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Tipping points in macroeconomic agent-based models

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ABSTRACT

The aim of this work is to explore the possible types of *phenomena* that simple macroeconomic Agent-Based models (ABMs) can reproduce. We propose a methodology, inspired by statistical physics, that characterizes a model through its "phase diagram" in the space of parameters. Our first motivation is to understand the large macro-economic fluctuations observed in the "Mark I" ABM devised by Delli Gatti and collaborators. In this regard, our major finding is the generic existence of a *phase transition* between a "good economy" where unemployment is low, and a "bad economy" where unemployment is high. We then introduce a simpler framework that allows us to show that this transition is *robust* against many modifications of the model, and is generically induced by an asymmetry between the rate of hiring and the rate of firing of the firms. The unemployment level remains small until a tipping point, beyond which the economy suddenly collapses. If the parameters are such that the system is close to this transition, any small fluctuation is amplified as the system jumps between the two equilibria. We have explored several natural extensions of the model. One is to introduce a bankruptcy threshold, limiting the firms maximum level of debt-to-sales ratio. This leads to a rich phase diagram with, in particular, a region where *acute endogenous crises* occur, during which the unemployment rate shoots up before the economy can recover. We also introduce simple wage policies. This leads to inflation (in the "good" phase) or deflation (in the "bad" phase), but leaves the overall phase diagram of the model essentially unchanged. We have also explored the effect of simple monetary policies that attempt to contain rising unemployment and defang crises. We end the paper with general comments on the usefulness of ABMs to model macroeconomic phenomena, in particular in view of the time needed to reach a steady state that raises the issue of *ergodicity* in these models.

It is human nature to think wisely and to act absurdly – Anatole France.

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1. Introduction

1.1. From micro-rules to macro-behaviour

Inferring the behaviour of large assemblies from the behaviour of its elementary constituents is arguably one of the most important problems in a host of different disciplines: physics, material sciences, biology, computer sciences, sociology and, of course, economics and finance. It is also a notoriously hard problem. Statistical physics has developed in the last 150 years essentially to understand this micro–macro link. Clearly, when interactions are absent or small enough, the system as a whole merely reflects the properties of individual entities. This is the canvas of traditional macro-economic approaches. Economic agents are assumed to be identical, non-interacting, rational agents, an idealization known as the "Representative Agent" (RA). In this framework, micro and macro trivially coincide. However, we know (in particular from physics) that discreteness, heterogeneities and/or interactions can lead to totally unexpected phenomena. Think for example of super-conductivity or super-fluidity[1]: before their experimental discovery, it was simply beyond human imagination that individual electrons or atoms could "conspire" to create a collective state that can flow without friction. Not only micro and macro behaviour do not coincide in general, but also genuinely *surprising* behaviour can emerge through aggregation. From the point of view of economic theory, this is interesting, because financial and economic history is strewn with bubbles, crashes, crises and upheavals of all sorts. These are very hard to fathom within a Representative Agent framework (Kirman, 1992), within which crises would require large aggregate shocks, when in fact small local shocks can trigger large systemic effects when heterogeneities, interactions and network effects are taken into account (see e.g. Brock and Durlauf, 2001; Ball, 2012, for a recent review, see Bouchaud, 2013; Bonart et al., 2014). The need to include these effects has spurred a large activity in "Agent-Based models" (ABMs) (for a concise overview of ABM for collective phenomena, see Goldstone and Janssen, 2005, for early papers on ABM for economics, see e.g. Axtell, 2000; Tesfatsion, 2002, More recent attempts can be found in Ashraf et al., 2011; Raberto et al., 2012; Dosi and et al., 2013, for some review papers on ABM for economics and finance, see e.g. Leijonhufvud, 2006; Hommes, 2006; LeBaron and Tesfatsion, 2008; Dawid and Neugart, 2011; Cristelli et al., 2011). These models need numerical simulations, but are extremely versatile because any possible behavioural rules, interactions, and heterogeneities can be taken into account.

In fact, these models are so versatile that they suffer from the "wilderness of high dimensional spaces" (paraphrasing Sims, 1980). The number of parameters and explicit or implicit choices of behavioural rules is so large (~ 10 or more, even in the simplest models, see below) that the results of the model may appear unreliable and arbitrary, and the calibration of the parameters is an hopeless (or highly unstable) task. Mainstream RA "Dynamic Stochastic General Equilibrium" (DSGE) models, on the other hand, are simple enough to lead to closed form analytical results, with simple narratives and well-trodden calibration avenues (see e.g. Gali, 2008). In spite of their unrealistic character, these models appear to perform satisfactorily in 'normal' times, when fluctuations are small. However, they become deeply flawed in times of economic instability (Buiter, 2009), suggesting that different assumptions are needed to understand what is observed in reality. But even after the 2008 crisis, these traditional models are still favoured by most economists, both in academia and in institutional and professional circles. ABMs are seen at best as a promising research direction and at worst as an unwarranted "black box" (see Fagiolo and Roventini, 2012 for an enlightening discussion on the debate between traditional DSGE models and ABMs, and Fagiolo et al., 2007; Pyka and Fagiolo, 2007; Kirman, 2010; Caballero, 2010 for further insights).

1.2. A methodological manifesto

At this stage, it seems to us that some clarifications are indeed needed, concerning both the objectives and the methodology of Agent-Based models. ABMs do indeed suffer from the wilderness of high dimensional spaces, and some guidance is necessary to put these models on a firm footing. In this respect, statistical physics offers a key concept: the *phase diagram* in parameter space (for a general, insightful introduction, see Goldenfeld, 1992). A classic example, shown in Fig. 1, is the phase diagram of usual substances as a function of two parameters, here temperature and pressure. The generic picture is that the number of distinct phases is usually small (e.g. three in the example of Fig. 1: solid, liquid, gas). Well within each phase, the properties are qualitatively similar and small changes of parameters have a small effect. Macroscopic (aggregate) properties do not fluctuate any more for very large systems and are robust against changes of microscopic details. This is the "nice" scenario, where the dynamics of the system can be described in terms of a small number of macroscopic (aggregate) variables, with some effective parameters that encode the microscopic details. But other scenarios are of course possible; for example, if one sits close to the boundary between two phases, fluctuations can remain large even for large systems and small changes of parameters can radically change the macroscopic behaviour of the system. There may be mechanisms naturally driving the system close to criticality (like in Self-Organized Criticality, Bak, 1996) or, alternatively, situations in which whole phases are critical, like for "spin-glasses" (on this point, see the interesting discussion in Kondor et al., 2014).

In any case, the very first step in exploring the properties of an Agent-Based model should be, we believe, to identify the different possible phases in parameter space and the location of the phase boundaries. In order to do this, numerical

[1] See e.g. Ref. Balibar (2007) for an history of the discovery of super-fluidity and a list of references.