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Corrado Di Guilmi , Mauro Gallegati , Simone Landini
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CHAPTER 1

Introduction

The economy is full of puzzles that arise
from the fact that reality stubbornly refuses
to obey the most outlandish and improbable mainstream hypotheses.
If only the empirical evidence would be less dull.

DOMENICO DELLI GATTI

This chapter provides the rationale of the book together with a reading road-map. Section 1.1 identifies the historical and methodological reasons for the current *impasse* in macroeconomics, while Section 1.2 offers some remarks about the issue of aggregation. The motivation for modelling economies with heterogeneous interacting agents, the necessity of coupling ACE (agent-based computational economics) and ASHIA (analytical solution to heterogeneous interacting agent-based models) and the ME (master equation) approach that the book suggests are discussed in Section 1.3. Finally, Section 1.4 details the structure of the book.

1.1 Why are We Here?

Magma, something in between solid and liquid states, describes well the state of macroeconomics today. Since after the Great Recession, it has been possible to find reports of deep states of disaffection (Solow, 2008) *vis a vis* comfortable views (Blanchard, 2008). However, the more relaxing approach has caveats of such a magnitude to alert even the quietest reader. According to their proponents, two (out of three) equations of the new Keynesian dynamic stochastic general equilibrium (DSGE) are manifestly wrong, while the methodology based on the representative agent (RA) cannot be reconciled with the empirical evidence. Lakatos (1978) would have described the present state of mainstream macroeconomics as having clear signs of a failing paradigm.

Economics is slowly moving from the classical physics to the statistical physics paradigm, from determinism to stochasticity, from equilibrium to interaction and complexity. That is a passage, from the isolated not interacting individual to a stochastically interactive framework, which generates an *emergent macroeconomics* (Delli Gatti et al., 2008).

Although speaking the language of probability and stochastic processes theory, which is familiar to economists, this book argues for the adoption of tools widely developed in the field of statistical physics. The introduction of this approach is not without consequences in the *corpus* of economic thought. As will be clearer in what follows, this modifies the characteristics of the equilibrium and the interpretation of dynamics, implying a change in the economic paradigm. The *Great Recession* is not due to mainstream economics virtues attributed to the market theory; but it has been worsened by a bizarre theoretical interpretation of the markets.

The internal coherence and ability of the mainstream approach in explaining the empirical evidence are increasingly questioned. The causes of the present state of affairs go back to the middle of the eighteenth century, when some of the Western economies were transformed by a technological progress which led to the *Industrial Revolution*. This was one century after the *Newtonian Revolution* in physics: from the small apple to the enormous planets, all objects seemed to obey the simple *natural* law of gravitation. It was therefore inevitable for a new avatar of the social scientist, the economist, to borrow the methodology of the most successful hard science, physics, allowing for the mutation of *political economy* into *economics*. It was (and still is) the mechanical physics of the seventeenth century, which has ruled economics. However, while falsification gave rigour to physics, the absence of empirical reproducibility left economics to the analysis of internal coherence alone. Forgetting the empirical evidence and the hypotheses of the model, a fallacious research programme, which presumed analytical formalism tantamount to coherence, was built.

From then on, economics lived its own evolution based on the classical physics assumptions of reductionism, determinism and mechanicism. Causality, at least in the sense of cause–effect, is a vague concept in complexity, since no definite link exists between a change in a variable and the final outcome. Reductionism is possible if we rule out interaction. If not, the aggregate outcome is different from that of the constitutive elements, as the properties of water, for example, are different from those of hydrogen and oxygen.

More than other hard sciences, physics inspired contributions in social sciences. Since the appearance of statistical and quantum mechanics, physicists reduced their error margins in understanding and modelling nature's behaviour. In particular, thanks to the *Quantum Revolution*, physics went beyond classical mechanic reductionism and started facing natural phenomena in a complex perspective. Mainstream economics neglected it at the cost of being so unscientific as to become an axiomatic discipline, *ipso facto* not falsifiable. The internal coherence (the logical consistency between assumptions and their development) has long been privileged over the external coherence (the empirical evidence). The need of a mathematical formalization initially led economics to borrow the dominant paradigm in physics at that time: reductionism.

The idea, or hope, is that the deterministic part determines the equilibrium and the eigenvalue of it the restoration of equilibria, while shock determines the deviations from it. One of the main problems of this approach is that small shocks may generate great fluctuations, and the standard theory based on non-interacting agents is badly equipped for it[1]. Once, one takes into account the issue of interaction, then there is no room for the Laplace demon.

The economic system is supposed to be in equilibrium and there are very famous interpretations of Walras' general equilibrium as the economic counterpart of the Newtonian system. Economic equilibrium is described as a balance of opposite forces, demand and supply. The optimality of it is granted by the maximization of the economic functions: in order to obtain it, one needs to introduce several assumptions, which are part of the economist's box of tools. With the passing of time, these assumptions became axioms. In a sense, Marshall's forecast is right when he said, talking about the process of mathematization of economics: it will be interesting to see to what extent the economist will manage it, or the equations will escape with him.

[1] Mainstream theory seems more interested in disentangling idiosyncratic shocks and heterogeneity (Guvenen, 2009) rather than dealing with their consequences and effects.

A very interesting case in point is the analysis of the business cycle. By assumptions, the system is described by mechanical equations (to which a stochastic element is added) which should generate a fixed point at which equilibrium and optimality reign. The equilibrium (which exists, but is not stable nor unique, as the Sonnenschein–Mantel–Debreu theorem shows) can therefore be perturbed by an exogenous shock (otherwise, the state will be maintained forever); the analysis of a cycle is therefore reduced to the analysis of the change from the old to the new equilibrium position. Note that the equilibrium is supposed to be a point rather than a path and the transition from the old view of business cycle (the so-called NBER approach) to the new one (the co-movements of aggregative time series) does not affect the underlying mainstream old-physics approach.

Quite remarkably, the approach of statistical physics, which deeply affected physical science at the turn of the nineteenth century by emphasizing the difference between micro and macro, was adopted by Keynes around the mid-1903s. However, after decades of extraordinary success it is rejected by the neoclassical school around the mid-1970s – the school frames the discipline into the old approach and ignores, by definition, any interdependence among agents and difference between individual and aggregate behaviour (being agents, electrons, atoms or planets). On the cause of the abandonment of the Keynesian tradition, there are several interpretations in the literature: from the lack of empirical success, to the failure of a coherent theory. The monetarist counter-revolution entered into the Keynesian *cittadella* claiming more rigorous foundation based on the maximizing behaviour of the agents. The so-called *microfoundation of macroeconomics* still uses the old neoclassical box of tools *de facto* reducing the macro to the micro by neglecting interactions; at the end one has a re-proposition of classical economics under new clothes. This book does not deal with the issue of the *Keynesian economics and the economics of Keynes* (Leijonhufvud, 1968). Rather, it proposes to abandon the classical mechanics assumptions for an approach based on the interaction of heterogeneous agents; the *interactive macroeconomics* which here emerges is therefore based upon the behaviour of the different agents.

One can put all the heterogeneity one wants into the general equilibrium framework; in a sense, the more heterogeneous the agents are, the more stable the system is. However, agents should not to interact directly between themselves because, as Marshall pointed out in the review of *Mathematical Psychics* written by Edgeworth in the nineteenth century, if agents directly trade there are transactions which are *false*, i.e., out of equilibrium, prices which undermine the equilibrium and its efficiency. If direct interaction follows from any kind of informational imperfection, the whole general equilibrium framework collapses.

Currently, the microfoundation of macroeconomics follows two main approaches: the DSGE and the ABM (Figure 1.1).

MICROFOUNDATIONS

1] Mainstream
- 1.1] RA models
  DSGE mark I
- 1.2] HNIA
  DSGE mark II

2] Agents-based-modeling
- 2.1] ACE
  Tesfatsion and Jude 2006
  Delli Gatti et. al 2016
- 2.2] ASHIA
  - 2.2.1] Statistical physics
    Foley 1994, Aoki 1996
  - 2.2.2] Learning, strategic behavior
    Landini et al. 2014a,b

Figure 1.1 Microfoundations of Macroeconomics.

The *mainstream* DSGE model, either with RA or heterogeneous agents, does not allow for direct interaction between agents. The only interaction contemplated is through the market, which rules out the possibility of any strategic behaviour (Schumpeter (1960) calls it *the principle of excluded strategy*). The assumption of an RA implies that one does not need to interact with others, unless one is mentally disturbed. On the other hand, if one assumes some form of imperfection or heterogeneity, the market clearing model framework has to be abandoned in favour of a game theoretical approach or evolutionary models.

Within the approach with heterogeneous and interacting agents, two schools can be distinguished: the so-called agent-based computational economics (ACE) (Delli Gatti et al., 2016; Tesfatsion and Judd, 2006) and the ASHIA, to which this book is devoted. The latter derives from statistical physics and analyzes economic agents as *social atoms*, i.e., interacting atoms. A recent development in this literature introduces the mechanism of learning (Landini et al., 2014a,b), for which an application in Part II provides an example.

In the classical approach, the ideas of natural laws and equilibrium have been transplanted into economics *sic et simpliciter*. As a consequence of the adoption of the classical mechanics paradigm, the difference between micro and macro was analyzed under a reductionist approach, or, in other words, there was only an analysis of a single agent, of his/her behaviour, without any link to other agents, so that the macro-behaviour is simply a summation of individuals and the aggregate properties can be detected at micro level as well. In such a setting, aggregation is simply the process of summing up market outcomes of individual entities to obtain economy-wide totals. This means that there is no difference between micro and macro: the dynamics of the whole is nothing but a summation of the dynamics of its components (in term of physics, the motion of a planet can be described by the dynamics of the atoms composing it). This approach does not take into consideration that there might be a two-way interdependency between the agents and the aggregate properties of the system: interacting elements produce aggregate patterns that those elements in turn react to.

What economists typically fail to realize is that the correct procedure of aggregation is not a sum; this is when emergence enters the drama. The term “emergence” means the rising of complex structures from simple individual rules (Smith, 1776; von Hayek, 1948; Schelling, 1978). Physics taught us that considering the whole as something more than its constitutive parts is not only a theoretical construction: it is a process due to interaction and, not least, it is how reality behaves. Empirical evidence, as well as experimental test, show that aggregation generates regularities, i.e., simple individual rules, when aggregated, produce statistical regularities or well-shaped aggregate functions: regularities emerge from individual *chaos* (Lavoie, 1989). The concept of equilibrium is quite a dramatic example. In mainstream economic models, equilibrium is described as a state in which (individual and aggregate) demand equals supply.

The notion of *statistical equilibrium*, in which the aggregate equilibrium is compatible with individual disequilibrium, is outside the box of tools of the mainstream economist. The same is true for the notion of *evolutionary equilibrium* (at an aggregate level) developed in biology, according to which an individual organism is in equilibrium *only when it is dead*. The equilibrium of a system no longer requires that every single element be in equilibrium by itself, but rather that the statistical distributions describing the aggregate phenomena be stable, i.e., in *[...] a state of macroscopic equilibrium maintained by a large number of transitions in opposite directions* (Feller, 1957, 356). A consequence of the idea that macroscopic phenomena can emerge is that reductionism is wrong.

1.2 Aggregation and Interaction

In the last few years, considerable attention has been devoted outside the mainstream to the interaction of heterogeneous agents and the role of the distribution of their characteristics in shaping macro-economic outcomes. The related literature, however, has not had much impact on standard macro theory, which claims, for example, that the main source of business fluctuations is a technological shock to a representative firm or that aggregate consumption depends on aggregate income and wealth, neglecting distributional effects and links among agents by construction. Even when heterogeneity is explicitly taken into account, interaction is generally ignored. While theoretical macroeconomics is moving away from the RA hypothesis, *that model has helped shape the direction of research* (Stiglitz, 2011).

The RA framework has a long tradition in economics (Hartley, 1997), but it has become the standard on which to build the microfoundation procedure only after Lucas' critique paper (1976). Despite the stringency of the logical requirements for consistent aggregation, the RA has been one of the most successful tools in economics. It is the cornerstone of microfoundations in macroeconomics because it allows the extension of individual behaviour to the aggregate in the most straightforward way: the analysis of the aggregate, in fact, can be reduced to the analysis of a single, representative individual, ignoring, by construction, any form of heterogeneity and interaction.

Mainstream models are characterized by an explicitly stated optimization problem of the RA, while the derived individual demand or supply curves are used to obtain the aggregate demand or supply curves.

Even when the models allow for heterogeneity, interaction is generally absent: the so-called weak interaction hypothesis (Rios-Rull, 1995). The use of RA models should allow avoidance of the Lucas critique, to provide microfoundations to macroeconomics, and, *ca va sans dire*, to build Walrasian general equilibrium models or, as it is now popularly known, DSGE models.

Since models with many heterogeneous interacting agents are complicated and no closed form solution is often available (aggregation of heterogeneous interacting agents is ruled out by assumptions), economists assume the existence of an RA: a simplification that makes it easier to solve for the competitive equilibrium allocation, since coordination is ruled out by definition. Unfortunately, as Hildebrand and Kirman (1988) noted: *There are no assumptions on isolated individuals, which will give us the properties of aggregate behaviour. We are reduced to making assumptions at the aggregate level, which cannot be justified, by the usual individualistic assumptions. This problem is usually avoided in the macroeconomic literature by assuming that the economy behaves like an individual. Such an assumption cannot be justified in the context of the standard model*.

Moreover the equilibria of general equilibrium models with an RA are characterized by a complete absence of trade and exchange, which is a counterfactual idea. Kirman (1992), Caballero (1992) and Gallegati (1994) show that RA models ignore valid aggregation concerns, by ignoring interaction and emergence, committing fallacy of composition (what in philosophy is called *fallacy of division*, i.e., to attribute properties to a different level than where the property is observed: game theory offers a good case in point with the concept of Nash equilibrium, by assuming that social regularities come from the agent level equilibrium). Those authors provide examples in which the RA does not represent the individuals in the economy so that the reduction of a group of heterogeneous agents to an RA is not just an analytical convenience, but is *both unjustified and leads to conclusions which are usually misleading and often wrong* (Kirman, 1992; Jerison, 1984).

A further result, which is a proof of the logical fallacy in bridging the micro to the macro, is the *impossibility theorem* of Arrow: it shows that an ensemble of people, which has to collectively take a decision, cannot show the same rationality as that of an individual (Mass-Colell, 1995).

Moreover, standard econometric tools are based upon the assumption of an RA. If the economic system is populated by heterogeneous (not necessarily interacting) agents, then the problem of the microfoundation of macroeconometrics becomes a central topic since some issues (e.g., *co-integration*, *Granger causality*, *impulse response function of structural VAR*) lose their significance (Forni and Lippi, 1997).

All in all, one might say that the failure of the RA framework points out the *vacuum* of the mainstream microfoundation literature, which ignores interactions: no box of tools is available to connect the micro and the macro levels besides the RA whose existence is at odds with the empirical evidence (Stoker, 1993; Blundell and Stoker, 2005) and the equilibrium theory as well (Kirman, 1992).

Heterogeneity, however, is a persistent feature in many fields. Empirical investigations, for instance, have repeatedly shown that the distribution of a firm's size or income is described by a skewed distribution with a power law tail. By itself, this fact falsifies the RA hypothesis and the related myth of the *optimal* size of the firm. The RA is also far from being a neutral assumption in econometrics. For instance, the results of the econometrics analysis of the relation between aggregate consumption and aggregate income depend on the assumption of linearity and absence of heterogeneity, as Forni and Lippi (1997) showed.

With the passing of time, therefore, economists have become more and more dissatisfied with the RA device[2] and have tried to put forward a theory of aggregation in the presence of persistent heterogeneity. The set of assumptions necessary to reach exact aggregation in this case, however, is impressive: the general equilibrium theorist may not feel at ease with the RA assumption because some of the building blocks of the general equilibrium theory do not hold in the presence of a representative agent (e.g., the *weak axiom of revealed preferences* or *Arrow's impossibility theorem*, (Kirman, 1992, p.122)). From a different theoretical perspective, the very idea of asymmetric information of the new Keynesian economics is inconsistent with the RA hypothesis (Stiglitz, 1992).

Moreover, the adoption of an RA framework ignores the problem of coordination (which is of crucial importance when informational imperfections are taken into account: see Leijonhufvud, 1981). Since the

[2] See Kirman (1992); Malinvaud (1993); Grandmont (1993); Chavas (1993); Delli Gatti et al. (2000); Gallegati et al. (2004) and the proceedings of the various WEHIA conferences.

empirical evidence does not corroborate the RA assumption (Stoker, 1993) and theoretical investigations also show its analytical inconsistencies (Kirman, 1992), one could ask why it is still the standard framework in economics. Several answers may be given to this question but the most fundamental reason is that if individuals are homogeneous, there is no room (and indeed need) for interaction: and this reduces the analytical complication of the modelling strategy. In an RA framework, aggregation is made simple and the connection between micro and macro behaviour is immediate. By construction, the RA behaves like Robinson Crusoe: problems arise when he meets Friday.

In the literature, one can find several attempts to produce adequate tools for aggregation in the presence of heterogeneity. From the realization of the impossibility of exact aggregation, this book moves to investigate an alternative aggregation procedure which allows to deal with a dynamic heterogeneous interacting agents framework.

In recent years, also in standard DSGE models, heterogeneity has become a necessary and relevant feature. Initially, heterogeneity has been introduced in DSGE models as a pre-defined distribution of a relevant characteristic of agents. Such a device basically amounts to the enhancement of the RA by adding a measure of dispersion to the traditional centrality measure. A subsequent generation of DSGE models treats heterogeneity as an idiosyncratic exogenous stochastic process. The models define a grid of possible states and a Markovian stochastic process governing the switching of economic agents among them. The transition probabilities and the characteristics of the stochastic process are exogenously defined, for example, estimating the transition rates from empirical data (Heer and Maussner, 2005). In such an environment, the behavioural rules for single agents are hardly distinguishable from the RA setting, usually assuming perfect knowledge and unlimited computational ability. Also in this setting, interaction between agents themselves and between agents and the environment is ruled out by construction while the exogenous stochastic mechanism prevents the modelling of the dynamic evolution of agents.

A more sophisticated modelling technique is applied by Per Krusell and co-authors (see for example, Krusell et al., 2012), who set up an iterative mechanism for the definition of agents' behaviour. Agents constantly update their informative set in accordance to the evolution of