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Corrado Di Guilmi , Mauro Gallegati , Simone Landini
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Interactive Macroeconomics

One of the major topics in macroeconomic theory is the coordination mechanism through which a large number of agents exchange goods in decentralized economies. The mainstream theory of efficient markets fails to provide an internal coherent framework and rules out, by construction, the interaction among heterogeneous agents.

A rigorous micro-foundation for macro models can overcome this limitation and provide more reliable policy prescriptions. This book develops an innovative approach to the analysis of agent based models. Interaction between heterogeneous agents is analytically modelled by means of stochastic dynamic aggregation techniques, based on the master equation approach.

The book is divided into four parts: the first presents the stochastic aggregation and macro-dynamics inference methods, based on the stochastic evolution of the microeconomic units; the second applies these inferential techniques on macroeconomic agent-based models; the third provides conclusions and stimulates further developments; the last part contains technical appendices.

This book offers a systematic and integrated treatment of original concepts and tools, together with applications, for the development of an alternative micro-foundation framework. In order to promote a widespread adoption among the profession and by graduate students, every non-standard mathematical tool or concept is introduced with a suitable level of detail. All the logical passages and calculations are explicit in order to provide a self-contained treatment that does not require prior knowledge of the technical literature.

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Physics of Society: Econophysics and Sociophysics

This book series is aimed at introducing readers to the recent developments in physics inspired modelling of economic and social systems. Socio-economic systems are increasingly being identified as 'interacting many-body dynamical systems' very much similar to the physical systems, studied over several centuries now. Econophysics and sociophysics as interdisciplinary subjects view the dynamics of markets and society in general as those of physical systems. This will be a series of books written by eminent academicians, researchers and subject experts in the field of physics, mathematics, finance, sociology, management and economics.

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Interactive Macroeconomics

Stochastic Aggregate Dynamics with Heterogeneous and Interacting Agents

Corrado Di Guilmi
Simone Landini
Mauro Gallegati

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To my family and friends, for their support. In particular to my friend Massimo, who could write a follow up of this book for all the times that I talked to him about it.
To Carl Chiarella, who helped me understanding what I was doing.
To K.P., K.R. and F.Z. who were somehow there at the time of writing.
CDG.

Alla mia famiglia, a mio cugino Stefano.
Agli amici, a Manfred.
SL.

Tra alti e bassi, la vita senza di te non mi appartiene.
MG

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Preface

The reasonable man adapts himself to the world:
the unreasonable one persists in trying to adapt the world to himself.
Therefore, all progress depends on
the unreasonable man

— George Bernard Shaw

More than ten years ago, Frank Hahn and Robert Solow, two of the most influential economists of the twentieth century, delivered a fierce attack against the main trend of macroeconomic theory and the methodological quest for micro-foundations by arguing against *[...] the belief that the only appropriate micro model is Walrasian or inter-temporal-Walrasian or, as the saying goes, based exclusively on inter-temporal utility maximization subject only to budget and technological constraints. This commitment, never really argued, is the rub* (Hahn and Solow (1995), p.1).

Admittedly, their criticisms and proposed solutions have gone largely unnoticed. The alternative proposal we shall put forward in what follows with the Walrasian paradigm is definitely more radical. As a preliminary step, however, it seems worthwhile to emphasize that Walrasian micro-foundations should be considered as a wrong answer to what is probably the most stimulating research question ever raised in economics, that is, to explain how a completely decentralized economy composed of millions of (mainly) self-interested people manages to coordinate.

The way in which billions of people, located everywhere in the world, exchange goods, often coming from very remote places, in decentralized market economies is a fundamental problem of macroeconomic theory. At

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present, there is no consensus regarding which theory best explains this problem. At one end of the spectrum, new classical macroeconomists work within frameworks in which the macroeconomy is assumed to be in a continual state of market clearing equilibrium characterized by strong efficiency properties. At the other end of the spectrum, heterodox macroeconomists argue that economies regularly exhibit coordination failure (various degrees of inefficiency) and even lengthy periods of disequilibrium. Given these fundamental differences, it is not surprising to see major disagreements among macroeconomists concerning the extent to which government policy makers can and ought to attempt to influence macroeconomic outcomes.

Since the mainstream efficient market theory fails in providing an internal coherent framework (*the failure of the general equilibrium Walrasian framework led to its refusal by its aficionados too, while the representative agent* (RA) *framework is an oxymoron if one wants to explain the coordination problem*) as well as understanding the empirical evidence (*e.g., it explains the huge mass unemployment of the US in the 1930s, or in some South European countries nowadays, above 30%, with the workers' preference for free time because of the low wages*), there is a need for an alternative framework. This book aims to supply tools for dealing with systems of heterogeneous interacting agents, providing the reader with the analytical tools of statistical physics (SP). This approach is very close to that inspiring the so-called agent computational economics (ACE; see Delli Gatti et al. (2016)). Both belong to the agent based models (ABM) literature and are complementary.

The standard hypothesis in the literature is that of assuming the existence of no interaction, which, by definition, allows the modeller to avoid all the problems of coordination. This book joins (and hopefully develop) a different stream of analysis, which focuses on the behavior of the economy as an emergent property of a system of heterogeneous interacting agents to which belong Foley (1994), Aoki's works (Aoki, 1996, 2002; Aoki and Yoshikawa, 2006), the works by Hommes and co-authors on heterogeneity in expectations (Hommes, 2013), the contributions by Lux and co-authors on opinion dynamics (Lux, 1995, 2009, among many others), Weidlich (2000) and the WEHIA conferences.

The shift of the methodological approach is quite challenging. In fact, the abandonment of the classical mechanical approach to statistical

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physics produces several effects: from reductionism to holism, from exogenously driven fluctuations to phase transition, to a new concept of equilibrium. While for the mainstream, economics is the study of 'a number of independent agents a collection of Robinson Crusoe' (Friedman, 1962, p. 13), the holistic-Keynesian approach disregards the individual.

In this book, we propose a different approach which regards individuals as the nodes in the network of relationships, from causal determinism and reductionism to complexity. Thus, economics would be quite different from what we know now. The first framework to be deleted would be the RA. Then, after having buried it without too many tears, heterogeneity has to be introduced and interaction among agents has to be modelled.

If one can still deal (at very particular assumptions) with heterogeneity, interaction introduces non-linearities and a full line of problems: from externalities to the issue of aggregation, from the multiplicity of equilibria to the question of small shocks determining large fluctuations. According to the complexity theory, heterogeneous interacting elements self-organize to form potentially evolving structures which exhibit a hierarchy of emergent properties.

Reductionism cannot be used as a tool due to the non-linearity of interaction: because of it, the causes and effects are not separable and the whole is not the sum of the parts. Identifying precise cause–effect relations is a difficult undertaking, especially in social sciences.

Josif Vissarionovic Dzugasvili, before he took the name of Stalin, applied unsuccessfully for a job as a night-porter in an Ancona hotel: to what extent can one plausibly attribute responsibility for, say, the Stalin gulags, to his rejection by an obscure Italian hotel keeper? By the way: Stalin did not get the job because he was, according to the owner, too shy.

Aoki (1996, 2002); Aoki and Yoshikawa (2006) introduce an approach which is fully dynamic and use the formalism of partial differential equations as well as stochastic differential equations. In principle, Aoki's analysis is able to overcome the problem of dynamic stochastic aggregation present in the literature. The mathematical subtleties of the formalism may have, of now prevented its widespread use among economists since Masanao's writings may come across as very

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technical and cryptic. Besides, the absence of a closed form solution made his contributions not so appealing for standard economists.

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