chance elements rather than sys-
tematic forces. Stochastic processes like that do not converge
automatically to a fixed-point distribution of outcomes, and are
called non-ergodic. In such circumstances “historical accidents”
can neither be ignored, nor nearly quarantined for the purpose of
economic analysis; the dynamic process itself takes on an
essentially historical character. [David (1985), p. 332]

In this respect, it is true that New Economic History has brought
neoclassical economics to economic history (Fogel, 1965), but
this has been done in our view at an unreasonably high price.
Cliometrics, and later, the “New Political Economy” focus on the
quantitative assessments of sociological and institutional variables
which are often then brought into the estimation of long-run pro-
duction functions. The price is the general assumption that there
is a functionally invariant generating process and an invariant eco-
nomic rationality applicable from Stone Age tribes to Space Age
societies.

Freeman and Louçã (2001) provide an enticing discussion on cliometrics. A series of unsatisfying outputs of this research stream
culminated with the description of slavery condition as a rational
optimizing behaviour for both parties of the contract: the owners
were praised for the superiority of their managerial capabilities
and the slaves for the superior quality of black labour. Cliometrics,
apart from abruptly importing the homo economicus, carried also
the notion that sheer randomness could adequately capture histori-
ical events: first, some of them are considered as random, exogenous
events altering the regular (equilibrium) dynamics; second, histori-
tical time series themselves are considered equivalent to a sample
from a universe of alternative realizations of the same stochastic
process. It is basically an ergodic world where “deep history” does
not count.

Landes (1994) emphasises the inappropriateness of the fore-
going research agenda in providing exhaustive explanation of
historical phenomena:

I am convinced that the very complexity of large systematic
changes requires complex explanation: multiple causes of shift-
ing relative importance, combinative dependency... temporal
Complex evolving systems are typically non-ergodic, thus displaying path-dependencies: where you go depends on where you come from.

2.6. Institutions

In absence of rational, profit-seeking maximizing agents, what does it shape the behaviour of individuals and organizations? How the relatively ordered patterns above mentioned are able to emerge? Is it all the outcome of self-organization?

We have been emphasizing above how (imperfect) coordination and (relatively) ordered change can be interpreted as phenomena of self-organization among multiple interacting agents. However, such processes are embedded into institutions which shape and constrain behaviours and modes of interaction. They include markets, but even more important, other non-market institutions ranging from families to firms, from unions to universities to public agencies.

In turn, “good-matches” or “mismatchings” among institutional forms are at the core of well-tuned and fragile phases of capitalism development. This is what has been studied by the (mainly French) Regulation School which identified the so called Regimes of Regulation (see Boyer, 1988).

Three main domains of the Regimes of Regulation are especially relevant to study the capitalist dynamics, namely: (i) the accumulation regime which entails the relations among technological progress, income distribution and aggregate demand, (ii) the institutional forms which encompass the wage-labour nexus and nature of the State, and (iii) the mode of regulation comprises the mechanisms by which the former two domains evolve, develop and interact. The modes of regulation capture the specificities of the process of adjustments in the accumulation patterns and in the coordination among different types of actors. Such dynamics yields phases of “smooth” coordination, mismatches, cycles and crises.

The major question is, then, the coherence and compatibility of a given technical system with a pattern of accumulation, itself defined by a complex set of economic regularities and mechanisms affecting competition, demand, the labour market, credit and state intervention. The major finding is the following: there are several different modes of development and regulation observed in history – there is no single universal mode. [Boyer (1988) p. 68]

The notion of mode of regulation disposes of the standard equilibrium-based idea of collective coordination. It is made of a set of norms, rules, behaviours collectively consistent entailing some distinctive features: (i) decentralised decisions are taken without the need for each individual or organization to understand the whole system; (ii) it shapes the accumulation regime; (iii) it reproduces a system of social relationships.

The role of the industrial relations, the mechanism of wage determination, the relative power of conflicting classes, the industrial and labour policies are also important elements in shaping the national systems of innovation (Nelson, 1993) and production. Non-market institutions are crucial for the understanding of the process of innovative search and more generally of economic dynamics:

[... ] there is a lot more to the institutional structure of modern economies than for-profit firms and markets. Firms and markets do play a role in almost all arenas of economic activity, but in most they share the stage with other institutions. In many sectors firms and markets clearly are the dominant institutions, but in some they play a subsidiary role. National security, education, criminal justice and policing are good examples. Some sectors, like medical care, are extremely “mixed”, and one cannot understand the activity going on in them, or the ways in which their structure, ways of doing things, and performance have evolved, if one pays attention only to firms and markets. [Nelson (2016), p. 18]

2.7. Methodology: why computer simulation

Given the foregoing interpretation of economic dynamics, the choice of the right instruments of analysis is of paramount importance (in the following, we shall just address the modelling domain, even if well aware of the complementarity with statistical and historical analyses). To overcome the straitjacket imposed by the standard tools, we advocate an extensive use of computer simulation, concerning both individual action and system-level interactions.

It would appear, therefore, that a model of process is an essential component in any positive theory of decision making that purports to describe the real world, and that the neoclassical ambition of avoiding the necessity for such a model is unrealizable. [Simon (1979), p. 507]

The choice of computer simulation models is not by chance: it allows to describe the economic agents as behaving according to procedural routines, which are executed under the form of algorithms, wherein sequence of actions and events in discrete time can be explicitly inserted and described, and heterogeneity is explicitly modelled. Simulations, in this respect, are not simply used to mimic but to test hypotheses.

By converting empirical evidence about a decision-making process into a computer program, a path is opened both for testing the adequacy of the program mechanisms for explaining the data, and for discovering the key features of the program that account, qualitatively, for the interesting and important characteristics of its behavior. [Simon (1979), p. 508]

Many criticisms have been addressed to computer simulation models, or as they are nowadays labelled, Agent Based Models, particularly, (i) lack of rigorous specifications of the behavioural equations; (ii) lack of parameter estimation; and (iii) lack of robustness.

The first critique in fact is rather superficial in so far as ABMs are a methodology which leaves room of manoeuvre to the modeller, allowing the choice among different specifications of behavioural rules. Conversely, in the neoclassical models only one rule is admissible, the maximizing behaviour. However, the greater discipline of the latter is deceiving. The mainstream modeller is allowed full freedom on the choice of the arguments of the function, the functional form and the constraints, without any external consistency check (“what do actually agents do that?”).

Conversely, ABMs undertake a thorough external consistency check on the behavioural rules, modes of interaction and timeline of events, which define the chronological order according to which the procedures are undertaken. Thus, the model is asked to be coherent and as close as possible to empirical data. Only abandoning the deductive-normative approach of the maximization endeavour, the modeller is able to test the validity of behavioural rules and algorithms vis-à-vis the corresponding evidence.

The second critique concerns the lack of parameter estimation. However, it is another misleading point. As Brock (1999) emphasizes, regularities or scaling laws which are particular widespread in economics are:

[... ] ‘unconditional objects’, i.e. they only give properties of stationary distributions, e.g. ‘invariant measures’, and hence cannot say much about the dynamics of the stochastic process which generated them. To put it another way, they have little power to discriminate across broad classes of stochastic processes. [Brock (1999), p. 410]
But the emergence of these scaling law, even if does not allow to discriminate among alternative stochastic processes all equally able to replicate the same unconditional objects, are useful to identify acceptable and non acceptable theories:

Nevertheless, if a robust scaling law appears in data, this does restrict the acceptable class of conditional predictive distributions somewhat. Hence, I shall argue that scaling law studies can be of use in economic science provided they are handled and interpreted properly [...] scaling laws can help theory formation by provision of discipline on the shape of the ‘invariant measure’ predicted by a candidate theory. [Brock (1999), p. 411]

Brock (1999) advocates both the analysis of unconditional objects and the estimation of conditional ones. ABMs, we suggest, are the best art-form so far available to undertake both exercises. Such models can be used for both thought experiments and also as laboratories for policy experiments. Instead of performing the usual methods of causality detection proposed by the toolbox of econometrics, what ABMs allow is to model “artificial” worlds.

When ABMs are implemented, the protocol one follows implies: (i) using unconditional objects to reject theories unable to match statistical regularities, (ii) performing policy experiments which allow to understand the reaction of the system when hit by both external shocks, including policy changes, and, equally important, endogenous technological, organizational ones, and structural changes as well.

The ability to match statistical regularities, and particularly large ensemble of statistical regularities at the micro level, attempts to reduce the external consistency criteria mentioned above. In accordance with Brock (1999), ones does not simply try to find unconditional objects, but to build models able to provide a sound explanation of the statistical regularities at different levels of observation. Not all statistical objects are equivalent limuts tests to accept/reject a theory. Replicating business cycle co-movements is difficult but not too difficult. Obtaining Pareto distributions or similarly skewed ones in whatever measure of micro interacting agents is relatively easy: in fact, they are all likely a signature of complexity as such. Getting the two together is much more difficult, and even more is matching the empirical regularities concerning the relative magnitude of the higher moments of different variables.

Finally, the last critique regards the lack of robustness, according to which the results in ABMs tend to be local and potentially valid only for a small set of the parameter space, with the value of these parameters often not estimated. Notably, ABMs are nonlinear, high dimensional, complex models wherein, to repeat, inputs strongly differ from outputs. Conversely, standard neo-classical models are linearised models around the steady-state. Hence, the two modelling approaches are poles apart in the “epistemological weight” they attribute to the appropriateness of the underlying assumptions about behaviour and interaction mechanisms vs. purported predicting abilities. In ABMs, the values of the parameters are set as close as possible to empirical data, whenever available, even if admittedly often without any direct estimation of their distributions, as they are not generally available.

On the contrary, neo-classical macroeconomic models like DSGE, being linearised in the neighbourhood of the equilibrium values, to exhibit a low ability in generating outputs which are different from the inputs themselves. Here, the epistemological strategy is exactly the opposite. The structural model is assumed to be axiomatically true, and on the ground of such “truth”, the value of the parameters are calibrated in order to match the empirics, by e.g. minimizing the distance between the series produced by the model and the empirical ones. Following a calibration procedure, the modeller does not perform any testing on the inherent model structure, but simply imputes estimated values of the parameters.

In a nutshell, while standard macroeconomic model focus on parameter estimations, ABMs entail a sort of theory corroboration. Whenever a model is able to robustly replicate a number of stylised facts, without imposing specific values for the parameters, the mechanisms inside the model itself are reliable explanations of the facts empirically observed.

One open challenge ahead is the comparability between high-dimensional ABMs and low-dimensional aggregate law of motions. Can we dramatically reduce high-dimensionality, both in terms of heterogeneity and in terms of variables and parameter space, and still capture some fundamental dynamics of the system? Or putting it another way, what are the complementarity, if any, between ABMs and genuinely classical non-micro-founded model such those in the tradition of Kaldor (1940), Goodwin (1951) and Pasinetti (1960)?

3. Domains

These are parts of the building blocks of a “grand evolutionary program” (discussed at greater length in Dosi and Winter, 2002) to put at work with respect to the formalization of four main domain of analyses: (i) technologies; (ii) organizations; (iii) corporate learning, competition and industrial dynamics; and (iv) coordination and growth from the micro to the macroeconomic patterns.

3.1. Technologies

Technological innovation, paraphrasing Landes (1969), has been and is a central driver of the Unbound Prometheus fuelling economic growth at least since the industrial revolution. The classics – and in particular Adam Smith – were well aware of it, but for almost two centuries thereafter, not much progress had been made in our understanding of the ways new technical knowledge is generated, and how its impact works through the economy (Karl Marx and Joseph Schumpeter stand out as major exceptions). The importance of technological change reappeared, almost by default, in Robert Solow’s growth analysis in the 50’s, but it is only over the last half century that one has systematically started looking inside the blackbox of technology (Rosenberg, 1982).

Fundamental contributions to such a de-blackboxing have come, first, from the analysis of the economic properties of information as such, including, as already mentioned, its non-rivalness; indivisibility; and scale freeness in its use; and the (related) increasing returns property both in its utilization and its accumulation over time. However, second, at least equally fundamental contributions have come from the appreciation of the differences between technological knowledge and sheer information – including its varying degrees of tacitness, its organizational embodiment, the difficulties of inter- and intra-organizational replication, and its crucial dependence upon the characteristics of particular technological bases.

In the opening up of the technological black box, the account of technologies in terms of pieces of knowledge, their combinations, and their changes has to be complemented by a more operational representation of technology in action. The conception, design and completion of whatever artefact, generally involves (often very long) sequences of cognitive and physical acts. Hence, it is useful to think of a technology also like a recipe entailing a design for a final product, whenever there is a final physical artefact, together with a set of procedures for achieving it.

A major advancement and contribution in the Economics of Innovation is the notion that each technology needs to be understood as comprising (a) a specific body of knowledge and practice – in the form of processes for achieving particular ends – together with an ensemble of required artifacts, on the input side; and (b) quite often some shared notion of a design of a desired output artefact. These elements, together, can be usefully considered as constituent parts.
of a technological paradigm (Dosi, 1982, 1988). A paradigm embodies an outlook, a definition of the relevant problems to be addressed and the patterns of enquiry in order to address them. It entails specific templates for the solution to ensembles of techno-economic problems based on highly selected principles derived from natural sciences, jointly with specific rules aimed at acquiring related new knowledge. Finally, technological paradigms identify the operative constraints on prevailing best practice, and the problem solving heuristics deemed promised for pushing back those constraints. Moreover, technological paradigms both provide a focus for efforts to advance a technology and channel them along distinct technological trajectories, with advances (made by many different agents) proceeding over significant periods of time in certain relatively invariant directions, in the space of techno-economic characteristics of artefacts and production processes.

The technologies as knowledge and as recipe perspective offers an enormous progress in the understanding of what technological knowledge is all about as compared to the blackboxing entailed by the traditional representation of technology as output = f(list of ingredients). Moreover, the recipe perspective offers promising venues also to the formal representation of the dynamics of problem-solving procedures involved in any technological activity, within organizations in particular. In such a procedural view, the orienting focus is not immediately the list of inputs and equipment used to produce, say, a semiconductor of certain properties, but rather it rests in the design of the devices and the procedures used in the transformation of the raw silicon into a microprocessor.

Concerning technological advance, modifications and refinements of procedures and designs are where the action is, while changes in input/output relations (the production functions) are in a way the by-product of successful attempts to achieve effective procedures and designs with certain performances, and to change them in the desired directions. Thus, what comes under the heading of production functions of whatever kind, is basically just the expression description of what appears in the quantity part of the recipes. Note also that, dynamically, in most cases efforts to change recipes directly entail changes in input characteristics and intensities and, conversely, attempts to substitute one input for another involve changes in production procedures. Symmetrically, attempts to substitute the more expensive inputs – so easy when seen from the angle of some standard production function – often require the painstaking search of new recipes and effective procedures.

Granted that, a question with crucial ramification for any theory of production regards precisely the mappings between procedure-centred and input/output centred representations of technologies. Suppose one has a metric in the input/output space, and one is also able to develop, a (albeit inevitable fuzzy) metric in the high dimensional problem-solving space. Next, how do the latter map into the former?

Issues of the same kind regard the relationship between changes in the recipes, on the one hand, and changes in the relative intensities in the use of the various inputs, on the other. Do small changes in procedures correspond to small changes in input/output relations? And, vice versa, do major technological revolutions affecting the way of doing things imply also major changes in the proportions in which different artefacts and types of labour enter into the recipes for whatever output? That is, basically, what are the relationships between changes in technological procedures and the characteristics of technological trajectories, both in the spaces of product characteristics and of input coefficients?

3.2. Organizations

A good deal of innovations are generated within corporate organizations, while technological and organizational innovations are often intertwined. Thus, it is crucial to progress in the formal exploration of the properties of economic organizations seen as problem-solving entities. It is promising to represent them in terms of explicit sequences of activities and procedures nested into specific organizational arrangements prescribing who send which signal to whom, and who does what and in which consequence.

Notwithstanding promising inroads (see Maredo and Dosi, 2005; Dosi et al., 2003; Dosi and Marengo, 2015), models still fall short of an explicit formal account of (i) the emergence and dynamics of organizational routines; (ii) the related role organizational memory; and finally, (iii) the links between organizational architectures, knowledge distribution and performances.

The knowledge of an organization regards, first, its cognitive memory – the structure of beliefs, interpretative frameworks, codes, cultures by which the organization interprets the state of the environment and its own “internal states” (Levitt and March, 1988). Second, organizational knowledge includes routines – comprising standard operating procedures, rules and other patterned actions. Both, cognitive models and operational repertoires are the outcomes of learning processes and thus evolve over time in response to experimentation and feedbacks from the environment. However, they might often bear quite high degrees of inertia and path-dependent reproduction, as in fact, by its nature, organizational memory reproduces over time what an organization has learned throughout its history.

Signals from the environments, as well as from other parts of the organization, elicit particular cognitive responses, conditional upon the collective mental models that the organization holds. Cognitive memory maps signals from an otherwise unknown world into cognitive states (this year the state of the market is such that it will be profitable to produce X). Conversely, the operational memory elicits operating routines in response to cognitive states (“this year we should produce X”), internal states of the organization (“the machines are ready to start producing piece P”) and also environmental feedbacks (“after all X is not selling too well”).

Cognitive and operational memories entail an if → then structure. A promising candidate to model them finds its roots into the formalism of Classifier Systems (Holland, 1975, 1986): a pioneering application developed in Marengo (1992) and subsequent refinements are in Dosi et al. (2017a,b). On the ground of such formal apparatus one can first analyze the effects in terms of performances of different distributions of knowledge and of the related memory elements within the organization (e.g., whether hierarchically versus horizontally distributed, etc. . . ) conditional upon different characteristics of the environment. Second, this type of models may help to explore the conjecture – well grounded in several empirical studies – that a memory structure well “fit” for a particular environment may turn out to be perversive under different technological or market conditions (cf. among others Tripsas and Gavetti, 2000 and Bresnahan et al., 2011). In fact, in many respects, much work has still to be done in the exploration of the outcomes of the mappings between types of knowledge, memory characteristics, organizational architectures and patterns of environmental change.

3.3. Corporate learning, competition and industrial evolution

In modern capitalism, business firms are a central locus of the efforts to advance technologies, develop new products and operate new production processes. Thus the knowledge and the procedures underlying each technology, discussed in the previous section, are to a good extent embodied in organizational routines and other “quasi genetic action patterns” of organizations (Winter in Cohen et al., 1996). Indeed, an emerging capability-based theory of the firm (cf. Dosi et al., 2001, 2008 among others) places the “primitives” of the nature of business firms in their problem-solving features, that is their abilities to address practical and cognitive
problems, ranging from, say, the production of a car to the identification of a malaria-curing molecules.

The approach, which finds its roots in the works of H. Simon, J. March, A. Chandler and S. Winter – fully acknowledging ubiquitous forms of human bounded rationality, grossly imperfect processes of learning and diverse social distributions of cognitive labour – attempts to identify the distinctive capabilities of organizations as emergent from their distinctive ensembles of organizational routines. And, dynamically, the approach tries to account for the processes by which organizational knowledge is acquired, maintained, augmented and sometimes lost – partly as a result of the dynamic capabilities of organization themselves (Teece et al., 1997; Helfat, 2007).

Idiosyncratic capabilities and, dynamically, idiosyncratic patterns of learning by firms are the general rule. In turn, such persistently heterogeneous firms are nested in competitive environments, which shape their individual economic fate and, collectively, the evolution of the forms of industrial organization. Differences in products and in processes of production – and as a consequence costs and prices – are central features of the competitive process in which firms are involved in different ways. Let us call Schumpeterian competition the process through which heterogeneous firms compete on the basis of the products and services they offer and obviously their prices, and get selected – with some firms growing, some declining, some going out of business, some new ones always entering. Such processes of competition and selection are continuously fuelled by the activities of innovation, adaptation, imitation by incumbent firms and by entrants. In turn, the processes of industrial evolution leaves statistical footprints in terms of industrial structures and firm dynamics. Thanks to massive infusions of micro-data over the last 20 years, one has begun to identify a few robust statistical properties characterizing industrial structures, their changes, and performance indicators.

In general, evolutionary interpretations are grounded on two basic building blocks. The first is a learning part wherein individual agents (firms), massively boundedly rational but always able to innovate, search for new techniques and new products and the second is a selection part whereby market interactions determine ex-post profitabilities, survival probabilities and firm rates of growth. More on the structure of evolutionary models of industrial dynamics in Silverberg et al. (1988), Silverberg and Lehnero (1994), Metcalfe (1998) and Dosi et al. (1995, 2017b).

The (idiosyncratic) learning part of the dynamics is often represented as a stochastic search for innovation and imitation in the neighbourhood of the incumbent techniques of each firm. Conversely, the selection part of the process is basically captured by different instantiations of some replication dynamics. The bottom line is a relation between some corporate characters – that is, technological, organizational, or behavioural traits – which the particular interactive environment favours, on the one hand, and the rate of variation of the frequencies in the carriers of such characters in the relevant populations on the other.

One has only begun to systematically link evolutionary models with the stylized facts of industrial dynamics discussed above. Here the big challenge regards the ability of the models of generating – and in that sense explaining – the rich ensembles of observed empirical regularities, both those that are generic, holding across sectors, countries and phases of the industry life cycles, and those that are regime-specific. In that the phenomena to be explained – ranging from size distributions and other measures of industrial structures such as concentration, to the distributions of corporate growth rates all the way to the determinants of growth itself – ought to be understood, again, as emergent properties stemming from the out-of-equilibria interaction of heterogeneous, far from omniscient, but potentially innovative, agents.

In particular, to date, the generality of evolutionary models has assumed some monotonicity in the relations between fundamental determinants of competitiveness/revealed fitness, and subsequent relative growth. However, the evidence on these selective processes suggests that selection forces are weaker than those theorised. In turn, this may well be the consequence of various forms of market imperfections – including informational ones – which, together with endemic satisfying behaviours, allow firms characterized by diverse degrees of efficiency and product qualities to co-exist without too much relative pressure. On the modelling side such evidence demands an account of evolution occurring over multidimensional fitness landscapes – explicitly capturing the multidimensional differences in product characteristics – rugged, thus allowing for multiple metastable states, but also intertwined by ample flat areas – whereby selective pressures are relatively low.

3.4. From micro to macro coordination and growth

We have already discussed above that the interpretation of macroeconomic dynamics must have, in our view, microfoundations explicitly resting on multiplicity of heterogeneous interacting agents. Granted that, there are two complementary modelling perspectives.

In a first one, which we could call coordination without evolution, one may study the condition under which coordination emerges, intertwined by major phase changes, in markets, and other interacting environments, wherein agents interact and adjust locally. The fundamentals of such environments might well be stationary (hence, strictly speaking, no evolution), but the thread of interactions and adjustments typically yields non-linear macroscopic effects characterized by diverse patterns of coordination (or lack of it). A lot of work has been done in this perspective (for surveys, see Tesfatsion and Judd, 2006 and LeBaron and Tesfatsion, 2008) offering theoretical tales on self-organizing patterns. Still, one is quite far from a thorough understanding of e.g. how markets work, conditional on their different network structures, as convincingly advocated by Kirman (2011).

Together, let us strongly urge the investigation of coordination with evolution on the ground of higher dimensional, phenomenologically much richer Agent Based Models. Within a growing ensemble of ABM efforts (see Fagiolo and Roventini, 2016 for a recent survey), the authors of this note advocate refinements and developments upon the family of “Schumpeter meeting Keynes” models (Dosi et al., 2010, 2013, 2015, 2016, 2017c). They clearly meet Solow (2008)’s plea for microheterogeneity: a multiplicity of agents interact without any ex ante commitment to the reciprocal consistency of their actions.

This family of models bridges Keynesian theories of demand generation and Schumpeterian theories of technology-fuelled economic growth. Agents always face opportunities of innovations and imitation, which they try to tap with expensive search efforts, under conditions of genuine uncertainty (so they are unable to form any accurate expectations on the relation between search investment and probabilities of successful outcomes). Hence (endogenous) technological shocks (the innovations themselves) are unpredictable and idiosyncratic.

This family of models builds on evolutionary roots, but is also in tune with genuine Keynesian insights. It tries to explore the feedbacks between the factors influencing aggregate demand and those driving technological change. By doing that, it begins to offer a unified framework jointly accounting for long-term dynamics and higher frequencies fluctuations. The model is “structural” in the sense that it explicitly builds on a representation of what agents do, how they adjust, interact and respond to policy changes. Indeed, the model has already proved to be able to generate jointly, as emergent properties, a wide set of stylized facts regarding both
micro/meso phenomena and macro stylized facts. They include (i) endogenous growth; (ii) persistent fluctuations; (iii) recurrent involuntary unemployment; (iv) pro-cyclical consumption, investment, productivity, employment and changes in inventories; (v) fat-tailed distributions of aggregate growth rates; together with persistent asymmetries in productivity across firms; (vi) spiky investment patterns; (vii) skewed firm size distributions; (viii) fat-tailed firm growth rates, and (ix) on the labour market side Beveridge, Wage (or Phillips), and Okun curves, (x) separation and hiring rates volatility, (xi) matching function, (xii) productivity, unemployment and vacancy rates volatility, (xiii) unemployment and inequality correlation (cf. Dosi et al., 2017c). To repeat, the foregoing robust statistical regularities and relatively stable relations amongst aggregate variables do indeed emerge out of turbulent, disequilibration, microeconomic interactions. As such, the model can be used also as sort of ‘laboratory’ for policy experiments. We have begun to do it, showing, for example, the complementarity between Keynesian and Schumpeterian policies.

4. Some challenges ahead, by way of a conclusion

In these notes we have tried to offer an evolutionary view on, possibly, the two major questions which cut across the whole history of economics as a discipline, namely the drivers of change and the coordinating properties of a system composed by multiple interacting agents. In many ways, they are a sort of advocacy of “back to the Classics”, especially Smith, Malthus and Marx, albeit with much more sophisticated formal and computational instruments. The basic interpretative conjecture here is that the properties we observe stem from the fact that the capitalist economies are the first ones in human history which incessantly “change from within”. And it is this very feature which accounts for the relatively orderly interactions which one often observes.

There is a lot that is there to be done on the theory side. And even more so, it has to be done on sides of statistics and of theory-informed, qualitative, historical interpretation, what Nelson and Winter (1982) call “appreciative theorizing”. Just to name a few domains.

Some challenges were already there in the largely unfilled “Santa Fe complexity programme” (see the introduction by Pines to Anderson et al., 1988). For example, first how do agents behave and learn in complex evolving environments? Economics, especially over the last half a century, has put an overwhelming emphasis on expectations in the interpretation of behaviour, unique in all disciplines, which matured beyond “Aristotelian” final causes. But that, in turns, implies universally transparent presents and futures, which is hardly in tune with innovation-ridden evolutionary worlds.

Second, how does one formally accounts for evolutionary processes wherein the dimensionality of the space-state progressively evolve?

Third, even short of that current econometric techniques are postulated upon unique equilibrium states shocked by exogenous disturbances. But, if what there are e.g. non-linear dynamics with multiple local attractors, persistently perturbed by endogenously generated shocks, how do we account for them?

Fourth, and well beyond the Santa Fe programme, what is the theory of value and income distribution in knowledge intensive worlds, generally characterized by increasing returns? Note, in this respect, that if one loosens convexity in production plans, one loosens also the link between the theory of production and the theory of income distribution. In our view, this is just a good news, but it poses a problem also for classical, cost-based theories: whenever the cost of replication is minor, like in the case of the reproduction of a software or a drug, is it just proportional to the cost of engineers and scientists who undertook the R&D?

The list is far from being exhaustive. And this is matched by equally important (or even more important) interpretative issues which have to do with the contemporary dynamics of capitalist economies.

A first one concerns labour market, wages and employment. The innovation-employment nexus deserves overriding attention. In the wake of a potential fourth Industrial Revolution, of a debate on productivity decline, “secular stagnation” and future robotization, research addressing the effects on both the quantity and the quality of employment is needed, as well as the balance between product and process innovation in terms of employment creation-destruction.

A second related one is inequality. It is and will be the core topic, together with unemployment, of the next many years. Even though the post-crisis period has been marked by an overwhelming and blossoming literature on inequality, detailed studies looking inside the transformation at shop-floor, the wage determination processes, the organization of the industrial relations, the process of de-unionisation are partly missing and badly needed. Beside that, what do we know about the potential link between productivity and wage dispersion, as possible determining mechanisms causing wage inequality, as compared to other mechanisms such as globalization and the financialization of the economies?

On the modelling side, the Schumpeter meeting Keynes model leaves scope for many potential avenues for further research: (i) the analysis of the effect of long-term versus short-term labour contracts on firm productivity, exploring the impact of contract duration on the process of workers skills accumulation, and consequently on productivity; (ii) a north-south version directed at studying the effect of flows of capital goods, consumption goods and workers among two countries, a leading and a lagging one, analysing the emergence of patterns of product specialization vis-à-vis diversification, cost-competitiveness vis-à-vis technological competitiveness, growth convergence vis-à-vis divergence; (iii) the effect of product vis-à-vis process innovation in terms of creation/destruction of labour demand.

And last but not least, policy analyses involve a fundamental paradigmatic change: the central concern for policies ought to shift away from efficient allocation issues, to the (imperfect) governance of coordination (Kirman, 2011), and of genuinely uncertain processes of change.

Acknowledgements

This work draws upon Dosi (1984), Dosi and Winter (2002), Dosi (2014) and Dosi and Virgillito (2018). We gratefully acknowledge the participants and the organizers of the workshop “Economic Change and Evolution” held at the Academia dei Lincei, 10–11 November 2014 and the support by the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 649186 – ISI.Growth.

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