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Complexity and Economics

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Abstract

Nobody will discuss that the economy constitutes a very complex system. The traditional approach to understanding it has been to reduce complexities to simple rules and behaviors, abstracting of many features of the real economy.
An alternative to reductionism consists of studying economic systems with a complexity approach. The complexity approach´s point of departure is that the behavior of the whole is much more complex than the behavior of the parts.
Complexity economics has focused on economic phenomena like business cycle, crises and other out of equilibrium behavior. Its use of non-linear models offers the advantage that the same model allows us to describe stable as well as unstable and even chaotic behaviors.
The use of non-linear models in finance as well as the possibility of finding chaotic behavior in economics are discussed. Models of interacting agents in economics and finance are mentioned as another promising line of research in complexity applied to economics.
Finally, whether the complexity approach is another twist of orthodoxy or constitutes a heterodox paradigm is another issue discussed in the paper.

Keywords

Complexity; non-linearity; chaos; interacting agents models; heterodoxy.

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<u>1.- Introduction</u>

The present paper provides an overview of the main ideas that comprise the complexity approach in economics.

Nobody will discuss that the economy constitutes a very complex system. The traditional approach to understanding it has been to reduce complexities to simple rules and behaviors, abstracting of many features of the real economy.

The key issue in this reductionist approach is what features of the real world are kept in the theoretical model and what features are dispose of. What one keeps in and what one gets rid of make the main difference between orthodoxy and heterodoxy in economics.

In the orthodox approach simplification is often done in order to make it mathematically tractable at the expense of the models' ability to capture relevant phenomena. Therefore in many cases mainstream economists conclude with models which exclude most of the features which may be of interest for policy making.

An alternative to reductionism consists of studying economic systems with a complexity approach. The complexity approach´s point of departure is that reductionism is not suitable to study systems with many parts that interact to produce global behavior; this behavior goes far beyond what can be explained in terms of interactions between the individual constituent elements: the behavior of the whole is much more complex than the behavior of the parts. From the interaction of the parts new behaviors or new phenomena emerge. The study of these new emergent behaviors and phenomena is the object of study of the complexity approach.

Is there any definition for "complexity"? The physicist Seth Miller has gathered at least 45 different definitions of "complexity." However, many of these are not appropriate for economics.

The economist Richard Day (1994) defined complexity in economics in terms of dynamic outcomes. An economic system is dynamically complex if its deterministic endogenous processes do not lead it asymptotically to a fixed point, a limit cycle, or an explosion.

Robert and Yoguel (2013) propose the following five dimensions to synthesize the fifteen elements they find in the different definitions of complexity: i) heterogeneity, ii) disequilibrium and divergence, iii) interactions and partial information, iv) network architecture, and v) emergent properties.

The complexity approach changes not just the answers but also the questions economics has to respond.

For instance, the neoclassical general equilibrium model is concerned with the static, timeless allocation of resources. Its dynamics has just to do with the existence, stability and uniqueness of the equilibrium.

On the contrary, the complexity approach focuses on processes, pointing out to the evolution of the economic system over time, including out-of-equilibrium dynamics.

The complexity perspective implies a rejection of the mainstream conceptual categories and tools including the economic methodology. While the received theory is based on deductive formal proofs of theorems that seek to derive general solutions broadly applicable, the complexity perspective relies on computer simulations and experimental methods to inductively determine possible outcomes and ranges of solutions.

According to Brian Arthur (2014), "complexity economics got its start in 1987 when a now-famous conference of scientists and economists convened by physicist Philip Anderson and economist Kenneth Arrow met to discuss the economy as an evolving complex system."

Complexity economics has focused on economic phenomena like business cycle, crises and other out of equilibrium behavior. On the contrary, mainstream economics main interest has been to show that the economic system converges to a stable equilibrium. Economic fluctuations are modeled as stochastic shocks attached to low order linear difference equations. The fact that economic fluctuations appear as a sole product of exogenous shocks is in line with the mainstream equilibrium approach in economic thought. In the absence of such shocks, the system would tend to a steady state, as different versions of the neoclassical model of optimal growth predict. "Everything is for the best in the best of all possible worlds" is the Panglossian neoclassical conclusion.

The mainstream approach to economic phenomena has little to do with empirical reality. Economic data provide little – if any – evidence of linear, simple dynamics, and of lasting convergence to stationary states or regular cyclical behavior. Irregular frequencies and amplitudes of economic fluctuations are persistent and do not show clear convergence or steady oscillations.

Orthodoxy developed a theory which excluded the possibility that a catastrophic crisis could ever happen. It not only assumes that the economy tends towards equilibrium but also that it is a stable one. Therefore, economists enrolled in this line of thought not only did not foresee the 2007-2008 financial crisis, they did not even consider it possible. Consequently, they were absolutely unable and unprepared to deal with it.

Alternative approaches to the fairy tale that neoclassical economics tells us came back to the fore after the crisis. One of them is the complexity approach to economic phenomena. Its use of non-linear models offers the advantage that the same model allows us to describe stable as well as unstable and even chaotic behaviors.

2.- The non-linearity assumption and its implications

Once non-linearity is admitted we are in the presence of positive feedback or increasing returns. Mainstream economic theory removed from most of its areas the assumption of increasing returns for its tendency to generate the existence of multiple equilibria. Convexity was a necessary assumption to warrant uniqueness of equilibrium.

However, the existence of non-convexities and increasing returns are widely used assumptions in some areas of economic analysis. International trade theory, macroeconomics, economic growth, industrial organization, regional economics and economics of technology are examples of it. Multiple equilibria are also a widespread result in game theory.

The multiplicity of equilibria means that there are many possible worlds. Which has finally resulted is the product of history: it is history dependent. Another dynamic trajectory may have led to another result. If the equilibrium is unique, history does not matter: sooner or later the system will arrive at that unique equilibrium. The process is ergodic: whatever the sequence of events, the outcome is always the same. On the other hand, if the process is non-ergodic, the path defines the result. From this perspective, the economy can be seen as a process of self-organization: the system “chooses” between the different options that are presented to it.

3.- Non-linearity, attractors and chaos

The equilibrium approach in economics is interested in only one type of attractor: fixed point attractors. Most efforts are devoted to find out the conditions under which a unique and stable equilibrium exists. In fact, linear systems either converge to a fixed point or explode.

Non-linear dynamic systems may evolve towards other types of attractors such as limit cycle or periodic attractors, quasiperiodic attractors and chaotic attractors.

The equilibrium approach, as Samuelson (1983, p. 21) points out, has been taken from equilibrium thermodynamics, which is based on linear relationships. It was the introduction of non-linear relationships which allowed the development of non-equilibrium thermodynamics.

Since sensitive dependence on initial conditions is the essential feature of chaotic dynamics, the measure of chaos is provided by the Lyapunov exponent, more precisely by the largest positive Lyapunov exponent. Lyapunov exponents (L) measure how quickly nearby orbits diverge in phase space. Unpredictability is an intrinsic feature of chaotic systems. Chaos implies the existence of a temporal horizon – defined by the Lyapunov time[1] – beyond which predictions lose any reliability.

The paradox of chaos is that we are in the presence of unpredictable behavior that is generated by a completely deterministic process.

Economists' interest in non-linearity emerges from its potential aptitude to model fluctuations in the economy and financial markets. It offers more options beyond the linear model's binary alternative between a stable and an explosive path.

4.- Non-linearities in the financial markets

The traditional approach in the literature on finance has been based on the efficient market hypothesis, which argues that the price of financial assets reflects all available information. If so, there is no opportunity for persistent speculative profits because any news is immediately reflected in the prices. However, the view that emerges from this traditional approach contrasts with the widespread perception that financial markets offer opportunities for speculative profits.

An alternative approach is based on the distinction between chartists – also called noise-traders – and fundamentalists. While the first extrapolate the past trends, the latter are investors who are governed by the fundamentals of the market. The fact that these models are very successful in replicating the stylized facts of financial markets is seen as a kind of empirical validation.

Altavilla and De Grauwe (2010) developed a simple theoretical model in which chartists and fundamentalists interact. The model predicts the existence of different regimes, and thus non-linearities in the link between the exchange rate and its fundamentals. The results suggest the presence of non-linear mean reversion in the nominal exchange rate process. Traditional linear rational expectations models cannot account for this except by introducing exogenous changes in regimes; that is, by leaving these switches unexplained. The most striking finding is that there appears to be two regimes: one in which the exchange rate follows the fundamental exchange rate quite closely and another one in

[1]The Lyapunov time (τ) is measured by the inverse of the Lyapunov exponent:

$$\tau = \frac{1}{L}$$

which the fundamentals do not seem to play any role in determining the exchange rate. Both regimes alternate in unpredictable ways; there are frequent switches between fundamental and non-fundamental regimes. As a result, the relation between the exchange rate and the fundamentals is an unstable one.
These results are in line with other empirical studies that have so frequently found a disconnection between macroeconomic fundamentals and the exchange rate. They corroborate the advantages of using a non-linear approach which allows detecting the existence of more than one state. The switching nature of the exchange rate process is inconsistent with a linear representation of the relation between the exchange rate and its fundamentals.
In a more recent paper, De Grauwe and Rovira Kaltwasser (2012) introduce a distinction between optimist and pessimist fundamentalist traders, referring to traders that systematically overestimate or underestimate the fundamental rate respectively. They show that, even in the absence of chartists, chaos can govern the asset price dynamics. Furthermore, chaos can indeed be triggered by the presence of biased fundamentalist traders alone and also by the interaction between biased and unbiased fundamentalist traders. The model is extended introducing unbiased fundamentalists and chartists. The latter prove to have a destabilizing influence: the larger the coefficient expressing the degree with which they extrapolate the past change in the exchange rate, the stronger their destabilization power. The system exhibits a Neimark–Sacker bifurcation of the steady state that leads to a stable limit cycle of the market exchange rate. Increasing the value of the chartists' extrapolation coefficient eventually leads to a break of the limit cycle and the exchange rate is governed by a chaotic attractor. This feature of the model is a common result obtained in the literature of heterogeneous agent models in finance where the interaction between fundamentalists and chartists is analyzed and the chartists act as a destabilizing force in the market.
Finally, the authors perform a Monte Carlo simulation. The model replicates the widely observed phenomenon that exchange rate returns are not normally distributed, but on the contrary exhibit fat tails.
It is clear that once the Holy Trinity of the unbounded rational representative agent, efficient markets and linearity hypotheses is put aside, new illuminating results are obtained.
Several models have been introduced where markets are viewed as evolutionary adaptive systems with heterogeneous boundedly rational interacting agents. They match important stylized facts in financial time series such as fat tails and long memory in the returns distribution and clustered volatility. They exhibit interesting dynamics characterized by temporary bubbles and crashes (see Hommes and Wagener, 2008).

5.- Chaos and economics

The detection of chaos in economic time series faces three difficulties: (1) the limited number of observations such series contain; (2) the high noise level in economic time series; and (3) the high dimension of economic systems.
While in physics, chemistry or biology experiments involve working with tens of thousands to millions of observations, economics work with much smaller series. This prevents many of the non-linear dynamics tools from detecting intrinsic irregularities even when they are present.

The detection of chaos in meteorology has been achieved thanks to the huge number of observations collected through the network of meteorological stations and satellites devoted to that purpose. These instruments have made it possible to significantly improve the accuracy of weather forecasts in recent times. One should wonder what would happen if an equivalent investment were made for the collection of economic data. Economic and financial storms have proved to be at least as destructive as natural storms.

Second, the presence of dynamic noise makes it extremely difficult to distinguish between (noisy) high-dimensional chaos[2] and pure randomness. On the other hand, concerning low-dimensional chaos, small noise easily causes the system to diverge to infinity in the chaotic parameter range. Hommes and Manzan (2005) show how the introduction of increasing levels of noise to a chaotic asset pricing model makes the Lyapunov exponent of the underlying chaotic skeleton model become negative due to the presence of even a small amount of dynamic noise. This may explain why there is weak evidence so far of low-dimensional chaos in economic and financial time series. However, robust deconvolution techniques may be useful for noise reduction (see Beker, 2014: 215).

6.- An interactive complex system

The economic system is a supremely interactive one. Economic agents influence one another directly. A rush to buy or sell a particular asset can prompt others to do the same. Crashes are an example of stampede phenomena in which individuals act simultaneously in a herd-like and sometimes panic-stricken manner. However, the basic assumption of the general equilibrium theory is that the only interaction among economic agents is through the price system. Assuming that the preferences and hence the choices of one individual are influenced by others introduces an important element of uncertainty which conspires against the possibility of arriving at a stable price equilibrium. On the other hand, a basic tenet of traditional mainstream economics has been that aggregate behavior must be derived from underlying *rational* microfoundations.[3] So, agents´ interactions are discarded at the micro level and, at the same time, to be acceptable, macro models are supposed to be derived from this sort of micro models. Not surprisingly, the result is that most of the real economic problems are excluded from economic analysis. The feedback that one‘s decisions have on others´ expectations and behavior is usually ignored. However, already in the 1930s, Keynes likened asset markets to beauty contests, where people have to guess which of the participants would get the most votes. In the same way, investors in asset markets try to guess which asset will be favored by other investors´ preferences in order to invest in it, independently of other factors. This sort of conduct may pave the way to a herd-like behavior. Episodes of collective mania are well known in economic history since the tulip mania in seventeenth century Holland -where tulip prices ballooned absurdly- to the recent subprime mortgage market crisis. Yet, as Ball (2005: 175) mentions, ¨irrational does not mean unpredictable¨.

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[2] Low-dimensional chaos is characterized by only one positive Lyapunov exponent while high-dimensional chaos by more than one such exponent.

[3] This is something in no other science is required.

Since the end of the eighties, multi-disciplinary research as done at the Santa Fe Institute has stimulated a lot of work on interacting agents in economics and finance. Models of interacting particle systems in physics served as examples of how local interaction at the micro level may explain structure at the macro level.[4]

In order to take account of the difference of behavior among economic agents in the financial markets an increasing number of structural heterogeneous agent models have been introduced in the economics and finance literature. Financial markets are viewed as complex adaptive systems consisting of many boundedly rational, heterogeneous agents interacting through simple investment strategies, constantly learning from each other as new information becomes available and adapting their behavior accordingly over time.[5]

Speculative bubbles have been observed in laboratory experiments by Nobel prize-winning Smith et al. (1988) and Hommes et al. (2005) using interacting agent models on actual financial data. Inspired by the econophysics literature, Kouwenberg and Zwinkels (2015) develop and estimate a simple multi-agent model for the U.S. housing market using housing market data covering the period 1960–2014. The main result is that the interaction between agents in the model can generate boom-bust cycles endogenously. In a companion article, they further show that the econometric model derived from this multi-agent system delivers better out-of-sample price forecasts for the U.S. housing market than standard models.

Another promising line of economic modeling is Agent-based Computational Economics (ACE), the computational study of economic processes modelled as dynamic systems of interacting agents.[6] As Davis (2006: 2) points out, contrary to the neoclassical view where agents are taken to be human individuals all of essentially the same kind of make-up, we have here heterogeneous agents with heterogeneous forms of interaction. Agent-based modeling is formulated in terms of non-Euclidian space; “this non-Euclidian view of the space of agent interactions when understood dynamically requires that the paths individuals take across a sequence of interactions be seen as heterogeneous as well. Thus individuals, it follows, must also be heterogeneous” (ibid.: 13).

An ACE macroeconomic model might include structural agents (e.g. a spatial world), institutional agents (e.g. a legal system, corporations, markets), and cognitive agents (e.g. entrepreneurs, consumers, stock brokers, and government policy makers); the system´s dynamics are driven by the successive interactions of their participants. ACE models implemented on modern computational platforms can include millions of heterogeneous interacting agents. ACE researchers seek possible causal explanations grounded in the successive interactions of agents operating in realistically rendered virtual worlds. Specifically, they try to understand whether particular types of observed regularities can be reliably generated within these worlds.

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[4] See, for instance, M. Batty (2005).

[5] Although I consider that microfoundations should not be a necessary condition for macroeconomics, this does not exclude the possibility of building a macro theory based on the collective behavior of interacting agents at the micro level. The aim should be to model the behavior of broad aggregates; if a model of interacting agents help describe their collective behavior, it may a useful tool to model the aggregates which that behavior gives rise to.

[6] See LeBaron and Tesfatsion (2008).

7.- The complexity approach: orthodox or heterodox?

Heise (2016) raises the question whether the complexity approach is another twist of orthodoxy or constitutes a heterodox paradigm.

I find this question absolutely premature. We don´t know yet what the final outcomes of the complexity approach may be. The issue is not what complexity economists think or feel. As Heise points out, Barkley Rosser Jr., Herbert Gintis and Alan Kirman openly display their esteem for heterodox economics while authors as Steven Durlauf, Lawrence Blume and Brian Arthur do not see their paradigm in opposition to neoclassical economics. But neither the former nor the latter have produced something related to complexity which can conclusively be labeled as heterodox or orthodox. For the time being, the complexity approach mainly remains as a methodological proposal. What is clear is that it focuses on different issues than mainstream economics - how an economy emerges, grows and changes structurally over time (Arthur, 2013: 17) - using also different tools than the neoclassical school. The complexity approach is in the line pointed out by Wade Hands: "neither neoclassical nor heterodox economics are the main focus of recent methodological inquiry" (Hands, 2015: 72).

It is too early to know whether the complexity approach will live up to its most ambitious promises like being able to take account "of some of the complexity, unpredictability and reflexivity of the economy to take us beyond a mechanistic view of policy" (Beinhocker, 2016: 7).

8.- Conclusions

The complexity approach offers an alternative to reductionism for the study of economic systems. Its point of departure is that reductionism is not suitable to study systems with many parts that interact to produce global behavior; this behavior goes far beyond what can be explained in terms of interactions between the individual constituent elements: the behavior of the whole is much more complex than the behavior of the parts. From the interaction of the parts new behaviors or new phenomena emerge.

The complexity approach changes not just the answers but also the questions economics has to respond.

Its use of non-linear models offers the advantage that the same model allows us to describe stable as well as unstable and even chaotic behaviors. Non-linearity offers more options beyond the linear model's binary alternative between a stable and an explosive path.

Is the complexity approach another twist of orthodoxy or constitutes a heterodox paradigm? I find this question too premature. We don´t know yet what the final outcomes of the complexity approach may be. For the time being, the complexity approach mainly remains as a methodological proposal.

It is too early to know whether the complexity approach will live up to its most ambitious promises but is clear is that it focuses on different issues and uses different tools than mainstream economics.

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