Available online at www.sciencedirect.com
ScienceDirect
EconomiA 21 (2020) 121–129
ECONOMIA
www.elsevier.com/locate/econ

Economic development and complexity: Introduction to special issue*

João Basilio Pereima
NeX-Nucleo of Economics and Complexity, Federal University of Paraná, Brazil

Received 24 April 2020; accepted 11 May 2020
Available online 20 May 2020

1. The special issue

This special issue on *Economics Development and Complexity* contributes to the economic theory by gathering ten articles each of which presents a different economic problem from a complexity perspective. The articles analyse economic issues such as growth and structural change, macroeconomic policy, international trade, industrial dynamics, and ethnocentrism by using approaches such as agent-based economics, genetic algorithms, non-linear systems and network analysis. These articles were selected among submissions of an open call and participants of the *1st Workshop on Economic Complexity and Development* held on 9 and 10 December 2018 in Curitiba, Brazil promoted by **Nex-Nucleo of Economics and Complexity** (UFPR, Brazil) and **SPRU-Science Policy Research Unit** (Sussex, UK).

Economic development is one of the most complex phenomena that humanity has ever encountered. Its understanding has challenged policymakers, managers, politicians and the scientific community for centuries. At the same time, a growing number of unexpected events has surprised all of us such as the emergence of rumpus around the world (the last one hatching on 20 October in 2019 in Chile), financial crisis (2008), political turns in Europe and USA and Latin American countries in 2017–2019, diffusion of disruptive technologies, and last but not least, the COVID19 outbreak and its disastrous impact on our lives and all world economies. We feel that to understand this kind of emergent phenomena, not only new theories and different tools are needed but also a completely new approach for economic science, an approach based on complexity theory.

2. Moving further with complexity

Since the beginning, economists have struggled to make the complex phenomena of the economic development simpler and understandable and then have tried to use this power to reach a dream. The dream of keeping the economic system under control, eliminate cycles, generate enough employment and at the end build a fair society where a human being could live peacefuly and properously with each other and nature. Despite the enormous progress in economic

* The editors are grateful for support from the British Academy by Newton Advanced Fellowship RD3 2017 under the Grant Agreement NAF2R2/100097 and from INET-Young Scholars Initiative; and are grateful for the participants of two-days workshop on *Economic Complexity and Development: Growth, Structural Change and Sustainability*, and participants of *Summer School on Computational Methods and Agent-based Modelling in Economics*, both taking place in Brazil in 2018.

E-mail address: joaobasilio@ufpr.br

https://doi.org/10.1016/j.econ.2020.05.001

science, we are far from realizing that dream. After 244 years of economic science (if we consider the publication of the *Wealth of Nations* by Adam Smith in 1776 as the starting point) we are not even able to accurately predict the GDP or the inflation for the next month, not less, eradicate the poverty in many parts of the globe or avoid environmental destruction. This is not to say that economic science has failed in its mission, but that our mission is not finished yet.

The reason is that we are dealing with a reality much more complex than economic science has anticipated. The distinct explanations for the mechanism supporting the economic activity in society are partial and touch only in a portion of the problem. Take the institutionalists[1] (North, 1990, 2005; Brousseau et al., 2008), for instance, they highlight the constraints imposed by the institutions on individuals and try to predict what kind of institutions would coerce or stimulate certain behaviours and thus burst or disentangle the development nations (Acemoglu and Robinson, 2012). The individual is absent or plays a secondary rule. Take also the NeoClassical approach based on general equilibrium theory (Heer and Maußner, 2005; Bryant, 2010). It assumes representative, rational and fully optimizing individuals exploring all the possibilities of arbitrage, like the one living inside the Edgeworth-Bowley's box, moving quickly or even instantaneously to a general equilibrium where every economy is heading. Of course, this tendency to an equilibrium exists and maybe we would move there if each individual does not interact with another, does not change opinion, does not invent something new, does not own multiples interests and wishes, does not adapt its behaviour to exogenous and endogenous shocks and does not evolve. New Keynesians (Galí, 2008; Lavoie, 2014) when trying to micro-found their macro-models use the same strategy as NeoClassical economists recurring to the figure of representative agent also dismissing all the heterogeneity and interactions between agents. The same applies to the dynamic stochastic general equilibrium (DSGE) approach (Long and Plosser, 1983; Kydland and Prescott, 1982; Plosser, 1989; Woodford, 2003; Wickens, 2008) which imposes an equilibrium condition that exhausts an initial exogenous shock after some time and nothing new is created on the way. General equilibrium approach is not well equipped to deal with key elements such as novelty and structural change (Fagiolo and Roventini, 2017; Dosi et al., 2019). Despite huge differences, Keynesianism and Marxism are both macroeconomic theories, that is, neither of them explains the motivations behind the behaviour of the agents. Keynesianism lacks a theory of innovato to deal with evolution and Marxism reduces the heterogeneity across the agents to a system of two social class: capitalists and workers.

Of course, all these traditions in economic science do much more and are more encompassing than we could expose here, and criticize a theory for what it does not do is not an appropriate judgement. These comparisons just help us to put the theoretical achievements in perspective and if we want to understand the process of economic development we need more scientific advances than we currently have conquered and accumulated. The reality is much more complex than we have imagined and to move further in the path of understanding economic development we need to view the economic system with different glasses. Complexity science,[2] as it has been defined by many scientists in different fields (Wolfram, 1994; Holland, 1995; Simon, 1996; Bonchev and Rouvray, 2005; Mainzer and Landauer, 2007; Érdi, 2008; Page, 2010; Mayfield, 2013; Du and Ko, 2014; Arthur, 2015), is a promising candidate to help us move further in our understanding of the world around us. This special issue is a step forward in exploring economic development as a complex phenomenon.

3. Complexity

Complexity economics is the application of complexity science to the problems of economics. The complexity science is not a unified field of the science (Ladyman et al., 2013) and therefore there is no precise definition of a complex system that satisfies all science fields and applications. As a consequence, the existence of multiples concepts makes the task of measuring complexity a challenge. Many alternatives have been suggested (Lloyd, 2001; Ladyman et al., 2013; Wiesner and Ladyman, 2019) which satisfy diverse interests and apply to several complex systems and recently some unifying effort has been attempted to develop a universal measure (Efatmaneshnik and Ryan, 2016). For this special issue, we consider a *complex economic system* a system that combines two or more of the following

[1] Without distinguishing between "old" and "new" strand (Rutherford, 1995). According Rutherford for some new institutionalist even departing from some kind of individualism rather than holism as the old branch does, the individual is only "seen as an overly rational and overly autonomous being, constrained, but not otherwise influenced by, his institutional and social setting" [p.4].

[2] If we can refer to it as a unified science.

features and proprieties: (a) it is populated by heterogeneous agents who strongly interact to each other[3]; (b) has many hierarchical levels from micro to macro; (c) evolves and is subject to a path dependence or cumulative causality process, not reversible; (d) is subject to endogenous innovation[4] of different types which is one of the major drivers that push the system out of the equilibrium; (e) preserves order and due to random events generate a set of diverse time series, some of them surprising and not directly deductible from the micro or macro behaviour (see the example right below); (f) is populated by intelligent but not fully rational agents which behave adaptively using bounded and procedural rationality; (g) agents in the system can learn, change behaviour, move spatially, be born and die; (h) information propagates in a network and is subject to some degree of percolation, and finally; (k) in the case of macrodynamic systems, they can be represented by a set of non-linear differential equations which can generate multiple attractors and bifurcations. Therefore, from the perspective of complexity science, the economy is a system in permanent motion that continually compute and perpetually rebuild itself anew.

Although complex thinking is not new in science and philosophy, only in the last three decades that the complexity has gained more notoriety. So, let us explore the implications of complexity for economic theory by building an example where small rocks work as agents, and then replacing that kind of inanimate agents by living ones, such as human beings or firms for instance.

Take a bunch of rocks and start arranging them in different ways to build a structure. A question someone might ask is how many different structures can emerge from arranging these rocks in different ways? If one can act freely, there is an infinite number of results, however, if one is constrained by a specific set of rules the combinatorial possibilities are fewer. Statistically, any structure like a bridge, a temple or a pyramid or something else could emerge from randomly combining those rocks, but with probability asymptotically approaching to zero depending on the number rocks available for combining. By employing this simple analogy, we can analyse many social phenomena. Let us explore two examples that can help us to understand the implications of complexity for economic science.

First is the origin of macro phenomena based on representative agents. The way one combines the same amount of rocks produces a myriad of results or final structures as the ones mentioned before. The final structure has shape and properties that are not found in the individual rocks. Take a final bridge, for instance. One can analyse the rock by any method including material composition, weight, form, colour, hardness and many other properties. No matter what someone analyses, taking a single rock one can never find something like a bridge inside it. Deductive thinking here usually fail, or at the best is an incomplete method. Thus, where does the bridge come from? The bridge does not exist in any specific place, it is a collective property that exists neither inside the rock nor pre-exists outside in the aggregate level but only emerges through the interactions among smaller components. The same rocks could result, in aggregated terms, in a church, a road, a dam, etc, depending on how we arrange them or which set of rules we used. The implication of this for economics is that one of the sources of complexity in economic systems is the interaction among the parts. To understand what is going on at the macroeconomic level and, more, to understand where some macroeconomic effects or dynamics *comes from*, we need methods and concepts different from those using simple aggregation by summing up representative agents.

When we just add representative parts, looking for the micro-foundations of macro phenomena what we are doing is to project or convert some macro proprieties in individual behaviour. Lets us consider the example of rocks once more. As an economist, we usually represent the aggregated economic system, now our bridge, by weighting the rocks and multiplying by the price getting the total value of production just computing $Y = \sum_{i=1}^{n} p_i q_i$, supposing we are using different rocks at difference prices. By using this method you can compute the value of total production in monetary terms only. Other proprieties, micro fundaments and macro consequences are missed. By this aggregation method, we cannot say anything about the origin and the *formation* of the bridge. The same amount of rocks, this time used in a church, would produce the same value $Y for completely different macrostructure. We could never get a bridge by just adding rocks and multiplying by prices. If this not works for simple and inorganic things like rocks, how this method could work and be applied for intelligent agents like humans playing their roles as consumers, workers, voters, citizens, entrepreneurs, firms, politicians and so on?

[3] The interactions in many cases can be formalized by using networks or graph theory.

[4] Innovation here has a large interpretation and do not means only technological progress such as productivity or quality. It can be interpreted as any case of mutation and diffusion as, e.g., in some genetic algorithm where the agent tries a new strategic or behaviour in a selective and evolutionary process.

This brings us to the *second* implication of complexity for economics, which concerns the problem of uncertainty and combinatorial analysis. Social phenomena, like world economic system, countries, markets, firms, families, governments, non-profit organizations, social groups like teams, churches, political parties, etc., are live systems, we mean, are system populated by generations of intelligent agents with an enormous repertory of behaviour when compared with the inert and passive rocks. Not only the behaviour can change adaptively in the short run when the incentives and constrains change, but also the agent can innovate rebuilding the system from inside, endogenously, in such a way that having passed some time the original system can reshape itself and generate new macro patterns, sometimes a surprising one. But more than just recombine the positions like the rocks in the bridge, in the social phenomena the live agents can also change the rules that govern the combinations options and change itself by mutation, opening room to emerge new macro consequences, like the emergence of unintended consequences such as economic crisis, riots, wars, bankruptcies, and so on. Even in the case we have intended results in mind, such as boosting economic growth and development or reducing poverty and inequality or protecting the environment by some economic policy, the outcome is many times frustrating. Although many countries have pursued intentional policies to foster growth only a few are being successful. Understanding failure and success requires complex instead of analytical thinking. And the economic system is by far one of the most complex systems we know, which bring us to the next question, how complex an economic system is?

To answer this question let us make some computation inspired by the informational measure of complexity. The amount of complexity of a system X "populated" by rocks could be computed by the combinatorial analysis[5] converted into an entropy measure such that of Shannon (1948) given by $H(X) = -\sum_{i=1}^{N} p_i \log_b p_i$. Imagine a combination of five hypothetical rocks with only two faces like a sheet of two sides arranged side-by-side. To facilitate we can represent the rock-like-sheet by numbering the sides 0 and 1. The number of combination ranging from 00000, to 00001, ..., 01010, to 11111 is $2^5 = 32$, so the probability the system be in a state X_i is $Pr(X = X_i) = p_i = 1/32$, supposing that all the state X_i has the same probability to manifest or emerge. In this case, the Shannon complex degree is given by $H(X) = -\sum_{i=1}^{32} 1/32 \log_2 1/32 = -\log_2(1/32) = 5$, which means that to represent such system we should use an amount of information equal to 5-bits string. If the probability varies across the states the Shannon measure is lower and in the limit where only one state has 100% of probability $H(X) = -1 \times \log_2(1) = 0$. This extreme case resembles a deterministic world, without uncertainty. If you assume an amount of ten rocks with four faces (cubes), then the number of possible attainable states is $4^{10} = 1,048,576$ and $H(X) = -\log_2(1/4^1 0) = 20$, or we should use a 20-bits string if we remain in a binary (base 2) representation. Now image a small city with a population, let's say, of 10,000 inhabitants who could choose three options of urban transportation: bus, car and shoes. The number of combination for this simple decision is $3^{10,000}$ a number by far unthinkable, even not computable for some purpose. How a social or economic system could choose the state of the system each step over time? Of course not computing all the possibilities and choosing the most efficient each moment (more variable would need be added in the problem to represent cost and benefits, making it even more complex), as the traditional economic theory of choice suggests. The cost for computation extrapolates by many the capacity of the universe to execute this. This simple exercise illustrates the problem of the complexity as a combinatorial problem and reveals how fast the complexity degree, and hence the uncertainty, increases. Of course, biological organisms, natural and social systems have found a way to solve this kind of problems, through an evolutionary mechanism of mutation and adaptation using decentralized and parallel computation (executed by interacting agents) which allows them to find solutions by using some kind of genetic algorithm or evolutionary behaviour. An interesting explanation of this evolutionary computation can be found in the suggestive book *The Engine of Complexity: Evolution as Computation* by Mayfield (2013).

But complexity is not just a matter of combinatorial analysis. What happens to the system if the rocks mutate from a cube (6 faces) to an octahedron (8 faces) and now recombine using new rules? Complexity is also about evolution and structural change and to access the evolutionary mechanism we need also an innovation, a behavioural and an ecological theory. To deal with innovation one needs to include a theory of changing describing the process of mutation, selection and diffusion. Since the system is populated not by inert rocks but mainly by intelligent agents, a behavioural theory

[5] Many measures has been suggested in the literature to evaluate complexity, see (Lloyd, 2001; Ladyman et al., 2013; Efatmaneshnik and Ryan, 2016; Wiesner and Ladyman, 2019) already quoted, and see (Hidalgo and Hausmann, 2009; Tacchella et al., 2012) for economic applications in product space.

would require also a theory of choice, interactions and learning. Finally, since the agents also reproduce reinvigorating the system, an ecological theory based on populational thinking close our list. The most general process where all these theories apply simultaneously is economic development. With the advent of high computational power and big and diversified set of data, new opportunities are making possible to conduct artificial experiments in complex adaptive systems in social science (Epstein and Axtell, 1996; Epstein, 2006; Tesfatsion and Judd, 2006) as a way to study and understand the economic development process in new and expanded basis.

4. Economic development is a typical complex adaptive system

An economic system, composed of different hierarchical levels and subsystems and populated by interacting individuals, firms, organizations of all sort and governments is one of the most complex systems we know. We even would say that it is much more complex than our brain as it results from strong interactions of millions or billions of brains. It is a dynamic, cumulative, adaptive, heterogeneous, multi-level, diversified and evolutionary process, it is a typical complex adaptive system. But a quick search on scientific databases and libraries will show lots of references about economic development and few about economic development as a complex system. The causes behind this can be assigned to three factors: economic development is a large and embracing topic with a myriad of angles; complexity is, equally, an encompassing field with many tools and theories; economists have been trained to reduce the complexity of the economic system to a minimum, many times up to the point that it destroys any remnant of complexity, as it happens when one assumes general equilibrium and representative agent.

The economic development has been studied throughout the last century as a system in equilibrium by a significant community of scientist. This is not surprising due to the basis on which economic theory has been built. Most of the economic theory developed in the last century is based on the theory of choice[6] and the better or efficient *allocations* of scarce resources (Fishburn, 1973; Elster and Hylland, 1989), rather than a *formation* theory about where the economic system and their proprieties and dynamics come from (Arthur, 2015). In this spirit a typical and spread definition of Economics is a social science concerned with the production, distribution, and consumption of goods and services. It studies how individuals, firms, organizations, governments, and nations make choices on allocating resources to satisfy their unlimited wants and needs efficiently exploring scarce resources to achieve some amount of wished output (Robbins, 1932). Moving to the definition of *economic development*, Lionel Robbins defined it as the "increase in the absolute size of, for instance, capital or annual production regardless of the size of population". Right after, the author dismisses a more broad definition writing that *development* "...might mean an increase in complexity, in the articulation of different functions. It might mean progress towards some ethically defined goal. *But I shall not use this term in any of these senses."* (Robbins, 1968, p. 4, italics added). A statement like this could be a curiosity on the history of economic thinking, belonging to the past, if it were not reproduced currently by other authors working on growth and development theory. In a famous paper, Lucas (1988) wrote: "By the problem of economic development I mean simply the problem of accounting for the observed pattern, across countries and across time, in levels and rates of growth of per capita income".

Both authors are conscious about the comprehensiveness and how complex the *economic development* is, but they, like many others, chose the concise and available method of building analytical models and respective theories. The question is that in reducing the concept of *development* to a minimum how much realism have we lost? Although the analytical method reproduces properly some aggregated patterns, it fails to explain where does that pattern come from and, mainly, how the aggregate level can evolve and change structurally. Backing to our previous examples, when one makes use of an aggregated theory based on simple sum such as $Y = \int_1^n f(x)dx$, we lost the bridge and the emergence of any structure. Bridges or any structure are lost because summing up in this way, all different structures built with the same amount of rocks would produce the same GDP. Economic development is about GDP and other macroeconomic variables also, but by proceeding in this way *only*, we simply can say anything about the emergence of a bridge and other structures. Summing up the values of rocks in this way a bridge is equal to a church that in turn is equal to a skyscraper and equal to anything else. We lost the complexity and hence a significant portion of the reality.

[6] Which includes production and consumer theory. In the supply side, producers decide where allocate inputs to produce goods and in the demand side consumers decide in which consumer goods allocate their income.

The next question then is how can we recognize the complexity embedded in the economic development process? Economic development is by far one of the most complex adaptive system (CAS) known. According to John Holland, CAS are systems that have a large number of components, often called agents, that interact, learn, and adapt. This implies that the agents and system as a whole share four major features: (i) *parallelism*, or decentralized action and decision by a population of interacting agents; (ii) *conditional action*, like '`if,...,then,..., else`' computation; (iii) *modularity*, sometimes organized in a hierarchical system; and (iv) *adaptation and evolution* (Holland, 2006). We could add a fifth feature (v) *heterogeneity and variety* to the list, which allows escaping from the dictatorship of average representation.

With these features, the agents and the system can not only solve allocations choices but also compute evolution or changing, some times generating a disruptive structural change. This is essential to understand the economic development process and the course it follows in different countries and societies. Despite some stylized macroeconomic facts, such that highlighted by Kuznets (1955) and Kaldor (1961) and reproduced in the modern theory of balanced growth, and despite the stylized fact about structural change where secular trajectories in agriculture, industry and services are very similar in many industrialized countries (Herrendorf et al., 2014), even so, a significant amount of heterogeneity remains. Different countries follow their trajectories and seem to track their path with a different pattern of growth rate, structural change, income distribution, etc.

Currently, a growing number of researchers are working to connect complexity and economic development in one framework which makes sense scientifically and avoids excessive subjectivity when dealing with developmental issues.

A new vintage of theory and agent-based models recognizing and dealing with some portion of complexity are shedding new lights on the economic development phenomena, some focusing on macro-dynamics, other on labour and financial market, environment, diffusion of innovation, social dynamics such as cooperation, altruism, corruption, crime and violence, segregation and urban and regional evolution. The list goes on. Special interest for this special issue is the large family of models relying upon micro and macro dynamics. Bottom-up or micro-macro models such as Lorentz et al. (2016), Ciarli and Valente (2016), Ciarli et al. (2019) are making possible to unify in the same framework (model) economic growth, structural change, personal income distribution and innovation and their interlacing effects, in a way that would be impossible to achieve using an analytical scheme. Innovation is the main driver for growth and structural change but it has been a gruelling 'black-box' to open. We better know its effects on economics dynamics than we know how it is generated at the microeconomic level. Contribution like Valente (2014) helps to understand how firms, using some class of genetic algorithm scan for innovation in a complex environment given by an irregular landscape with distinct technological opportunities. Micro-macro models of growth and business cycles with endogenous innovation in a multi-sector (Possas and Dweck, 2011), or North-South (Fernandes and Porcile, 2007) or multi-country (Dosi et al., 2019) and complex agent-based models for macroeconomic analysis such that of Gatti et al. (2008, 2011) and Dosi et al. (2010, 2017) are revealing a richer set of emergent dynamics, all showing that a population of heterogeneous and interacting agents can push the economic system to a result many times different from that predicted (or deducted) by the analytical models and hence are helping to shed lights on the evolutionary mechanism behind each macro-dynamics.

5. Contributions of the special issue

Going back to this special issue, we can now summarize the ten contributions at hands. Each contribution shares the complex view outlined above but handling a different issue on economic and development.

Alexandre and *Lima* build a model that explores the effects of *trade credit* between upstream (intermediate goods) and downstream (consumption goods) firms. Trade credit is an important channel of credit, but not recognized by monetary theory, which focuses on bank-credit. The authors show that in an economy populated by heterogeneous firms using trade credit there exist a potential trade-off between financial robustness and mean output level.

Araujo et al. use a dynamic model based on a non-linear differential equation system to show that if we introduce a money wage Phillips curve with a perfect spillover of price on wage inflation, thus the integration of the Foley's money liquidity and firm profit cycles with Goodwin cycles requires State intervention to stabilize the growth rate since the stable equilibrium can degenerate to a Hopf-bifurcation or a cycle limit dynamics under certain circumstances.

Dosi et al. discuss the research findings from the labour-augmented Schumpeter meeting Keynes (K+S) agent-based model, characterised by different degrees of labour flexibility, and by institutional shocks entailing labour market structural reforms. Using this model the authors show that the most proposed macroeconomic policies are likely inadequate to tackle the short-term crises consequences, and even risk demoting the long-run economic prospects.

In the same spirit, *Dweck et al.* discuss the role of fiscal policy in a demand-led growth, by using a multi-sectoral agent-based model. By conducting some computational experiments the authors conclude that all scenarios imposing a tighter constraint to government spending present signs of self-defeating fiscal consolidation and unconstrained countercyclical policy prevents the contagious effect of external crises, leading to better economic performance and reducing the likelihood of crises.

Gabardo et al. build a three-sector agent-based model where growth is generated endogenously by technical progress and structural change is driven by income and relative price effect. The structural change is analysed by the migration of employment between sectors over a century. The authors use the model to show that both effects, income and relative price, are necessary elements in a theory of growth and structural change. The model is calibrated to reproduce the sectoral employment shares of the Sweden economy from 1890-2010 as an empirical validation.

Oliveira et al. discuss the expansionary fiscal austerity hypothesis using a demand-driven agent-based model and show that the reduction of government spending can generate expansionary effects on the economy by increasing the confidence of agents. The model analyses the contagion across firms and analyse whether fiscal consolidations can be expansionary due to a positive effect on investors' expectations, which could be the result of a dominant public discourse on the need for austerity. The results show that the austerity hypothesis does not emerge from the behaviour of agents, not even when a share of the firms board the wave of optimism.

Hartmann et al. address the problem of income inequality associated with the types of products traded between countries and different regions of the world. Using network analysis to analyse the data on imports and exports of 116 countries in the period from 1970 to 2010, the authors show that the core-periphery structure of global trade affects not only the income inequality between countries but also the income inequality within countries.

The next two contribution uses genetic algorithms to deal with different issues. *Passos et al.* analyse the effects of machine learning in a market structure and build an evolutionary model containing firms that use a genetic algorithm to decide their investment in innovative R&D. A model of industrial dynamics was implemented and simulated using several population distributions of the three types of firms: firms that use a genetic algorithm to investment decision, firms that use an investment function which depends on the demand and profit rate, and firms that use a random strategy of investment. The simulations bring contrasting results when compared to previous works an show that machine learning led to market dominance, but the same did not occur when considering the improvement of technological efficiency and social welfare.

Carrão et al. build an agent-based model that extends the ethnocentric models existing in the literature, by adding a process of inductive reasoning where the decision of the agents depends on the perception of the others toward him. Ethnocentric behaviour is defined as high intra-group cooperation rates while interactions with external groups are non-cooperative. The authors find that individuals who understand and interpret part of the environment where they are inserted and react inductively tend to be more cooperative at the expense of discriminatory and ethnocentric behaviour observed in the original model and find also that the cooperation in society can be stronger than the literature predicts.

Finally, *Muller* brings us a more encompassing discussion about adopting public policies in complex environments, not a specific one but any case of public policy. The author argues that the failure of public policies is ubiquitous and this is ascribed to the complex nature of public policies. There is a contradiction or a paradox between public policy and complex reality. While the traditional approach is fundamentally based on both control and prediction, the reality and its complex proprieties make it difficult to be closely controlled or predicted. The author argues that policymakers should start to recognize the complex environment and adjust their decision and actions using instruments that can work within those informational and epistemological constraints.

Closing this introduction, these ten articles selected in this special issues make contributions in different fields of economic theory relying upon micro-macro models, growth, structural change, productive structure, income distribution, innovation and industrial dynamics, ethnocentrism and public policies. Many tools and methods were used such as agent-based micro-macro model, network analysis, and genetic algorithm, some times in combination. We hope that this special issue can contribute to stimulate further research in the field, broaden our understanding of the economic development process and improve our skills to promote suitable economic policies.

References

Acemoglu, D., Robinson, J., 2012. Why Nations Fail. Crown Publishers, New York.

Arthur, W.B., 2015. Complexity and the Economy. Oxford University Press, New York, NY, USA.

Bonchev, D., Rouvray, D.H., 2005. Complexity in Chemistry, Biology, and Ecology. Springer-Verlag, New York, USA.

Brousseau, É., Glachant, J.M., 2008. New Institutional Economics: A Guidebook. Cambridge University Press, Cambridge, UK.

Bryant, W.D.A., 2010. General Equilibrium: Theory and Evidence. World Scientific Publishing Co. Pte. Ltd., Singapore.

Ciarli, T., Lorentz, A., Valente, M., Savona, M., 2019. Structural changes and growth regimes. J. Evol. Econ. 29 (1), 119–176.

Ciarli, T., Valente, M., 2016. The complex interactions between economic growth and market concentration in a model of structural change. Struct. Change Econ. Dyn. 38, 38–54.

Dosi, G., Fagiolo, G., Roventini, A., 2010. Schumpeter meeting Keynes: a policy-friendly model of endogenous growth and business cycles. J. Econ. Dyn. Control 34 (9), 1748–1767.

Dosi, G., Napoletano, M., Roventini, A., Treibich, T., 2017. Micro and macro policies in the Keynes + Schumpeter evolutionary models. J. Evol. Econ. 27 (1), 63–90.

Dosi, G., Roventini, A., Russo, E., 2019. Endogenous growth and global divergence in a multi-country agent-based model. J. Econ. Dyn. Control 101, 101–129.

Du, D.Z., Ko, K.I., 2014. Theory of Computational Complexity, 2nd ed. John Wiley & Sons, Inc., New Jersey and Canada.

Efatmaneshnik, M., Ryan, M.J., 2016. A general framework for measuring system complexity. Complexity 21 (S1), 533–546.

Elster, J., Hylland, A., 1989. Foundations of Social Choice Theory. Cambridge University Press, Cambridge.

Epstein, J.M., 2006. Generative Social Science: Studies in Agent-based Computational Modeling. Princeton University Press, Princeton, NJ, USA.

Epstein, J.M., Axtell, R., 1996. Growing Artificial Societies: Social Science from the Bottom Up. The Brookings Institution, Washington.

Érdi, P., 2008. Complexity Explained. Springer-Verlag, Berlin, Germany.

Fagiolo, G., Roventini, A., 2017. Macroeconomic policy in DSGE and agent-based models redux: new developments and challenges ahead. Jasss 20 (1), 1–47.

Fernandes, A.L., Porcile, G., 2007. Um modelo evolucionário Norte-Sul. Rev. Econ. Polit. 27 (4), 633–650.

Fishburn, P.C., 1973. The Theory of Social Choice. Princeton University Press, Princeton, NJ, USA.

Galí, J., 2008. Monetary Policy, Inflation, and Business Cycle: A Introduction to the New Keynesian Framework. Princeton Univerity Press, Princeton, NJ, USA.

Gatti, D.D., Desiderio, S., Gaffeo, E., Cirillo, P., Gallegati, M., 2011. Macroeconomics from the Bottom-up. Springer-Verlag, Milano, Italy.

Gatti, D.D., Gaffeo, E., Gallegati, M., Giulioni, G., Palestrini, A., 2008. Emergent Macroeconomics. Springer-Verlag, Milano, Italy.

Heer, B., Maußner, A., 2005. Dynamic General Equilibrium Modelling: Computational Methods and Applications. Springer-Verlag, Berlin, Germany.

Herrendorf, B., Rogerson, R., Valentinyi, Á., 2014. Growth and Structural Transformation. In: Aghion, P., Durlauf, S.N. (Eds.), In: Handbook of Economic Growth, vol. 2, pp. 855–941.

Hidalgo, C.A., Hausmann, R., 2009. The building blocks of economic complexity. Proc. Natl. Acad. Sci. USA 106 (26), 10570–10575.

Holland, J.H., 1995. Hidden Order: How Adaptation Builds Complexity. Helix Books, New York, USA.

Holland, J.H., 2006. Studying complex adaptive systems. J. Syst. Sci. Complex. 19 (1), 1–8.

Kaldor, N., 1961. Capital accumulation and economic growth. In: Hague, D.C. (Ed.), The Theory of Capital. M Stokton Press, London, UK, pp. 177–222, Proceeding edition (chapter 10).

Kuznets, S., 1955. Economic growth and income inequality. Am. Econ. Rev. 45 (1), 1–28.

Kydland, F.E., Prescott, E.C., 1982. Time to build and aggregate fluctuations. Econometrica 50 (6), 1345–1370.

Ladyman, J., Lambert, J., Wiesner, K., 2013. What is a complex system? Eur. J. Philos. Sci. 3 (1), 33–67.

Lavoie, M., 2014. Post-Keynesian Economics: New Foundations. Edward Elger, Cheltenham, UK.

Lloyd, S., 2001. Measures of complexity: a nonexhaustive list. IEEE Control Syst. 21 (4), 7–8.

Long, J.B., Plosser, C.I., 1983. Real business cycles. J. Polit. Econ. 91 (1), 39–69.

Lorentz, A., Ciarli, T., Savona, M., Valente, M., 2016. The effect of demand-driven structural transformations on growth and technological change. J. Evol. Econ. 26 (1), 219–246.

Lucas, R.E., 1988. On the mechanics of economic development. J. Monet. Econ. 22 (1), 3–42.

Mainzer, K., Landauer, R., 2007. Thinking in Complexity: The Complex Dynamics of Matter, Mind, and Mankind, 5th ed. Springer-Verlag, Berlin, Germany.

Mayfield, J.E., 2013. The Engine of Complexity. Columbia University Press, New York, USA.

North, D.C., 1990. Institutions, Institutional Change and Economic Performance. Cambridge University Press, Cambridge, New York.

North, D.C., 2005. Understanding the Process of Economic Change. Princeton University Press, Princeton, NJ, USA.

Page, S.E., 2010. Diversity and Complexity. Princeton University Press, Princeton, NJ, USA.

Plosser, C., 1989. Understanding real business cycles. J. Econ. Perspect. 3 (3), 51–77.

Possas, M.L., Dweck, E., 2011. Crescimento econômico num modelo micro-macrodinâmico de simulaç ao. Econ. Soc. 20 (1), 01–31.

Robbins, L., 1932. An Essay on the Nature & Significance of Economic Science. Macmillan and Co. Limited, London, UK.

Robbins, L., 1968. The Theory of Economic Development in the History of Economic Thinking. Macmillan and Co Ltda and St Martin's Press, London, UK.

Rutherford, M., 1995. Institutions in Economics: The Old and the New Institutionalism, vol. 32. Cambridge University Press, Cambridge, UK.

Shannon, C.E., 1948. A mathematical theory of communication. Bell Syst. Tech. J. 27, 379–423.

Simon, H.A., 1996. The Sciences of the Artificial, 3rd ed. The MIT Press, Cambridge, MA.

Tacchella, A., Cristelli, M., Caldarelli, G., Gabrielli, A., Pietronero, L., 2012. A new metrics for countries' fitness and products' complexity. Sci. Rep. 2, 1–7.

Tesfatsion, L., Judd, K.L., 2006. Handbook of Computational Economics: Agent-based Computational Economics, vol. 2. North-Holland, Amsterdan.

Valente, M., 2014. An NK-like model for complexity. J. Evol. Econ. 24 (1), 107–134.

Wickens, M., 2008. Macroeconomic Theory. Princeton University Press.

Wiesner, K., Ladyman, J., 2019. Measuring Complexity. Cornell University, arXiv:1909.

Wolfram, S., 1994. Cellular Automata and Complexity. Westview Press, Champaign, IL, USA.

Woodford, M., 2003. Interest and Prices: Foundations of a Theory of Monetary Policy. Princeton University Press, Princeton, NJ, USA.