New Economic Windows

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To Tonino
Who, whether it was snowing, or on the long walks in the Sibylline mountains looking for mushrooms, or during dinners by the fireplace with lentils, chestnuts and wine, tried to teach me about the beauty of art, opera and knowledge.

Preface

"Why did no one see the crisis coming?" asked the Queen about the Great Recession. The problem, however, lies not in the prediction, but in the fact that the dominant economic theory does not contemplate the possibility of a large crisis. This notion is now being questioned and a new perspective is emerging, according to which markets evolve spontaneously toward an unstable situation, even though each individual agent acts in its own interest. In this case, the triggering event becomes irrelevant, while the key point is to identify the elements of instability. [This also leads us to review the statistical measures. The GDP, for example, disconnected from measures as to its distribution among households or companies, is not very informative, especially regarding resilience and robustness, Pijpers 2018].

The limitation resides in the adopted paradigm that favors analytic rigor over empirical coherence [well exemplified by Reis (2018, p. 133): "It is worrying to see the practice of rigorously stating logic in precise mathematical terms as a flaw instead of a virtue."] Furthermore, a state of equilibrium excludes all pathological phenomena. But economics is a social discipline in an evolutionary context, made up of actors different from one another who interact directly with each other. Physics abounds in examples of mathematically correct theories, which are completely irrelevant, because they are based on incorrect hypotheses: these theories lead to results contradicted by reality. And if an experiment is in disagreement with the theory, we question the hypotheses on which the model is based and identify the ones that are wrong. And, of course, we change the model: rather than mathematical rigor, it is empirical relevance that is important, the comparison with reality.

Instead, mathematics has become synonymous with scientific rigor in the dominant economic paradigm [in the course of this book, I will use the following terms interchangeably[?]: *axiomatic* or *mainstream* economics, referring to the dominant paradigm]. The time has come to ask whether the economic theory itself—and with it, the toolbox—should not be rethought. Mainstream economists do use advanced mathematical techniques; only they use the wrong ones, because they don't consider economics to be a complex system, as it is composed of heterogeneous and interacting agents. They still use nineteenth-century mathematics to analyze complex systems, while hard sciences (such as physics and chemistry) have continually updated their methods. As the theory of complexity demonstrates, the interaction of heterogeneous agents generates non-linearity: this puts an end to the age of certainties. Furthermore, if agents interact directly, dynamic networks are formed whose characteristics influence the characteristics of stationary states. When direct interaction between agents is taken into account, the behavior of the system as a whole cannot be presumed or fully understood merely by looking at the properties of the behavior of the individual components, taken separately one from the other. Interaction between these components generates emerging properties of the system, which are different from the micro ones. [All of this is masterfully expressed—for example—by Reis (2018, pp. 233–234): "It is perplexing to read arguments being boxed into macroeconomic theory (bad) as opposed to microeconomic empirical work (good), as if there was such a strong distinction." Too bad that the mainstream model is strongly non-linear and generates those emerging phenomena—see Chap. 2—that differentiate the macro from the micro.] Economics is based on the methodologies of physics before the quantum revolution. The elementary particle doesn't even exist as a single entity, but rather as a network, that is, an evolutionary system of interacting units. This is a lesson that has been adopted by all of the sciences, be they physical or social, but is completely inconsistent with the work carried out in mainstream economics. The methodology and the tools to be used—imitation of behavior, the direct interaction of heterogeneous agents, and the historical period—open the door to an economic model that is different from the dominant, deductive, and axiomatic one.

As we shall see, the DSGE (Dynamic Stochastic General Equilibrium) theory is subject to Gödel's incompleteness theorems and cannot generate empirically falsifiable propositions. For a new paradigm, in which quantitative tests are fundamental and analytical coherence does not derive from axiomatic models, the ABM approach is very promising (Farmer and Foley 2009; Stiglitz and Gallegati 2012; Richiardi 2017), even if still immature. [In his *Essay on the popular errors of the ancients*, Giacomo Leopardi writes: "The world it is full of errors, and man's first care must be to know the truth [...]. It is far easier to teach a truth than to establish it above the ruins of error; it is far easier to add than to replace."] These are models that aim to represent economic systems as complex adaptive-evolutionary ones, composed of heterogeneous and rationally limited agents who interact with each other, generating the emergent properties of the system. Economic equilibrium, with its uniqueness or multiplicity, its stability or instability, becomes only one of the possible outcomes of the model, not an a priori assumption.

Supporters of the mainstream accuse the ABM of adopting an *ad hoc* methodology, in which "everything goes," an accusation concerning the non-optimal behavior of agents [in Chap. 3, I argue that the optimality of the mainstream is, instead, an *ad hoc* hypothesis, a necessary condition to eliminate complications arising from learning and from strategic behavior and to reduce/simplify the economic agents to atoms] and the choice of the arbitrary value of the parameters, calibrated to reproduce empirical evidence. If anything, this is true for the process of calibration without validation of the mainstream. With the ABM, the methodology arises "from the bottom-up": individual parameters and their distribution are estimated and then evaluated to verify if aggregate regularities emerge when taken together. In short, there is a micro, meso, and macro (Dopfer et al. 2004; Foster and Potts 2007) empirical validation; with the ABM, falsification of the hypotheses—four centuries after Galileo—is applied to economics.

The ABM is a tool that allows us to validate hypotheses (Guerini and Moneta 2017) at the individual, sectoral (meso), and macro levels and in which the relationships among several heterogeneous objects generate regularities that can change over time. There are two typical responses from the DSGE. The first is that non-mainstream criticisms are addressed to straw man models. The second is that the criticisms are always addressed to previous versions: the new epicycles, added one after the other, explain everything. [Note the similarity of this argument with that of Simplicio—against Salviati—in the "Dialogue concerning the two chief world systems" by Galileo.] So, *menu costs* are introduced to explain price rigidity, *staggered wage*s for that of salaries, the *efficiency wage* for unemployment, heterogeneity for risk, *shadow banking* for the Great Depression, or the currency that is introduced into the utility function to justify its existence in a system designed for barter. But it won't be the epicycles that will save the mainstream model.

The superiority of the AB approach lies precisely in its superior ability to grasp empirical evidence [Delli Gatti et al. 2005, 2008; Gaffeo et al. 2007; Dosi et al. 2010]. The future of economics will be that of an empirically founded social science in which instruments—rational expectations or heterogeneous agents that do not interact or change—end up next to the epicycles as memories of failed theories.

Recently, authoritative exponents of the mainstream (Christiano et al. 2017) defined all economists who do not use DSGE models as "dilettantes" (e.g., Romer 2012, and, most of all, Stigitz 2018). Evidently, they have not read Montaigne ("no one is exempt from talking nonsense, but it is important not to say it with presumption") or even reflected on Einstein. ("As long as the laws of mathematics refer to reality, they are not certain, and as long as they are certain, they do not refer to reality.") Moreover, they argue that their lack of consideration of shadow banking in their DSGE models induced them not to consider the possibility of the recent crisis—forgetting that, when an incomplete model is used, no rational expectations can be made, and so the Lucas critique also applies to all of those models that are not updated according to the latest epicycle.

It was not the dominant economic theory that provoked the crisis. But neither did it do anything to pull us out. Could it have? And how? By indicating the same path that has led us to where we are now? Now, and also before, in 1929?

The economy that has prevailed so far is in dire straits. From student protests to the disaffection of a growing part of the professional classes to the persistence of a crisis that theory did not contemplate, the signs of an imminent collapse are multiplying. From physics to biology, from neurology to chemistry, a continuously increasing number of sciences assist the now bedridden patient, once considered the "dismal science," but also the queen of social sciences. Seeing it in such a sorry state is distressing, as it is also distressing and infuriating witnessing the mass unemployment that axiomatic economics doesn't know how to cure, stubbornly prescribing bloodletting to an anemic patient. Admittedly, at this rate, it will reach a dearly coveted equilibrium: an equilibrium that, biologists remind us, is the typical state of any dead body.

It is worth mentioning that an axiom, in epistemology, is a statement taken to be true. A set of axioms is the basis of every deductive theory that presents itself as an axiomatic system (such as religion and economics, for which the axioms are often dogmas, and the "let's assume" of economists becomes a "let's axiom"), but not as a science, be it strong or weak. The models of axiomatic economics look like Renaissance paintings of the ideal city. What may seem odd is that the intent of these models is to enhance our understanding and management of the real world, more or less like wandering around the streets of an unfamiliar city using the map of an urban utopia. So, it shouldn't surprise us when we end up who knows where, only to discover that what we are looking for isn't there, because, not being *optimal,* it wasn't taken into consideration.

Obviously, a model only represents reality (https://www.theguardian.com/business/2017/dec/21/ideas-for-an-economics-in-which-people-matter). No one wants to wander around a city with a 1:1 map, but neither do they want to visit Lisbon with a map of La Plata, or any other city in the world with the same single map. But the dominant economic system today works exactly like that. It provides a useless guide for our lives, at best incomplete/incoherent, and often harmful.

We frequently read comments by axiomatic economists who, in spite of the Great Recession we're undergoing, continue tirelessly to argue that the *mainstream* model is the most important one, due to its internal logic and because it explains the real economy pretty accurately. These are claims that we have heard before, even in recent history. They are like the Japanese "ghost" soldier Hiroo Onoda, who was found in 1974 on the island of Lubang (Philippines), still intent on defending the Empire of the Rising Sun nearly 30 years after the end of World War II.

Moreover, we have to abandon the paradigm, this economy that ignores nature and the "laws" of physics. I will repeat again that having growth of the GDP as the only objective is both shortsighted and misleading. *Jobless growth* (a factor in all industrial countries since the 1990s) explains the limits of growth in simple language: in this case, there is a GDP increase with unvaried employment. Instead, we should start looking at things in terms of *a growth*; we should live in a world that contemplates well-being indicators (e.g., nature, timelines and formulas for working and living, social relationships) and include economics in our approach to nature and society.

As Alfred Marshall said (1890, p. 1), "economic conditions are constantly changing, and each generation looks at its problems in its own way." Unfortunately, contemporary economics is still dealing with current economic problems using outdated and outworn economic tools. If we continue using the old paradigm, then we can't complain that economics seems incapable of offering solutions to the present crisis.

I graduated under the direction of Hyman Minsky with a thesis on "Financial instability and the economic cycle." I started working in 1987 on financial fragility in St. Louis, where I met a young—and handsome, he would add—Domenico Delli Gatti, beginning a long, fraternal, and very funny collaboration. In Minsky's theory, it is proposed that financial fragility is produced by the dynamic interaction of three types of agent (robust, fragile and speculative, or Ponzi). Three years later, I started collaborating with Joe Stiglitz, who, 11 years later, would be awarded the Nobel Prize in Economics for the asymmetric information theory. For Domenico and me, it was immediately evident that economic analysis with the representative agent was flawed and that it was necessary to "invent" the analysis with heterogeneous interacting agents. The resulting non-linearities make the investigation complex and almost impractical, unless you are lucky enough to work with Laura Gardini and Gian Italo Bischi. In 1997, Alan Kirman and I promoted the WEHIA in Ancona (Gallegati and Kirman 2018), whose main aim was to bring together scholars—very few of whom existed at the time, with those who did being scattered around the world and working in various disciplines—of HIA. It was already evident then—just like the recognition of DSGE now (Ghironi 2018)—that the RA doesn't work and—for us—that heterogeneity in economics implies direct interaction. And this, it seems to me, indicates the theories of Minsky and Stiglitz. Once taken seriously, the market cannot be considered an efficient coordinator, and therefore, we need an approach that analyzes direct and indirect interaction between heterogeneous agents: specifically, the complex agent-based approach (Gallegati and Richiardi 2009; Delli Gatti et al. 2010).

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Contents

Chapter 1
Axiomatic Economics: The Biggest Dying Paradigm

This work is built on the assumption that the current crisis is both ecological and socio-economical, and also one of economic theory. I won't deal with the climate and eco-social crises here (see Klein 2014; Danovaro and Gallegati 2018). I shall focus instead on why the crisis is creating a radical rethinking of economic theory. The economic crisis has, in fact, produced a crisis in economics. And not just because it wasn't able to predict the arrival of the crisis itself (a very doubtful possibility in social and complex disciplines), but rather because such a massive decrease cannot even be imagined by the dominant economic theory, obsessed as it is by the straitjacket of equilibrium, unless you consider, for example, that a reduction of 20% in production is a healthy state of equilibrium. Like a physician who *specializes in healthy patients*: please only contact him when things are going (or seem to be going) well; that is, when you don't need a physician.

The dominant economic theory today is about to fail, because its internal logic is weak and because it is belied by facts. Rather like astronomers who wanted to analyze the motion of planets using the Ptolemaic model: in order to explain the different properties of the same heavenly body, scholars were forced to resort to abstruse combinations of epicycles and different eccentrics depending on the size, speed or direction of movement (Astronomers had observed that some planets seemed to move in an irregular orbit, sometimes appearing closer and sometimes further away from Earth. To account for these apparent irregularities without refuting the axiom of the perfect circularity of all celestial motions, astronomers were forced to introduce the theory of epicycles. According to this theory, some planets are not attached—directly—to their deferent sphere, but are fixed to a smaller sphere—called an "epicycle"—which revolves around a center placed on the main sphere). These were ad hoc hypotheses, introduced to mathematically justify the observed data, that is, to save the model, the axiom ("Axiom is a general and unprovable rule that can serve as a premise to a line of reasoning, a theory, a demonstration. If the rule that is taken as the foundation of a demonstration is an unclear and unproven proposition, but equally accepted, you have a postulate. Dogma instead belongs to the language of religion and not of philosophy, the

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truth of faith proposed as unquestionable; in an extended sense we call *dogma* any principle considered as indisputable truth," from Zanichelli's Dictionary), even though it disproved reality. Little wonder then that the same theory describes the motion of the planets as an effect of the thrust of angels. Not a scientific statement, but rather an axiomatic one. In economics, the transition from an axiomatic discipline to a falsifiable one has yet to be made [Falsifiability here means that a theory or a hypothesis has scientific status only if it can be disproved by facts (Popper 1935). In Chap. 2, I will deal with the problem of falsifiability and its incompatibility with *mainstream* theory]. The axiomaticity of standard economics, based on rationality and the maximization of utility, seems to ignore the empirical correspondence between axioms and reality, raising mathematics to the role of arbiter of the validity of the theory.

This introductory chapter provides a framework for our arguments about the economy of tomorrow, which will have to be based on the idea of *agrowth*. Chapter 2 deals with the crisis of axiomatic economics, well-known crises and contradictions that the Great Recession has merely brought to light. In Chap. 3, I present an approach based on heterogeneous interacting agents (Blume 1993; Blume and Durlauf 2001), which I believe is a more promising alternative theory. These models, though still in their growth phase, have all of the characteristics to become a solid and reliable social discipline. It is the interaction of agents that determines dynamics and emergent properties, just like the properties of water differ from those of its constituents and emerge from the interaction of two hydrogen atoms with one of oxygen. Chapter 4, before suggesting a possible way out of the ruins of the mainstream paradigm, reminds us why the king is naked.

1.1 A Clock That Always Marks the Same Hour

If we look at the evolution of GDP per capita in the world over the last 2000 years, one fact stands out clearly: its centuries-old stagnancy was shaken by the Industrial Revolution. Technological innovation continues to transform the destiny of humanity. It makes us progressively less dependent on labour, hunger and basic needs. Not for everyone though. Even today, for most of the human race, the leap has yet to come. And we might well ask, will it ever? Is growth sustainable? And does it spread?

These questions were tackled in my 2014 book, in which I found myself in disagreement with Domenico Delli Gatti, starting with the title: it was *Beyond the Hedge* for me (though the English edition carries the title *The Economy of the Hamster*), *Behind the Thicket* for him. The framework outlined there is as follows: if non-reproducible resources are limited, growth will also be limited. In an economy in which the manufacturing industry is dying because machines are replacing human beings (as was the case for agriculture), new needs, and therefore new jobs, are invented to perpetuate *the hamster economy*; that is, work more to consume more, disregarding the pleasant things in life. A way of life that pursues an accumulation of goods instead of well-being, of GDP instead of *buen vivir*. We should instead try to free the hamster, opening the cage to facilitate a paradigm shift.

If we work less, the demand may decrease, but the supply can, in any case, increase, even with fewer people being employed, if the technology continues to become progressively more efficient. An unsustainable disproportion in the long run, which must be rebalanced, by means of redistribution. Given the constraint of resources, it should not be difficult to imagine a "zero waste" policy that takes into account the entire "life cycle" of a product (for example, instead of buying a product and throwing it away after a while, one could propose a sort of rent that envisages the product being returned to the producer, who will recycle it, having designed the product with this possibility in mind) or of innovations that save non-renewable resources according to the vision of a *circular economy* proposed by Walter Stahel, one of the founding fathers of the concept of sustainability. Innovations will be, whether we like it or not, continuously more oriented towards sustainability, as it is now clear that the finiteness of non-renewable resources also poses a limit to growth (unless we discover how to violate thermodynamics). Technology can only postpone the moment, but the end of the capitalism that we know will arrive (Ruffolo 2009; Comin and Speroni 2012).

The gradual replacement of human workers with machines results in an inevitable lack of demand. But also in a continuous introduction of new goods, and hence of new jobs, and this feeds both supply and demand. Economists speak of the "non-saturation of needs," which, in other words, means: needs, and therefore consumption, are limitless. The question is, in principle, infinite. Which means that we will never be satisfied—in *Affluenza,* Hamilton and Denniss (2005) describe exactly this: despite rapidly rising incomes, the percentage of people who want to have more does not decrease. "Non-satiety" in the enjoyment of goods keeps driving us to produce more, i.e., to infinitely increase the GDP. But it cannot grow indefinitely. We are hamsters, like I said before, all of us in our individual wheels, which we ourselves spin. The non-saturation of needs is a recipe for unhappiness.

Economic development has shaped our way of life, enabling us to move from a lifestyle of mere survival to one of opulence. And our life is very different from what it was three centuries ago, because technology has transformed it by freeing us from heavy manual labour, but it has also given us the illusion that possessing more goods will make us happier. And because the goods and services that go through the market enter into the GDP, increasing the latter would equal increasing well-being. We produce and consume. We spin our wheels running after money, yet our well-being is always beyond our reach. Of course, if, in order to live, despite technology, we have to work to consume, earn to spend, there seems to be no other path, no other way of life.

But we live in a finite world, subject to the laws of physics, the second law of thermodynamics included. All of this leads us to imagine a future in which society will be post-industrial, goods will be dematerialized and our civilization will be one of knowledge. It will therefore be a future of research. The creation of wealth did not come about without a price. Suffice to say that, as a result of this process, the loss of biodiversity has become a dramatic reality. If it was estimated that, in the pre-industrial era, between 0.1 and 1 species per million became extinct per year, since 1700, this number has risen to more than one hundred (Wijkman and Rockström 2014). With the industrial revolution, ecosystems have become increasingly fragile. As John D. Gould wrote in 1972: "Pollution, loss of natural environment, traffic congestion and accidents have clearly resulted from industrialization and modern technology and have no obviously important analogues in pre-industrial societies. Moreover, the more work that is done on 'traditional peasant societies' the clearer does it become that these societies have often achieved an almost miraculous accommodation with nature, balancing present use and preservation for the future with a degree of success which the modern economic machine has rarely approached."

Yet science, since the time of Darwin, has been quite clear: man is a part of nature and his well-being depends on goods and services obtained by interacting with the ecosystem. If this teaches us anything, it is that economics is connected to nature and that nothing lasts forever. Not even growth. Development depends on biodiversity (reproducible and non-reproducible natural capital) and on human labour. So when economists talk about growth without considering the finite limits of the world, that is, of nature, they *talk nonsense*. Economics is a part of nature: we have to rethink its foundations. We can't forget about it just because considering nature is not consistent with the axiomatic model. If reality provides indications that contradict the theoretical hypotheses, I would change them. However, some people prefer to deny reality and keep the model. This way, growth becomes an evolutionary trap (Evolutionary traps are scenarios in which an environmental change leads organizations to prefer to settle in environments that are good in the short term, but deadly in the long term. Traps occur when the attractiveness of a habitat increases according to its value for survival and reproduction. The result is a preference for a falsely attractive habitat).

From now on, when I refer to quantitative increase of the GDP, I am talking about *growth*; if, instead, growth is accompanied by higher productivity (for example, the same number of workers produce more goods), then I am talking about *development*; the latter becomes *progress* when new products are introduced. By *agrowth*, I mean that well-being is multi-systemic and that GDP growth captures only one of the multiple dimensions of living well.

But what can be done at this stage, seeing that the present decline will necessarily result in a paradigm shift? This booklet attempts to identify the causes of a moribund paradigm and outline possible ways of escaping the crisis.

Economics is a social discipline, combining history, mathematics and sociology in a complex environment composed of heterogeneous agents who interact with each other largely outside of the markets. And here, the double scam is revealed: the market includes and fixes everything. It gives a price to everything, and a value to nothing: GDP is a measure of our lives. But it's an incorrect one. It balances everything, equating supply and demand: but how is this possible if so much takes place outside of its range? The question as to whether markets will save us is, of course, legitimate, but it's wrong. The ecosystem to which we all belong isn't taken into consideration, as if natural capital were interchangeable, and therefore infinite.

We need another paradigm, one that encompasses economy, nature and society, all together.

In axiomatic theory, nature plays the role of an externality. If one produces by polluting the environment, a negative externality arises that the market can't correct. Yet, a sort of *carbon tax* could mitigate this distortion. When the market fails, the intervention of an external agent can lead to improvement. And if the market fails its pivotal measure, the GDP also fails. In fact, *welfare economics* asserts that, in the presence of negative externalities, such as environmental issues, the solution lies in considering them as a cost imposed on the "polluter." By turning them into an encumbrance for whoever causes them, negative externalities begin to be taken into account in decision-making. This presupposes that it is possible to monetize the damage; for example, evaluate the cost of killing a polar bear with the melting of ice caps due to CO_2 emissions, or the extinction of the Pyrenean goat. The idea has, in practice, been implemented in different ways. The main ones are a tax on the polluting product (but, again, how do we quantify the real environmental cost in economic terms?) and the right to pollute. The latter has become very fashionable in recent decades, and is exemplified by the Kyoto emission rights, one of the most shining examples of how axiomatic precepts of neoclassical theory can result in an economic policy that is deplorable from an ethical point of view and absurd from a logical one. Acknowledging the "right to pollute" as a "right of ownership" that can be freely sold/bought has sparked off a series of disputes in which industrialized countries are scrambling to grab (often using economic and geopolitical blackmail) the emission rights of non-industrialized countries, instead of investing to reduce emissions.

In short, with an externality, the maximization of individual profit does not coincide with the maximization of collective welfare. Perverse results are generated that lead individuals to over-produce, regardless of the limits with which nature confronts us.

1.2 GDP Versus Well-Being

By separating economics from nature, the much-vaunted growth becomes an evolutionary trap. We pursue well-being by identifying it with the GDP (and therefore income, revenue and profits), but if growth separated from nature leads us to jeopardize the latter, with a sort of negative growth that the GDP fails to take into account, we can do nothing else but head, more or less unhappily, towards collapse. It's not a question of *if*, but *when*.

If what we had was only reproducible capital, we would have the possibility of increasing the GDP indefinitely, in a manner compatible with technical and demographic progress. And only under this condition can we talk about sustainable development. The picture changes with non-reproducible capital, since a limit to growth is introduced and the concept of sustainable growth becomes an oxymoron. GDP is a measure of economic activities that can be given a monetary value, determined by the market (Campagna et al. 2017; Spaiser et al. 2017). And if, as we shall see, the market "fails," prices no longer indicate even the scarcity of goods.

It is useful to remember how the GDP was born. We are at the height of the Great Crisis—when 1/3 of the US Labor Force is unemployed—and policymakers do not have aggregate labor or income measures; they don't know what measures to take to contain the fall and stimulate the economy. In 1932, the *Economic* Research Division of the Bureau of Foreign and Domestic Commerce was appointed to estimate US income. Kuznets (1934) works on the project but, contrary to what is believed (Mitra-Kahn 2011), acts as a fierce opponent of the concept of GDP by developing an accounting scheme that excludes the public sector and those goods and services that diminish well-being (while increasing GDP). Meanwhile, Keynes elaborates, for the British Treasury, the macroeconomic scheme still in use today.

The alleged link between GDP and prosperity only takes place later, while the relationship between GDP and employment is immediate: if GDP grows, so will employment—as formalized by Okun, in his "law." The question then becomes: how can GDP be increased? If the GDP grows, then—perhaps not immediately—the number of employees and the amount of well-being will also grow. Hence, the mantra of growth that forgets the effects on Nature and Society. For workers, more GDP equals more jobs (and therefore the possibility of consuming more); for the capitalists, it equals growing profits. The positive relationship between GDP and employment terminates, however, at the end of the last century, in the 1990s, with the fourth industrial revolution: that of artificial intelligence (Brynjolfsson and McAfee 2011). Since then, the growth of GDP no longer corresponds to an increase in the number of employees: productivity increases, but occupation does not, due to automation, digitization, robots. This phase of *jobless growth* is, moreover, preceded—by about 10 years—by a period, still ongoing, in which the increase in productivity translates, minimally, into a reduction of working hours, without any significant effects on wages, determining the stagnation of aggregate demand. Aiming to increase the GDP—passed off as a *conditio sine qua non* because it increases employment, while today, in a jobless growth economy, it only produces more profits—is only one of the "tales" that are told in economics.

GDP represents the value of goods and services produced and sold on the market in a country by its inhabitants, over a period of time, intended for the end user, for private and public investment, for public expenditure and net exports. GDP is a flow that does not consider stock, and therefore the consumption of resources: we produce by impoverishing natural resources, but national accounts ignore this fact; production pollutes the environment, but there is no trace of this in the GDP, because it includes only elements with a positive sign.

GDP per capita is often used as an indicator of a country's standard of living, and economic growth as an indicator of its improvement. It has become common practice to judge whether one country is better than another based on the level of income per capita. In this way, the GDP growth rate was considered as an index of a country's economic health, while, at most, it can be considered only one of the indicators of a country's economy. When we use the GDP as a measure of our lives (Stiglitz et al. 2010), we make a series of mistakes. (The "average" thinking does not apply in complexity. Power laws reflect a pattern of organization that is typical for complex systems, because the bell curve is true if and only if events are *independent*. When one event influences another, there is interdependence, and the bell curve does not apply.)

There are, in fact, two types of problem relative to GDP: a methodological one and a semantic one.

The first point involves measurement problems. Over time, in fact, the prices of different goods vary, and their nominal value grows: inflation occurs. Moreover, product innovations are continuously introduced: eggs are eggs, and those in 1715 are, or should be, similar to those in 2015, but some products, like personal computers, didn't exist in the past, and modern cars can hardly be compared to horse-drawn carriages (and yet that's what we do when we compare baskets over several years). And there's still more. A developed economy is based on services (with an important role for the government), but productivity is poorly measured for this sector, usually on an hourly wage. We also don't know how to evaluate the prices of non-saleable services.

So, what does the GDP measure? Is the GDP something more and different than an economic index? Is it able to measure, albeit crudely, well-being? My answer is no: if we want to live well, we must not follow the indications of the GDP. Because it's not an indicator of our happiness. As Robert Kennedy once declared, the GDP "measures everything except that which makes life worthwhile."

In this sense, we must free ourselves from the myth of growth—hence the emphasis on *agrowth*—and realize that well-being is not only material, as expressed by the GDP. Revisiting the concept of the GDP as a measure *tout court* of our lives—and here comes the second point, the semantic one—goes hand in hand with a search for well-being measures that should lead us from "living to work and consume" to *buen vivir*. The GDP derives from the market, which, it is sometimes useful to remember, is only a part of our life. The motivations of economists who believe that the GDP is a measure, albeit approximate, of well-being are, in a sense, circular, as they argue that a series of needs exist and that the level of well-being depends on the ability to satisfy these needs with goods; because our needs are satisfied by goods, the more the GDP grows, the more these needs are met. Obviously, there is much more than this simplistic view of the world: even if a set of primary goods does exist, new needs are constantly being added. GDP is a number, but it's not neutral, nor does it hold true for every season, and it may differ significantly across countries.

GDP is not only a product of statistics; it also has very deep connections with the growth theory. Being well integrated with traditional theory, it is very technical and formal, with no connection to the moral sciences (contrary to the classical approach to economic policy). This is equivalent to saying that the GDP is a "neutral" index, a touchstone, a natural result of the system, and from the point of view of economic policy, this means that one model fits all countries and historical periods, since maximizing profits means maximizing the GDP, that is, maximizing well-being.

It has been over four decades since Richard Easterlin (1974) made it clear that, during the span of a lifetime, people's happiness was not related to variations in income or wealth (the happiness paradox). According to his results, when income increases, human happiness also increases, but only up to a certain point, beyond which it starts to decrease. Going beyond the GDP does not mean being committed to developing a significant synthetic indicator, but rather overcoming the logic of the market as a value in itself. The measure of well-being is not a purely technical problem, as it reflects the values and preferences of society and of the individuals who compose it. So, it doesn't make much sense to compare the health of an economy using only one indicator: the recommendations of the Sarkozy Commission (Stiglitz et al. 2010) suggest using multiple indicators of social progress.

Academic contributions from very different disciplines show us the value of diversity and heterogeneity. In economics, this means that the maximization of a single aspect of human life (for example, assets or income) originates from the idea that material wealth is able to continuously provide more well-being. But when the GDP is calculated, the impact of economic growth on the environment is not considered at all, nor the fact that ecosystems don't provide us with free services, but services which, at a price, we try to restore. It is not taken into account that these services, which do not have a market price, are not negotiable and are not included in the GDP, are causing a net loss for future generations (and often for the current ones). These services—climate and atmospheric gas regulation, decomposition and absorption of waste, flood control, soil formation, pollination—are invaluable and can in no way be replaced if they deteriorate or are irreversibly destroyed. So, when we focus only on the GDP, we glance distractedly at the loss of bio-diversity (exponential population and consumption growth is leading to an ecological collapse that will cause rapid extinctions, mass extinctions at rates one hundred times higher than "normal" ones), at deforestation and its consequent effects on the soil (erosion, geomorphological instability, desertification, salinization, etc.), at the atmosphere (climate regulation at different scales) and at human communities (mass migrations due to desertification).

It is in the light of all of the above that a reflection on the current development model is, at the very least, urgent. What we need is a system that guarantees a basic income for the current generation that doesn't affect that of the following one (Di Tella et al. 2003).

Economists usually attribute the distinction between well-being and the production of goods and services of a country to Arthur Cecil Pigou, the founder of welfare economics. This distinction is not neutral, meaning that taking the GDP as a measure of our lives does have consequences. If the GDP really did measure our well-being, then continuously producing more really would make us happier: the more I work, the more income I have and the more goods I can buy and enjoy (if I still have time for it). What perspectives do we have or need to invent to get out of this tailspin situation of the current economic system? I believe that it is absolutely necessary to rethink our targets.

The slow deterioration of growth prospects has created unease in capitalist societies, affecting increasingly consistent levels of the population, with a marked imbalance among the generations. These aspects are becoming progressively more evident, and the global economic and financial crisis can be viewed as a lifestyle crisis, i.e., of producing to consume, of consuming to justify further production for consumption purposes, and so on. As, over time, restrictions on further growth in production become increasingly stringent, the unsustainability of unlimited growth of economic activity determines the default of weaker economies and companies.

The Population Bomb (Ehrlich 1968) and *The Limits to Growth* (Meadows et al. 1972)—the report on the "limits to growth" commissioned by the Club of Rome to the Massachusetts Institute of Technology over 40 years ago—emphasize how the rapid exploitation of resources can lead to their systemic collapse and, ultimately, to that of our planet (the gloomiest scenarios envision growing and widespread famine and wars to control the remaining resources). The ecological footprint seems to confirm this apprehension when it reveals that we are consuming natural resources much more rapidly than their rate of regeneration.

However, economic growth is only possible when accompanied by an increasing consumption of resources, because goods can't be produced without the input of resources (renewable or not) and energy. *The Limits to Growth*, in particular, shows that constant growth in consumption of non-renewable resources is impossible (Coyle 2011). If the currently known mineral and energy supplies were multiplied by five (as a result of new discoveries and technologies), the exponential nature of growth would lead to the depletion of most of the resources in less than a century at the current growth rates of consumption. If the amount of extractable resources is not infinite, the fundamental mathematical fact still remains that consumption growth cannot continue forever (The environmental and ecological effects of economic growth, particularly those related to mining, agricultural, forestry and industry arouse widespread concern. Many scholars believe that the effects on the environment can have irreparable repercussions on the ecosystem).

The concept of development has been extended to meta-economic dimensions (For example, in the UN *Human Development Index,* composed of per capita income, life expectancy and schooling). Economic growth is therefore not a sufficient condition for development. Ardeni (2014) reminds us that there are four main criticisms concerning growth, namely:

1. It has negative effects on the quality of life, and many of the things that have this effect do not pass through the market system (as in the case of the natural environment);
2. It encourages artificial needs and creates a sort of preference for growth itself, like the continuous need for more and new goods and services: needs are created and consumers have become servants, not masters, of the economy;
3. It uses up resources: this argument is similar to that of Malthus, and the fact that growth rapidly leads to the depletion of non-renewable resources is not taken into consideration;
4. It does not lead to a better distribution of income (Piketty 2013).

In the following chapters, I will talk about the crisis of economics. In fact, the economic crisis is also a crisis of theory. As already mentioned, the latter probably did not cause the crisis, but neither did it do anything to help us to understand it, let alone foresee it, caged as it is in its fantasy vision in which everything is in equilibrium in the best of all possible worlds. And how can what is belied by reality regarding the behavior of an individual firm, worker or bank be true at the level of productive sectors or countries? Macroeconomic theory guarantees that the crisis does not and cannot exist, because everything is in equilibrium [As Lucas prophetically reminded us (2003, p. 1), "macroeconomics in this original sense has succeeded: its central problem of depression prevention has been solved, for all practical purposes"]. You just need to pursue private interests, and these will be extended to the common good. And there's still more. The market is able to transform private vices into public virtues, *under certain conditions*. Too bad that the same conditions are logically contradictory and are not conceivable endogenous innovations (hence, not fallen out of the blue), i.e., of the actual driving force of the economy as we know it from the times of the industrial revolution. The currently dominant theoretical *corpus* could, at best, attempt to describe the economy that preceded the industrial revolution, but not that of today.

Economics is regarded as being independent from nature. As if natural capital was infinite, that is, *reproducible*, like a forest, and not *non-reproducible,* like a mine. In the first case, we could talk of *sustainable development* and of the disappearance of the steady state: innovation allows production to increase at the same rate as input. In the second case, instead, if capital is not reproducible, the concept of sustainability becomes an oxymoron (Spaiser et al. 2017). Innovation that saves non-reproducible resources can delay the end of the materials economy. By this, I mean an economy free from physical resources and based on learning.

Beyond GDP, there's nature. And, as axiomatic economists tell us, nature cannot be included in the wealth of a country, because, by doing so, externality is taken into consideration. But if we rely on a GDP that excludes nature and its free services, we assume a predatory attitude and, as the philosopher and science historian Paolo Rossi (1987, p. 89) reminds us, "the philosophy of dominion is likely to cancel nature and with it, of course, also man."

Reflection on the crisis (which, it must be remembered, is both economic and environmental) is necessarily divided into two parts: crisis of the economic theory and crisis of economics. I will indicate possible ways out of this impasse in the following chapters.

1.3 The *Agrowth* Hamster Roams the World

To understand what *agrowth* means [As Fuà 1993, remarked, "A single model of development and life (currently focused on the growth of consumer goods) is proposed and accepted as the only valid one; instead one should appreciate that each population is looking for a way that corresponds to its history, its character, its circumstances, and does not feel inferior to another by the mere fact that it produces more goods"; see also van den Bergh 2011; van den Bergh and Kallis 2012], just assume that we are faced with an infinite variety of needs and that these are met by consuming, and therefore by production, of goods and services: increasing production would mean gradually satisfying a greater number of needs. But this, as we have seen, creates a vicious circle: induced needs are increased, and to satisfy them we produce more, but as technology increases, employment decreases (and with it, the demand, seeing that machines don't consume). If new needs aren't invented, there won't be any new demand or new jobs. Non-renewable resources are limited, and this constitutes a barrier to infinite growth, which leads us to imagine production without exhaustible resources. So, while we continue to work in order to consume, it would be necessary to imagine a new paradigm, a renaissance that allows our life to move from higher GDP research to that of greater well-being. And from the economics of production to a systemic vision.

Agrowth means just that: well-being doesn't depend on (basic needs being satisfied) the amount of goods on hand, but on the possibility of enjoying life without compromising an equal opportunity for future generations. Humanity cannot be valued with references to a single dimension, that of production: every country should reject the precept of following one path and pursue its own, indicated by its unique culture. So, besides the GDP, we should consider our well-being through a series of other indicators, which, if only roughly, are useful for understanding where we are going, and how (http://hdr.undp.org/en/content/human-development-index-hdi, or http://www.oecd.org/statistics/measuring-well-being-and-progress.htm).

It has so often been repeated—in the media, by politicians and economists—that GDP growth is a *conditio sine qua non* for increasing wealth and well-being. One of the necessary connections is the one that goes from productivity to wages, to employment. A real connection for the first three industrial revolutions, but not for the fourth. Wages have decoupled in all of the advanced countries since the 1980s, as did jobless growth in the following decade. In this way, however, only income and profits grow with ever-increasing distribution inequalities. Technological innovation is considered the source of growth, a miracle-cure, and as if the relationship of the "market" with Nature were non-existent. However, having GDP growth as a sole objective is not only short-sighted, but also counterproductive. In fact, welfare is multi-systemic, and taking the GDP and its growth as the only reference is uninformative and misleading.

How are we supposed to conciliate the aspirations and desires of unlimited growth with the reality of a limited world, starting from the limitation of basic resources, raw materials, and the surface of the earth? A complex question, to which a simple but wrong answer is nearly always given: with technology. This has indeed freed us from most of the primary needs, but often at the expense of Nature and in an unsustainable way, resulting in the privileging of only the present at the expense of the future. Like all human endeavors, technological progress can be read in many ways. In relation to Nature, we can use the GDP, which, however, doesn't consider it and even gives it a distorted measure. For example, if one produces by polluting, the GDP increases two times: for production and for cleaning up (assuming that it can be done). Or—as "complexity" teaches—you have to use a "dashboard of indicators."

The development of economics has shaped our way of life, carrying us from mere survival to opulence. And our life is profoundly different from what it was three centuries ago, because technology has transformed it, freeing us from heavy work, but it has also mislead us by making us believe that having more goods at our disposal would make us happier. And since goods and services that pass through the market enter the GDP, its growth would be equivalent to an increase in well-being. We produce and consume in a continuous cycle. Yet instead, as suggested by Easterlin in his "happiness paradox," income does not increase our happiness, at least over a certain limit. But the search for economic growth gives us the illusion of achieving greater happiness.

I like to compare us human beings, intended as economic agents driven by this insatiable need for goods, to hamsters, each in our own wheel, which we ourselves run on without ever reaching our goal: we run on the wheel, chasing the money we need to consume, but our well-being is always beyond our reach. The non-saturation of needs is a recipe for unhappiness. Not only that: the increase of needs must go hand in hand with the increase in production to meet the demand, but this process is not unlimited. Moreover, after a while, the hamster gets bored with the game and, before resigning to becoming blind, starts looking for a partner with whom to interact. Of course, if, in order to live, despite the machines, you have to work to consume, to earn to spend, there seems to be no other option, no other way of life (although jobless growth and the chronic lack of demand open up other scenarios). But we live in a finite world, limited and subjected to the laws of physics, the second law of thermodynamics included, which determine a yield of any machine or biological system always less than 1.

It is almost a *cliché*, not only among economists, that growth and technological progress are an indissoluble binomial. Technical progress, therefore, is generally conceived as a bearer of absolute benefits and capable of governing Nature. But this is a statement yet to be proven. Furthermore, progress involves the increasing replacement of people with machines in the workplace (process innovation) and forces us, at least at first, to a vacuum of demand. The unemployed consume less than the employed, and the resulting lower demand for goods means (further) unemployment. But technical progress also means continuous introduction of new goods (product innovation), and therefore of new jobs, and this fuels both supply and demand. The boundary between the two types of innovation is, however, unstable: often, a new product incorporates improvements in production efficiency. Then, some problems arise. Will someone buy the product? Or will greater production efficiency increase the supply more than the demand? Will there be under-consumption or over-production, or, rather, will the market bring supply and demand into balance? Even if this hypothesis were realized—as in the aspirations of economists but, unfortunately, not in reality—we would have a pathology that the current production system needs to sustain in order to survive: the exploitation of exhaustible natural resources, and indeed, in some cases, these are already on the verge of depletion.

The creation of wealth took place at the cost of Nature and is leading to a progressive loss of natural capital and biodiversity. "Natural Capital" is defined as the entire stock of natural goods (living organisms, air, water, soil and geological resources) that contribute to providing goods and services of value, directly and indirectly, to humanity and that are necessary for the survival of the environment from which they are generated. Today, we are facing a new process of global extinction, which, according to some scientists, would be similar to those that have already taken place in the history of the Earth, the last of which occurred with the extinction of the dinosaurs about 66 million years ago in the Cretaceous period. Nevertheless, we are faced with significant differences compared to the past. Today's threat of extinction has also spread to the oceans, which, in the past ages, suffered fewer consequences, and appears to be linked to the size of the species. In the past, extinctions were generalized and often involved smaller animals, while today, large animals, those hunted by man, are at risk.

With the industrial revolution, ecosystems have become increasingly fragile. Pollution, fragmentation, habitat destruction and excessive resource extraction are clearly the result of the increased use of cement, industrialization and modern technology, and are not to be found in pre-industrial society. The latter managed to establish a miraculous equilibrium with the environment, balancing present consumption with preservation of the future, a success that is unimaginable in modern capitalism. Yet science, after Darwin, made it clear: humankind is a part of nature and our well-being depends on the goods and services derived from interacting with the ecosystem. The problem was determined, as often happens, by incorrect assessments, even by scientists.

Economics is connected to nature and, contrary to what we hope for or fool ourselves into thinking, nothing lasts forever, not even growth. Indeed, economic development depends not only on labor, human ingenuity and physical and social capital, but also on biodiversity (which we could define as the engine and generator of natural capital) and the services that nature provides. So, when we talk about growth without considering the finite limits of the earth, that is, of nature, we talk wildly about growth. This way of reasoning is implicitly based on the hypothesis that natural capital is interchangeable, and therefore infinite. But since this is not the case, the glimmer of unlimited growth becomes an *evolutionary trap* when we deplete resources with which to grow.

In the dominant economic theory, nature plays, at most, the role of a passive subject involved in an externality—defined as the effect deriving from an economic activity on a subject not engaged in the activity itself. In other words, if it is produced to the detriment of the environment, a negative externality is generated for the area of the settlement and for the environment (and therefore also for the human beings who are a part of it). An externality is the source of a collective cost that, by definition, is not incorporated into the company's production cost, and therefore not included in price determination. This is a typical market failure: this alone cannot correct the effects of externality. An *ad hoc* tax, such as a carbon tax for CO_2 emissions, can alleviate this distortion, provided it is effectively used to mitigate climate change and contrast the effects of these changes on natural ecosystems and on humanity.

When the market loses its capacity to self-regulate, the intervention of an external agent—such as a public authority that imposes environmental taxes—can make an improvement. The public agent in this way transforms the externality into a burden for whoever caused it, forcing the company to take it into account in its future decisions. All of this implies that it is possible to monetize environmental damage, but environmental damage can be very diverse and extremely difficult to evaluate, essentially for two reasons. The first is that it is difficult to identify clear cause and effect relationships. The second is that the damage often becomes apparent years later or far from the source. And, above all, believing that we can place a price on everything is just a sign of the intellectual limitation of those who believe that the well-being of humanity is one-dimensional.

If it is difficult to quantify the direct damage done by Man in the course of production activities, it is even more difficult to quantify the cost of indirect damage, such as that caused by climate change. What is the cost of the extinction of polar bears due to melting ice, which is due to global warming? (AU: Generally speaking, in my language editing, I try to encourage the use of gender neutral terms. The use of 'Man' here, capitalized as it is, tends to refer to a more conceptual notion of the species, and, let's face it, the damage of which the text speaks was, indeed, perpetrated largely by the male of the species, so I'm inclined to recommend letting it stand.)

How do we price the costs of these externalities? In addition to the tax on polluting producers, the "right to pollute" is also considered. One of the most "shining" examples is the emission rights market launched with the Kyoto conference. This is a textbook example of how, according to logic, axiomatic precepts can lead to ethical, aberrant and absurd economic policy implications. Recognizing the right to pollute as a "property right" that can be freely sold/bought has given rise to a series of controversies in which industrialized countries compete to seize (often with economic and geopolitical blackmail) emission rights of non-industrialized countries, instead of investing to reduce emissions.

Debate on the issue is open. For years, we have witnessed a "denialistic" attempt that disputed the very existence of climate change. Today, the discussion has gone from "denying the evidence" of these changes to "denying the usefulness" of investing in order to fight them. To think that the battle against climate change is a useless waste of money is an unforgivable mistake, which we risk making because, on the part of some researchers, there is little trust in the mathematical models that predict these changes, and this feeds the position of skeptics who affirm that it's not necessary to do anything. But, in this case, the data are incontrovertible. That climate change is a fact is asserted not only by scientists and all of the official statements of the world's scientific academies, but also by the great international scientific societies. Ice melts and the species living in cold environments suffer, seas warm up, corals whiten and die, fish migrate north in search of cooler waters. Deserts extend, and the Mediterranean area is becoming increasingly hot and dry. Furthermore, analysis of the time series tells us that, in recent decades, climate change has accelerated rapidly. The problem therefore is not whether the planet's temperature will increase by 1.5 or 2 °C over the next 30 years, but rather the consequences these changes have on ecosystems, biodiversity, well-being and human development with a population that has never been so numerous.

Sustainability tells us that we need progress that does not deteriorate renewable resources and does not consume beyond the non-renewable ones; now, after years of indiscriminate looting, sustainability is no longer sufficient and should be accompanied by the recovery of degraded ecosystems. But the recovery time of Nature left to itself, of a passive recovery, is too long. We need to actively intervene with the restoration of natural systems to reduce the recovery time of their functions, which are indispensable for our sustainable future. This is why Danovaro and Gallegati (2018) talk about *meta-sustainability*. A meta-sustainable economy that creates development not only in a lasting way but also with the aim of recovering the damage perpetrated from the time of the industrial revolution and with the beginning of the Anthropocene. Fighting climate change and the destruction of natural habitats is therefore a great opportunity to set up a new circular economy, with new business models and professions. It is about developing innovative technologies and making precise choices of development that privilege the creation of new businesses and jobs with high technological content, but in favor of nature, not against it. Awareness that nature, when healthy, resists climate change better promotes virtuous human activities and creates sustainable, non-destructive growth. This is not an idealistic or rearguard battle, but a different vision of healthy and lasting development.

Well-being is multi-systemic, linked to the quality of the environment in which we live and to social equilibrium, as well as to economic wealth. GDP growth only captures one of the elements of living well. We should therefore enter the perspective of *agrowth*, in which the mantra of GDP growth no longer exists, regardless of what happens all around us: that is, living in a world that includes various indicators of well-being (the quality of the environment, nature, the times and ways of work and life, social relations, for example), includes economics in nature and in society, and does not have the sole objective of growth (or degrowth) of goods and services. In Nature, *agrowth* is the "norm" of all mature systems; indeed, it is a symptom of achieving the well-being of the system, a climax, or, if we want, the well-being given by the achievement of "equilibrium" of the natural system. Lack of GDP growth should therefore be seen as an indicator of the achievement of the limits imposed by environmental conditions, by the availability of resources. When the climax is reached, the rest is superfluous. And it is also like this in economics, if we respect the constraints of resources and space, but with one more ace up our sleeve: technology. A card to play well, in order to increase well-being (not only that of today), rather than just income. As happens in Nature, where the climax is not only a point of arrival, but also the starting point, because maintaining equilibrium in a system in which the underlying conditions change requires continuous evolution, a progressive adaptive change.

Agrowth therefore, as a model of development in which economics is a part of nature, that is, without the false myth of indefinite growth, and contributes to the development of society without the obsession—typical of a predatory and opportunistic economy, which, to obtain more profits today, destroys everyone's tomorrow—of perennial growth (Hirsch 1976). And as a starting point for a new, meta-sustainable phase, in which humankind increases its well-being, without doing so at the expense of the Planet. There are no other possible worlds for humans and life, and there will be no new Noah's arks. There is no "Plan B" in the event that humans make the land uninhabitable. We cannot deplete this world because of the need for continuous growth. {AU: In this case, I am recommending switching to gender neutral, because advances in gender equality, however insufficient, mean that everyone is now free to profit off the degradation of our environment. Talk about a double-edged sword.]

A paradigm is called for capable of combining economic, social and environmental aspects. A secular paradigm, one that is free from that “confessionalism” characteristic of the current economic mainstream. If non-renewable resources (raw materials, fossil hydrocarbons, space) are limited, growth will also be limited. In an economy in which machines replace humans (not just the unskilled ones), new jobs must be invented and income redistributed. A way of life that pursues the accumulation of goods and the growth of GDP, rather than welfare, is destined to be a long-term loser. It is my belief that we have entered a phase in which the old scheme is dying and a new one is upon us, but is struggling to be born. Crises arise precisely from this gap between a way of moving forward that does not work and a new one that has not yet been affirmed: a paradigm shift is needed.

Chapter 2
The Crisis of Economics

Economics is navigating in troubled waters. And even if a mainstream approach does exist, theoretical solidity and the ability to explain the empirical evidence are obviously increasingly fragile and challenged. "When the crisis came—recalls the former Governor of the ECB, Jean-Paul Trichet 2010—the serious limitations of existing economic and financial models became immediately apparent. Arbitrage broke down in many market segments, as markets froze and market participants were gripped by panic. Macro models failed to predict the crisis and seemed incapable of explaining what was happening to the economy in a convincing manner. As a policy-maker during the crisis, I found the available models of limited help. In fact, I would go further: in the face of the crisis, we felt abandoned by conventional tools."

The economic theory taught in almost all universities around the world is axiomatic and seems inadequate to explain the real world. The standard theoretical model is questioned by a crisis that has dragged on for over 9 years. Students have already begun to challenge what they are taught, and in many faculties, Business Studies have become more popular than Economics.

In science, it is said that models should be externally and internally coherent. External coherence refers to the conformity of data with the predictions of the model. Internal coherence refers to the non-contradictory nature between the hypothesis and the resulting theorem. *Mainstream* economics has addressed internal coherence, but the resulting outcome is not what was hoped for: the free market guarantees the existence of an efficient equilibrium, but not its uniqueness or its stability. We could, for example, find ourselves faced with the passage from one equilibrium to another: two equilibria, but with different unemployment, one high and one low. If we wanted to increase employment, without stability, nothing could guarantee that the new balance would be maintained. What's more, empirical evidence often contradicts theory. Strictly speaking, mainstream axioms describe the behavior of the single agent, which is unrealistic at the micro-level and false at the meso-level, but could become plausible at the macro-level.

One wonders: how does a theory in which "anything is possible" (although without stability, any attempt to improve one's condition is useless), divorced

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from reality ("observing facts without the theory has become the main activity of economists," as Bergmann says, 2007, p. 2), and is axiomatic (like a religion) manage to resist, regardless? Inertia, mental laziness, convenience and collusion, perhaps. But even the Copernican system was able to supplant the Ptolemaic one after centuries. Or maybe because the message it conveys is one of tranquility: the market, just like Providence for Catholics, puts everything right. And so, the only option is to do nothing, change nothing: consumers and producers of goods, with the blessing of their lethargic consciousness, don't even contemplate the possibility of changing *economic laws*. That the latter, in fact, do not exist, we will see further on.

It would seem like a *curiosum* of the history of science. And it would have no practical consequences if economics didn't permeate our life. How? Let's suppose, for example, that the model advises us to make work more flexible in order to increase production and employment. To draw workers to physical capital, considering them only as suppliers of a service, or as goods-work, indiscriminately increasing the inhuman labour force: we'll produce more without costs, but to whom will we sell the product? To robots or to beasts of burden? And can anyone—"outside a lunatic asylum"—imagine an economic policy that always works, and for everyone, indiscriminately? Economic structure changes continuously because of innovations, interaction and learning: it evolves because economic agents are different from atoms.

The hope of *mainstream* economists was to show that equilibrium was also desirable and could not be improved by external interventions. Sadly, this is just wishful thinking. The dream world of orthodoxy is a world where "anything is possible," and so nothing is true: "the future which the dream shows us is not that which will occur, but that which we would like to occur," wrote Freud. It is as if dominant economic thought were trapped in seventeenth century physics and still unable to break free from this deadly embrace. The history of science in the future, looking back to the present day, will compare the situation of the current economic theory with that of astronomy in Galileo's time, when Ptolemaic orthodoxy was laboriously kept alive only thanks to torture. Gramsci reminds us that a crisis comes when "the old is dying and the new cannot be born; in this interregnum a great variety of morbid symptoms appear."

Let us now analyze the reasons for the crisis of a moribund but dominant model and see which among the new ones is the most promising.

2.1 Children and Fools Imagine Reality: And Also, Sometimes, Queens

"Why did nobody predict the financial crisis?" asked the Queen in the middle of a discussion on the Great Recession at the London School of Economics. The economists who were present didn't answer, both out of respect and out of embarrassment of not having an immediate and credible answer. This silence unsettled the more sensitive ones. Others waited, believing that the market would sooner or later enlighten them. After all, Max Planck was not all that wrong when he maintained that "a new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it!"

One of the more astute economists finally found an answer: no one foresaw the severity of the crisis and its explosion due to the lack of collective imagination of very intelligent people. Thus, we are led to wonder: what if they had been less intelligent? But no lack of imagination was apparent in the abundance of explanations regarding the cause of the identified crisis: the mistaken economic policies of the Bush II administration (debt explosion); abolition of the Glass-Steagall Act (The provisions of the 1933 US banking law limited commercial activities, the exchange of bank securities and shareholding between commercial banks and brokerage firms, but, in 1999, the Gramm-Leach-Bliley Act repealed the provisions that limit shareholding between banks and brokerage firms); the excessive confidence of the former Federal Reserve chairman, Alan Greenspan, in the efficiency of markets; excessively loose credit conditions for *subprime* loans; the financial ignorance of the borrowers; the greedy behavior of investment banks and their predatory lending during the swell of the real estate bubble; incorrect assessments of the relative risk to the boom and collapse of the shadow banking system (the intermediation outside of the banking system); the surge in commodity prices and energy; the increasingly unequal distribution of income; the role of economic forecasts (whether intentionally erroneous or not) of credit rating agencies; the global food crisis; global inflation. To conclude with more elaborate theories: the increase of financial expenses; balance sheet deterioration of banks-firms-households; the crisis as the optimal economic response to the new preferences of workers who prefer leisure over work; growing income inequality in favour of the rich, which diminished aggregate demand.

The real problem lies not only in the accuracy of the prediction so much as in the fact that the dominant economic theory does not contemplate a major crisis. In short, it seems to work only when everything goes well. Standard economic theory assumes that markets are always in equilibrium. According to this view, movements of prices and quantity are determined by reactions to external events. Economics would thus be in a perfect state of bliss, with full employment and productive and allocative efficiency markets. Were it not for external disturbances, economics would always be in the *best possible world*. And even if equilibrium is disturbed, the system always manages to come back home. From this perspective, a very strong variation must result from causes that are just as strong. We should expect a direct link of cause and effect between a given event and its consequences. If, as happened in Italy in 2009, the GDP decreases by almost 6 percentage points, there must be a cause that is just as strong. We saw another example of this in 2012, when the GDP went down by 2.5%. And a lesser one in 2014, with a fall of 0.5%.

This vision of economics is being deeply questioned, and a new perspective is emerging according to which markets, in certain situations, spontaneously evolve towards unstable situations despite the fact that every single person, company or bank acts in their own interest. As if *The Fable of the Bees* had returned in its dreamlike dimension: a fairy tale, in fact, and not a fierce condemnation of private vices behind public virtues. In this case, the triggering event becomes irrelevant, while the key point is to identify the elements of inherent instability.

What market fundamentalism assumes (not *shows*, but *assumes*, as if it were an axiom—actually, the third of GE) is that economics is in equilibrium. Why, then, is imagination so limited? The limit does not lie in the imagination of economists, but in the paradigm adopted, which is useful only to a comforting vision of harmony, of equilibrium. Almost as if all diseases were excluded by statute. This booklet argues that it is precisely because of this anomaly that economics is a discipline in great crisis. A scientific paradigm in crisis, incomplete and not verifiable, since axiomatic economics, which asserts that everything is possible, eludes scientific verification. It's like having a theory of gravity that establishes that bodies "fall to the ground," but they can also be suspended or shoot upwards, meaning that the theory does cast a few doubts. And also apprehension, if I consider that this is the economy that controls our lives, imposing fiscal discipline that produces misery for the impoverished and turns the world upside down, theorizing an expansionary fiscal contraction or a cascade economy in a *top-down* way and not, as would make sense, from the *bottom-up*, given that the propensity to consume (the share of income allocated for consumption) of the poor is just slightly higher than that of the rich. Or create occasional workers. Or save the banks by taxing us all.

On closer inspection, the economists' answer was not stupid. Indeed, a lot of imagination was required, seeing that the dominant economic model doesn't even consider crises, but only equilibrium. So, it's not surprising that, if you're an economist and are questioned about the crisis, you hope to be overcome by uncontrollable drowsiness, because you have nothing plausible to say.

The problem then is not the quantitative method in itself or which quantitative methods are used, but rather the particular theories on which they are based. Physics, for example, teems with cases of mathematically correct theories that are completely irrelevant because they're based on false assumptions: these theories lead to results disproved by experiments. And if an experiment disagrees with the theory, we don't conclude that this discredits the quantitative method, but, instead, we analyze the assumptions that underlie the model and identify the ones that aren't correct. And, of course, we change the model: what is important is the empirical relevance, a comparison with reality, rather than mathematical rigor. We should bear in mind that, while physics is concerned with "how" reality works, economists find it more important to ask "why," deriving everything from the initial axioms.

It will be difficult to exit this crisis using the same political economy tools that have supported it. It is not so much a question of when we will exit the crisis, but what it will be like once we're out of it. In other words, how to step out of the structural crisis, and hopefully out of the paradigm, and not simply out of the crisis as a contingent phenomenon? Maybe it's high time to rethink the toolbox.

The *mainstream* does use advanced techniques; it just uses the wrong ones. For example, modelling the entire economy as if it were a representative, or average, agent multiplied by the number of individuals present in the whole economic system. And asserting, perhaps, that this operation allows us to have sound micro-foundations to macroeconomics, that is, to explain aggregate economic evolution based on the behavior of a single agent. These micro-foundations can be refuted by the Sonnenschein-Mantel-Debreu (SMD) "theorem," which ascertains that it is impossible to univocally and unequivocally derive macroeconomic behavior from the behavior of individuals, in other words, that the macro is not the simple sum of individual behaviors. So, even if we assume that the single agent pursues its own personal interest, this doesn't mean that economics as a whole will emulate it and reach the same goal: after all, the sum of non-linear functions is not an aggregate function of their sum. The theorem demonstrates why neoclassical economics, despite its manifold declinations, is unable to produce a unique and stable equilibrium. This result is due to the presence of the wealth effect. When the price of a good varies, this has two effects. The product in question becomes more or less convenient than other products, and therefore its demand increases or decreases (substitution effect). On the other hand, the variation in price also affects the wealth of consumers, making them more or less wealthy, with repercussions on their demand (wealth effect). These two effects point in opposite directions, which means that more than one set of prices can balance all markets simultaneously, except in the case of a single agent and a single good. Hence, the name of the "anything is possible" theorem. Those who recognize the fragility of "general economic equilibrium" are mathematical economists, and the importance of the theorem does not escape them. All of the others, even though *ignorantia non est argumentum*, continue quite happily to use this model as if the objections raised by the SMD theorem were merely formal. The edifice was brought down, in the words of Alan Kirman (1989), "because of a palace revolution."

Axiomatic economic analysis is one of equilibrium, while we know from empirical evidence, and from research in the fields of science and mathematics, that complex systems (such as economics) are always in disequilibrium. Axiomaticists are still using nineteenth century mathematics to analyze complex systems, while the real sciences (such as physics or chemistry) are continually updating their methods.

2.2 Economy "Ad Usum Delphini," Even Though We're Hamsters

In the words of one of the leading *mainstream* theoreticians, Olivier J. Blanchard, former chief economist of the International Monetary Fund, the dominant *New Keynesian* DSGE model (*Dynamic Stochastic General Equilibrium Models*, or the new Keynesian economy based on dynamic and stochastic models of general economic equilibrium) is "simple, analytically convenient, and has largely replaced the IS-LM model as the basic model of fluctuations in graduate courses" (Blanchard 2009). Shortly after, he admits that the first two equations of the new model are patently false. In particular:

- the equation of aggregate demand, that is, the demand of goods and services of an economic system as a whole, over a certain period of time, ignores the existence of investments [Almost all of the pre-crisis DSGE models had no such equation. After the Great Recession, other epicycles (with banks, currency and financial markets) were added, to safeguard the theoretical framework that continues to suffer from the disarming consequences of the SMD theorem (the one that states that it is impossible to unequivocally derive macroeconomic behavior from individual behavior) and the ungovernability of reality, which persists in its refusal to conform to what the axiomatic theory prescribes];
- the same equation of aggregate demand is based on an intertemporal substitution effect in response to the interest rate, which is actually difficult to detect;
- the inflation equation eventually entails perfectly farsighted behavior of individuals or agents that appears at odds with the data.

These models—as described by Blanchard—were used, up until the Great Depression, by almost all Central Banks, Treasury Ministries and the IMF—the Washington Consensus "triad"—and are now all part of actual mainstream DSGE economics. Compared to the original Arrow-Debreu model, today's DSGEs are dynamic: instead of a fixed equilibrium point, an equilibrium path is studied, investigating the way in which the economy evolves over time, continually affected by external disturbances.

Not surprisingly, the transition from static to dynamic doesn't solve any of the problems highlighted by the SMD theorem: if, with the static approach, equilibrium points are too numerous and unstable, with the dynamic approach, the same occurs for the paths. All are unstable, except for a very special one: in mathematics, it's called a *saddle point*. This is because the time value (the dynamics) breaks down and collapses right from the start, when the future has already been decided by agents who know—directly or through learning—everything, the future, therefore, included. As in general equilibrium models, DSGE models attempt to describe the behavior of the economy as a whole by analyzing the interaction of multiple agents in the market. And just like in general equilibrium models, the references and constraints of agents must be defined so that they are able to achieve maximum results with minimum effort. In brief, the DSGE model strives to represent an economy made up of agents, such as households and firms, as economic paradigms, as if they were *average*, so that, for example, by analyzing the buying behavior of an average household, one can plausibly obtain the consumption expenditure of the aggregate. An average family, an economist would say, maximizes a utility function subject to a budget constraint. Namely: households decide how much to consume, save and work depending on the solution of how to reach their maximum *expected utility*, consistent with their budget. This means that individual agents (i.e., households and firms) must necessarily also have expectations about the expectations of all other agents (i.e., all other households and all other firms). According to mainstream tradition, such expectations are rational, that is, it is assumed that these agents have a thorough knowledge of the real economic model, and are therefore able to evaluate the consequences of *shock* (which is what happens, for example, if oil prices suddenly collapse). That being said, it's not surprising that N. Gregory Mankiw (2006), considered one of the founders of the *New Keynesian* DSGE, recently stated that "these models have had little impact on macroeconomic practice."

In light of all of this, Blanchard's conclusion is that the state of macroeconomics is good. Imagine if it were bad.

Thanks to the SMD theorem, we can argue that any model based on optimizing behavior of the Walrasian kind (as described by Leon Walras, an idea that I'll discuss in a moment) is built on sand, as there exists no condition to guarantee the uniqueness and stability of the equilibrium, let alone the dynamic path.

The roots of this impasse go back a long way. When society begins to transform itself as a result of the technological revolution, the figure of a new social scientist emerges: the economist. Who isn't really a scientist. Besides not having the tools—something that is entirely understandable, seeing as the discipline is new—he lacks empirical tests that would make the hypotheses falsifiable. Among the possible alternative paths, taken by other disciplines, from biology to sociology, economics chooses to adopt the model of the queen of sciences: physics. But, as we will see further on, only the mathematical tool was taken from physics, and not that of hypothesis verification (giving rise to axiomatic deviation and the non-falsifiability of these hypotheses).

The causes of the current situation go back to the mid-eighteenth century, when some Western economies were transformed by technological progress, leading to the industrial revolution. This happened a century after Newton and the total upheaval in physics: from the small apple to huge planets, all objects seemed to obey the simple law of gravity. So, it was natural for a new kind of social scientist, the economist, to borrow the language (the form) of the most successful science, physics. From that moment on, the mechanical physics of the seventeenth century has governed economics. So, if, as Keynes wrote in the final chapter of his *General Theory*, politicians were slaves to outdated economic theories, in turn, the same economists are still slaves to Newtonian physics. In 1803, Louis Poinsot, a French physicist, published a highly successful book, *Eléments de Statique*, destined to have practical and social influences well beyond those the author had ever imagined. This influence is mainly due to the work of Léon Walras, who took Poinsot's system of simultaneous and interdependent equations as the basis for his economic theory. Walras assumed that price adjustments should be made by an external agent. Although not explicitly introduced by Walras, the agent was later identified as an *auctioneer*, a device that allows for the reduction of economic agents to atoms, devoid of any learning ability or strategic behavior, since information and markets are assumed to be complete (moreover, one should keep in mind that the incorporation of new information makes sense *if* there is no radical uncertainty, if the future is similar to the past). We are in the 1870s, on the eve of the decline of classical mechanics and reductionism. The physics of interacting microelements is yet to come, and economics remains locked in the Walrasian "tightrope" viewpoint. From that point on, the addition of axiomatization and non-falsifiability has led to the degeneration of the research paradigm of standard economic theory (Lakatos 1970).

The classical, Newtonian, method is no longer adequate to study the constituents of matter, although it is still suitable for analyzing the kinematics of macroscopic bodies. This method in physics is surpassed when the problem of studying the *micro* world arises: a new problem poses the need to "invent" a new method. And so, the physicists did. For their part, economists haven't changed either the problems or the method: the same old paraphernalia can remain, just so long as additions are linear and there is no heterogeneity or interaction. So, for them, *macro* is nothing more than the sum of *micro* elements. Things get complicated, however, because heterogeneity and interaction, in fact, do exist, and therefore externality has to be considered, namely, the fact that what one agent does produces effects on another agent (though not necessarily on all of the others). Now that we want to analyze the economic behavior of the individual, we claim to do so by continuing to use the classical physics approach, suitable only for macroscopic bodies, as the physicists themselves agree. The factors that determine the emergency are heterogeneity *and* non-linear interactions. If—and only if—a system is linear, the proportionality between cause and effect is preserved and the analytical separation of the former is possible. If the independent variables are separable, the ceteris paribus analysis is possible. In the presence of non-linearity, in fact, small idiosyncratic shocks are sufficient—they spread rapidly through domino effects—to make future configurations unpredictable. Indeed, as we know, interactions—and non-linearities in general—show a marked dependence on initial conditions. Path dependence implies that the particular way in which events have developed over time influences future results. The *mainstream* economist can analyze macroeconomics using the microeconomic method without changing the mathematical tools only by assuming that all agents are equal. This does not prevent, as we have seen, the SMD theorem from demolishing the axiomatic construction.

The Wealth of Nations (1776) by Adam Smith originated as a book on moral sciences (and the concept of the invisible hand, the parable that Smith used to explain the unpredictability of nature, particularly lightning, thanks to the *invisible hand* of Jupiter, appears for the first time in his *History of Astronomy*, from about 1750; it is only in the *Theory of moral sentiments* of 1759 that it is used in reference to the market and, as such, cited there, albeit rarely ("It is to no purpose, that the proud and unfeeling landlord views his extensive fields, and without a thought for the wants of his brethren, in imagination consumes himself the whole harvest that grows upon them. The homely and vulgar proverb, that the eye is larger than the belly, never was more fully verified than with regard to him. The capacity of his stomach bears no proportion to the immensity of his desires, and will receive no more than that of the meanest peasant. The rest he is obliged to distribute among those, who prepare, in the nicest manner, that little which he himself makes use of, among those who fit up the palace in which this little is to be consumed, among those who provide and keep in order all the different baubles and trinkets, which are employed in the economy of greatness; all of whom thus derive from his luxury and caprice, that share of the necessaries of life, which they would in vain have expected from his humanity or his justice. The produce of the soil maintains at all times nearly that number of inhabitants which it is capable of maintaining. The rich only select from the heap what is most precious and agreeable. They consume little more than the poor, and in spite of their natural selfishness and rapacity, though they mean only their own convenience, though the sole end which they propose from the labours of all the thousands whom they employ, be the gratification of their own vain and insatiable desires, they divide with the poor the produce of all their improvements. They are led by an invisible hand to make nearly the same distribution of the necessities of life, which would have been made, had the earth been divided into equal portions among all its inhabitants, and thus without intending it, without knowing it, advance the interest of the society, and afford means to the multiplication of the species. When Providence divided the earth among a few lordly masters, it neither forgot nor abandoned those who seemed to have been left out in the partition"); see Roncaglia 2005).

About a century later, in 1870, mathematization erupts onto the scene, supplants political economy, classical political economy, and transforms it into economics, a pseudoscience. Completely legitimate, but compared to physics, it is missing a leg, that of falsifiability. All conclusions are safe from being proved wrong, and to date, pages and pages of the most important economic journals are dedicated to a puzzle, that is, to how and why reality refuses to obey the improbable *mainstream* model. We could argue, a little paradoxically, that when reality is determined not to obey the requirements of the dominant model, axiomatic economics denies reality. Like political economy, economics had the mission of improving society. With the victory of economics, the outcome was exactly the opposite. Economics has become a system subject to the laws of nature, and therefore neither changeable nor improvable, except by removing everything that distances it from perfect markets. From this, we get the myth of flexibility, or the impoverishment of a number of generations.

2.3 Sediments of History and Not Falsifiability

Neoclassical economics deals with analyzing optimal resource allocation. This means that, given the natural resources, the population, the available capital and technology, it is up to the market, or a benevolent dictator, to establish a pricing system that ensures the best possible situation, namely a situation in which the well-being of a person cannot be improved except at someone else's expense. Economists speak of "Pareto optimality," which takes no account of how income is distributed (and when they talk of distribution, they use an inadequate measure: the Gini index, and not Zanardi's one, see Clementi et al. 2018).

In the static approach that searches for the equilibrium point, this "optimal" situation can be usefully represented by a line, which goes from a starting point (where consumer preferences and production technology and endowments are given) to an end point, at which consumers and producers reach the maximum possible level of their own well-being. Substantially nothing changes in the dynamic case, when the optimal point is replaced by a path, also optimal and balanced. And all of this thanks to the *invisible hand* of the market, which makes the countless tastes and preferences of the economic agents compatible, producing the best possible result for everyone. Unfortunately, things are not exactly like this: the SMD theorem has shown that this result is wishful thinking, and not a theorem. First of all, because the end point is not just one point, but rather infinite points. This means that the same starting situation can produce results that are different, and therefore not falsifiable. Kirman (1989) reminds us that axiomatic theory is an empty one in the sense that it is a theory incapable of producing empirically falsifiable propositions. Falsifiability, as mentioned above, is the criterion formulated by Karl Popper to identify the scientific nature of a theory. Popper (1935) shows that verification is not sufficient when you want to guarantee the validity of a scientific theory. As Bertrand Russell claims, the turkey that formulates the theory as to "how good the farmer is who feeds me and fattens me up like a piglet" is destined to be contradicted on the day of its slaughter. That theory, verified for months, collapses in an instant.

We should stop treating economics as a science, because it is nothing of the sort. A proper science involves testing a hypothesis against the available evidence. If the evidence doesn't support the theory, a physicist or a biologist will discard the theory and try to come up with one that does work empirically. The scientific nature of a theory is determined by its being falsifiable, otherwise it is impossible to check its validity regarding the reality it presumes to describe. Also because if a hypothesis can't be subjected to a control that can falsify it, then whoever proposed it can advance, starting from the hypothesis, all sorts of other concepts without the possibility of contradiction. The initial hypothesis can lead to any kind of conclusion without it being refuted. So, we can read about contractionary fiscal policies with expansionary effects, or labour market liberalization that increases employment, or flat tax rates that don't produce any deficit.

To the question as to whether we can hope for global uniqueness and stability relying on individual behavior, the answer is a categorical no. It just isn't possible to base the aggregate behavior (i.e., the sum of individual behaviors) of an economy on that of individual agents, because it's exactly like thinking you can admire Michelangelo's *Judgement* merely by contemplating the lapis lazuli and morellone pigments. Aggregate demand can't be derived logically from individual activities, because it can be created only by taking into account direct interaction, i.e., that not mediated by the market, among individuals. Instead, effects originating from imitation, fashions and domino effects are excluded from the Walrasian theory, in which an omniscient fictitious agent (the auctioneer) coordinates the economy. But instead of admitting the failure of the axiomatic theory (and its ideological core), an innovation was proposed, always in the same direction: to represent society using a representative agent (i.e., a statistical construction that is the virtual image of an average of economic agents).

The equilibrium theory therefore fails in the actual formulation of the laws of the way in which capitalism works, making the economic policy prescriptions that *mainstreamers* inflict upon us on an almost daily basis worthless.

In the hearts of axiomaticists, equilibrium should be:

1. a state that an economy spontaneously tends to achieve and maintain in the absence of external disturbances;

2. a state in which each economic agent is in the best possible position, given its financial constraints and preferences;
3. a coherent and workable trading system, in the sense that everyone can exchange what they have planned to exchange, i.e., supply and demand are equal in all markets.

But it remains a dream representing a *desire for happiness*, which, on awakening, vanishes. And the awakening produced by the SMD theorem, as we have seen, was abrupt. Fortunately, some did awaken, as reflected in the words of Werner Hildebrand (1994, p. 169): "Until the SMD theorem, I was under the naive illusion that microfoundations of the general equilibrium model, which I had so much admired, made it possible to prove that such a model and equilibrium were logically compatible. This illusion, but perhaps I should say this hope, was destroyed forever." If, as the SMD theorem states, apart from improbable conditions, that is to say, when you have to deal with reality, the market demand curve can have any shape. (AU: This appears to be an incomplete sentence. In the 'if/then' construct of the sentence, there is no 'then.') In order to obtain a demand curve showing that, when the price decreases, the quantity increases, you have to purposely excogitate an implausible condition: income increases and you continue to buy the same things, only a little more. Obviously, this is plausible only if there is just one person and one good on the market. Taking mathematics seriously, we can conclude that the aggregate demand and supply curves can't logically derive from individual behavior, because interaction between individuals has to be taken into account. The result is clear. And only fideistic motivations can keep alive that which once was so.

In the world of general equilibrium, everything is real, and there is no currency that is not a medium of exchange between two goods. It has been widely recognized since Debreu (1959) that integrating money into the theory of value represented by the GE model is, at best, problematic. Given that, in a GE model, actual transactions take place only after a price vector coordinating all trading plans has been freely found, money can be consistently introduced into the picture only if the logical keystone of the absence of transaction costs is abandoned. By the same token, since credit makes sense only if agents can sign contracts in which one side promises future delivery of goods or services to the other side, in equilibrium, markets for debt are meaningless, both information conditions and information processing requirements are not properly defined, and bankruptcy can be safely ignored. The very absence of money and credit is a consequence of the fact that, in GE, there is complete information and rationality, i.e., there is no time. The only role assigned to time in a GE model is, in fact, that of dating commodities. Products, technologies and preferences are exogenously given and fixed from the outset. The convenient implication of banning out-of-equilibrium transactions is simply that of getting rid of any disturbing influence of intermediary modifications of endowments—and therefore of individual excess demands—on the final equilibrium outcome.

It begins from the labour market, where demand and supply come face to face. These curves meet at a point that determines full employment and the equilibrium wage. The situation is *in equilibrium* in the sense that all of those who want to work find employment. Involuntary unemployment is frictional, i.e., due to rigidity or limited information. Currency enters the scene later on, to regulate the price level (i.e., inflation), because the real income is already determined by the number of people employed. So, inflation is always a monetary phenomenon, which only depends on how much money is printed (Friedman and Schwartz 1963). It is therefore not surprising to observe that inflation is not generated by new banknotes thrown from the helicopter of the Central Bank, as is often assumed by the axiomaticists.

We have seen that the basic model starts with households (with certain preferences in the purchase of goods and in the distribution of time between work and leisure) and firms (with available technology and natural resources, which, being infinite, *sic*, impose no constraints). And the banks? We'll see further on. In a successive epicycle, following the teachings of Ptolemaic astronomers. But, as should be obvious, this creates some problems. A bit like the movement of planets in the Ptolemaic model. In fact, adding currency or credit at a later date does not affect the results of the model at all: relative prices are determined only by the real part, and currency is not involved. This means relegating finance to a secondary role in spite of the increasingly invasive phenomenon of *financialization* of the economy. Currency, however, promotes trade, and this is an important detail.

Let's go back to general equilibrium, following a classical description (Ingrao and Israel 1993): it occurs when each single player is in equilibrium. Equilibrium has a central role in economic theory, because of the very concept of economic phenomena, according to which agents' behavior *naturally* leads an economy towards a condition of compatibility, and thus equilibrium, of the different goals they pursue. In contrast to the approach of utility maximization of the axiomatic theory, experiments carried out in laboratories demonstrate that choices are never optimal (Colasante 2017). However, there is a *caveat*: real agents, that is, individuals, endowed with limited knowledge and rationality, usually choose well, provided they have a sufficiently long period of time in which to learn. After a while, the application of good "rules of thumb" produces results close to utility maximization. In other words, at an aggregate level, the rational choice theory comes close to the goal by following much simpler empirical rules acquired from what has been learnt. If collective rationality can emerge from simple "rules of thumb," then there is no need to cling to far-fetched assumptions and move in hyper-rational environments in order to be rational and efficient: it is sufficient that agents interact and learn.

Compatibility of goals, which leads to market equilibrium, is characterized by being optimal and efficient: agents prefer a state of equilibrium rather than other states, because, in it, they can make their favorite choices, given their individual constraints and preferences. On closer inspection, this concept is an antiquated remnant of the Newtonian theory of physics, and it presents some problems. Basically, it assumes that all agents are identical and are all Robinson Crusoes who never bump into a Friday, not even in the market. They meet, and don't speak. They ignore one another because they have nothing to say to each other: they find each other totally uninteresting because they're identical, too identical to whet even a spark of curiosity.

But the scenario changes when Friday appears. Exchange becomes direct, interaction subverts the equilibria, and what occurs depends on the exchanges themselves and on financial conditions, with heterogeneity and expectations becoming endogenous because of interaction. And the *mainstream* model that attempts to efficiently allocate everything a priori through the market is revealed as empty, incoherent and contradictory. At best, it is insufficient to understand what already exists. The original sin is that it has to assume specific initial conditions in order to reach *one* final distribution. But it doesn't reach it, nor will it ever, no matter how many epicycles are added. Unlike the Catholic religion, no purification is possible here: an incorrect proposition will never become a correct theorem.

We should also consider that the process is independent of time and of the accumulation of goods, not to mention innovation, i.e., the *creator* of capitalism, which generates an oxymoron alongside the unchanging data-allocation process. The trick used to make the (static) AD model dynamic is to extend time indefinitely, with an axiom that is as far-fetched as it is essential: the perfect prediction, or the completeness of the markets. These problems were already clearly outlined at the dawn of mathematical economics, in a famous letter from Poincaré to Walras, in which the following passage is found: "I thought that at the beginning of every mathematical speculation there are hypotheses and that, for this speculation to be fruitful, it is necessary (as in applications of Physics for that matter), to account for these hypotheses. For example, in Mechanics one often neglects friction and assumes the bodies to be infinitely smooth. You regard men as infinitely self-seeking and infinitely clairvoyant. The first hypothesis may perhaps be admitted as a first approximation, but the second hypothesis calls, perhaps, for some reservation" (Jaffé 1965).

The problem highlighted by Poincaré stems from Walras' attempt to introduce the hypothesis of perfect rationality, with the sole aim of obtaining formal results. In fact, in mainstream models, in which it is assumed that agents make decisions in order to maximize expected utility, some hypotheses about the probability distribution of possible future states of the economy are needed. The hypothesis of *homo oeconomicus*, able to solve problems of optimization and capable of predicting future developments of the economy, seeing as he/she knows its laws—and therefore the model, unique and eternal, in other words *natural*—just like a physicist knows the laws of nature, is in contrast with the studies in which it is shown that the psychological component and limited skills and information play a fundamental role in the behavior of economic agents.

Taking time into consideration certainly complicates the concept of equilibrium, because it introduces a variability that the general equilibrium model usually shuns. Coherence and conformity of agents' choices don't only affect present choices, but also future ones, through their *expectations*. If we state that economic agents make choices and carry out their activities in the course of successive periods of time, then we must explicitly take into account the fact that trading plans, made in the present to be immediately implemented, also apply to choices and projects that are based on expectations about future events, which agents can review and correct according to the confirmation they receive from facts or from prediction errors. The choice of optimal plans is an intertemporal choice, which invests a succession of periods and implies a training process and verification of expectations. This happens to every individual and every household when they do their weekly shopping but find it is not sufficient, program a holiday but then have to give up on a leg of the journey, or stipulate a mortgage and then surrogate it.

Regarding dynamics, we can't even disregard the accumulation of capital. The many attempts that have been made only emphasize, if we want to be unkind, the radical inadequacy of the Walrasian model, which is unable to coherently account for an equilibrium with long-term accumulation of capital because it doesn't guarantee the condition of uniformity of the rate of profits (i.e., the ratio between annual surplus-value and invested capital is always the same) or, in a more benign interpretation, that this modification changes the nature of equilibrium into a temporary equilibrium model, a succession of equilibrium states over time.

Whatever our inclination, it has to be acknowledged that, where dynamics is concerned, the general equilibrium theory epitomizes the impossibility of taking into account historical time and of reconciling these innovations with price adjustment. Thus, we find ourselves absurdly hoping that a static model, transformed into a dynamic one, could almost miraculously function.

Furthermore, all forms of learning are excluded from the model: the agents already know everything or, just like professors of axiomatic economy, think they do. After all, if atoms were able to think, we would come out of the naturalness of physics and recognize that economics cannot be a hard science. Information itself must be considered as a datum, which, however, is not generated a priori by the system.

In short, the traditional model explains everything, except innovation, the real novelty of capitalism. We can argue, then, that the growth that followed the technological leap of the eighteenth century cannot be understood with the tools of orthodox economics. Of course, you can add heterogeneity to the model. Or even network. Provided they do not change endogenously and don't evolve over time. Let them be epicycles, and leave it there.

To summarize, in the first general equilibrium theory, we can already identify the core of all of the later versions of the theory in a market of *perfect competition* in which rational agents are so small as not to affect the prices and in which the compatibility of independent decisions made by agents is ensured by the prices themselves. In this way, it is hoped that the following can be obtained:

– goal coherence and conformity, within the limits of technology and resources, which establish the equilibrium;
– comparability among different states of economic equilibrium if they change constraints or preferences, leading to an optimal equilibrium;
– global stability, because the *invisible hand* price mechanism leads the market towards equilibrium.

In spite of the lack of concreteness and realistic vision of the theory, logical contradictions have been demonstrated. The literature has pointed out several logical inconsistencies in the mainstream approach. Davis (2006) identifies three impossibility results that determine the breakdown of the mainstream, i.e., neoclassical, economics:

1. Arrow's 1951 theorem showing that neoclassical theory is unable to explain social choice (Arrow 1963);
2. The Cambridge capital debate pointing out that mainstream theory is contradictory with respect to the concept of aggregate capital (Cohen and Harcourt 2003); and
3. The Sonnenschein (1972), Mantel (1974), Debreu (1974) results showing that the standard comparative static reasoning is inapplicable in general equilibrium models, i.e., that GE is neither unique nor locally stable under general conditions.

The SMD theorem, as we have said, regarding the presumed uniqueness of equilibrium and its even more unlikely global stability, has devastating consequences. The consequences of this failure of the entire general equilibrium research program can be ignored... of course. Especially if you want economics to become a "science" like that of soothsayers or readers of coffee grounds.

2.4 Applying Newton's Theory to the Movement of Electrons (and Attributing the Failure to the Imperfection of Reality)

The statistical physics approach profoundly affected the physical sciences of the late nineteenth century, highlighting the difference between micro and macro. Without formally adhering to the new tools of physics, Keynes, in the mid-thirties of the last century, partly in response to the Great Depression, founds macroeconomics. However, in the passage from macroeconomics to axiomatic economics, the concept of macros is lost, and aggregation is simply a formal procedure that allows us to summarize the market results of individual entities in terms of economics, like a drawing reproduced on a larger scale thanks to the pantograph. This means that there is no difference between micro and macro: the dynamics of the *whole* are none other than the sum of the dynamics of its parts (in physical terms, it's as if the motion of a planet can be described by the individual dynamics of each constituting atom).

This approach does not take into account the fact that there may be bi-directional interdependencies between agents and the overall properties of the system: agents who interact produce "emergent phenomena" (which are structures that have become complex, but derive from simple individual rules that the system didn't hypothesize or predict, "promoted" by interaction itself), which is why the correct aggregation procedure is not the summing up of individual behaviors. In other words, what's good for the individual isn't necessarily good for the community, like tax evasion.

There's no need to resort to hyper-sophisticated and axiomatic assumptions about the behavior of individuals in order to obtain examples of aggregate-rational outcomes. Take the case of the fish market in Ancona. In a "Dutch" auction (the price starts from an arbitrary level chosen by the auctioneer and is lowered until one of the buyers is willing to buy at the going price), there are usually thirty to forty vendors (fish sellers) and one hundred and seventy to two hundred buyers (shop and restaurant owners). Let's suppose that the bids of the buyers are vertical lines that reach a reserve price, i.e., a price over which you're not willing to buy: for example, 50 kilos of sole at the maximum price of 20 euros per kilo. The heterogeneity of buyers ensures that you will have many vertical applications. When we aggregate them, a market demand curve emerges with a negative slope, since there are few bids when prices are high and then gradually more when prices fall. We could say that we get a rational aggregate relationship from unsophisticated individual behavior. (The study of price formation in the Ancona fish market was accompanied by an anonymous questionnaire designed to understand buyers' behavior. One reply in particular caught my attention. The question was: "Why do you buy a certain amount of fish, say at 20 euro per kilo one day, and the same amount the following day at 40 euro?" The answer was interesting: "Because customers are a bit stupid." Intrigued, I tried to determine the person to whom ID number 169 of the questionnaire corresponded. It was the fishmonger I always go to. Offended, I changed fish shops. But the new seller behaved in the exact same way. Diplomatic conclusion: the consumer is a weak player in the market. Plausible conclusion: I can't be that smart.)

Economics and cosmology are surprisingly similar. Both are very dogmatic disciplines, because, despite the amount of data available, they are dominated by a priori assumptions, and the data used often depends on how they conform to these concepts. Indeed, axiomatic economics behaves exactly like this, and is therefore a discipline that takes inspiration from a science and its tools, designed to investigate what is very big. But economics has no natural laws, and the transposition of *sic et simpliciter* from physics into economics produces monsters. It produces them both because it attempts to deal with macro and micro using the same tools, as we have seen, and because it is under the illusion that analytical rigor can replace falsifiability. It wants us to believe that only a solution that can be studied with pencil and paper is rigorous. If such reasoning were applied to physics, we would assume that there is only one atom in nature: hydrogen, as it is the only one that can be solved analytically.

The dominant economic model assumes, then, that agents behave rationally and do not interact with each other except through the market, that is, through prices. In so doing, the market takes on the role of coordinator, setting the prices that equilibrate supply and demand. There is a reason for assuming that agents are individuals with a fundamental rationality. And not only because it reflects the falsifiability mentioned above, as there are many ways of behaving irrationally and only one way of being rational, but also because it is the only way to identify physical atoms and agents ("Imagine how hard physics would be if electrons could think," acknowledged the Nobel prize for physics Murray Gell-Mann, that is, if they used behavior strategies). Hypothesizing the absence of thought, learning and strategy, the physics method can be applied to economics without too much trouble.

But there is more. The vices of individuals, still in the dominant model, are transformed into virtues for the community. So, our daily bread depends more on the baker's desire to make profits than on his own good will. The market turns vices into virtues. But not always. It often appears shortsighted and unable to coordinate the system, as the Great Recession and Global Warming demonstrate.

Statistical physics has taught us that the macro emerges from the behavior of the micro. And that applying laws of the macro world to the micro world is, at best, misleading. Just like those who want to apply Newton's laws of motion to the dynamics of electrons, so economists who want to transform this reckless choice can only create harm to others and to themselves, as stated in the third law of human stupidity of Carlo M. Cipolla (1986): "A stupid person is a person who causes losses to another person or to a group of persons while himself deriving no gain and even possibly incurring losses." For example, as absurd as it may seem, one might think that, in the presence of unemployment, a wage reduction could produce benefits, forgetting that a reduction in income results in reduction in aggregate demand. And therefore fewer jobs. In spite of the flexibility of labour. If consumption depends on permanent income, i.e., a stable source of income, job insecurity kills consumption.

In economics, the mainstream model assumes (Woodford 2009) the existence of perfect rationality and limited information of agents in a general equilibrium [Information limitations or the absence of complete markets (for each commodity and until the end of time) are still being investigated, provided that the usual allocative scheme is maintained: given the initial endowments, it is analyzed how the market, through prices, distributes these endowments among agents. Also, in this case, the theorem of "anything is possible" is applied]. The fact that almost all data contradict the assumptions of the model is considered a minor problem compared to the advantage, which results from the fact that these assumptions can be treated mathematically and make it possible to derive analytical closed forms. The risk estimate based on this method has contributed to leading us to the financial disaster of recent years. Mathematical tractability cannot be the ultimate gatekeeper of science when it comes to modelling real-world systems. Or rather, it can be, but without taking it out on reality if the latter persists in not wanting to obey the precepts of the theory. As if expressing thought in mathematical terms would endow it with both rigour and realism. It is clear, however, that nonsense expressed as theorems doesn't make it true, but rather merely formalizes the nonsense.

The most emblematic story, for me, is that of Long-Term Capital Management (LTCM), a speculative mutual fund investment: a hedge fund. The term hedge refers to hedging and protection strategies used to reduce the volatility of portfolios, thus lowering market risk. Hedge funds are considered a hazard for the real economy, as they can accentuate the dangers of speculative bubbles and create trading disruptions. This is true of operators who are not adequately prepared, as was certainly the case with the founders of LTCM, Robert Merton and Myron Scholes, who won the Nobel Prize in Economics in 1997 for launching the era of *derivative contracts* in the stock market and contributed to the *control and surveillance of institutions and financial markets*. Initially, the success of the fund was enormous, with returns of around 40% on an annual basis, but in 1998, due to the Russian crisis and to the greater leverage assumed by the LTCM managers, the latter collapsed, and bankruptcy was avoided only with the intervention of the Federal Reserve. The theory on which the fund is based unfortunately forgot about the imitation effect (i.e., direct interaction among agents), did not distinguish (for analytical convenience) good phases from bad ones, and was based on "normality" in risk [The probability of Wall Street losing 8% of its value in 1 day (something that happened 48 times in the twentieth century) is slightly less than 0.1%. Sometimes, modelling choices depend on analytical convenience rather than on reality. This, for example, happens due to uncertainty—and not risk. See Robert Hillman on "Why investors need agent based models": http://neuronadvisers.com/Documents/Why%20Investors%20need%20agent%20based%20models].

2.5 Economics Is a Science, UFOs Are Spying on Us and Cats Bark

The dominant economic model, as already mentioned, is an imitation of physics, both in appearance and epistemology. This is because the contemporary economic paradigm is based on a formal theory of general equilibrium, with clearly articulated axioms, mathematical models for applications, systematic data collection and statistical analysis for empirical evidence. However, even though it outwardly resembles physics, and despite being allegedly equipped with numerous "laws," economics is not a science [For more, see Hicks (1983)]. Science can be defined as a set of assumptions obtained through the scientific method, which consists of iterative applications of deductive and inductive methods to achieve consistency between theory and observation. Most economic knowledge, however, has not been obtained from the application of the theoretical-experimental method. A stable theory, i.e., one coherent with observations, does not seem to exist in economics. And we wonder if it ever will. Are there, one is tempted to ask, economic laws?

In a letter to Maffeo Pantaleoni, Pareto writes about a fellow economist of the German Historical School, who, after having railed all morning at a conference against those who upheld the existence of laws in economics, asked him where he could find a good restaurant with moderate prices. Buying the same product at the lowest price is a constant, almost a law—Pareto claims—which can have two different explanations: *utility*, according to economic orthodoxy; *entropy*, according to physics. When one buys a product, as good as another—but cheaper, one still has energy to continue buying other goods. In order to move on to a higher state of entropy, each actor in the market has a preferred strategy. If circumstances change, perhaps as a result of the action of other actors, the strategy can be reconsidered to optimize the consumption of free energy. Therefore, it is impossible to predict, in detail, the growth and decline of economics a priori: the energy density of economics is not constant, and a decision made by each actor influences future decisions of all other actors.

The second law of thermodynamics [In a closed system, like the Earth, disorder (*entropy*) increases continuously until it reaches an equilibrium. In the seventies, Nicholas Georgescu-Roegen (2003) introduced this principle in economics (*bioeconomics*). The *time arrow* breaks the circularity of the *mainstream* view and considers that any economic process that produces material goods today diminishes the future possibility of producing other goods, because matter degrades in the economic process. If released into the environment, renewable matter can be reused in the economic cycle only to a much lesser extent, and at a higher expenditure of energy. Matter and energy, then, enter the economic process with a relatively low degree of entropy and leave as high entropy: this will stop growing once equilibrium is reached, i.e., when resources become completely depleted (Prigogine and Stengers 1979; Giacobello 2012)] encourages those activities that make free energy decrease in the quickest possible way. This leads to productivity growth and the search for new energy sources. But the same law reveals that it is impossible to determine what the best path of energy use will be, because the path that is selected influences the choice of future operations.

Economic laws are, in fact, assumptions, and assumptions often seem to contradict facts. Or, at best, they are good for some periods but not for others. The aforementioned Alfred Marshall, who believed in the quantity theory of money, claimed that, at certain periods (for example, in times of war), that theory was not valid. As if war suspended the law of gravity. The anomaly lies in the fact that the nature of economic laws is different, because its agents, unlike atoms, learn from experience. Discovering a "law"—from whose application one can make a profit—ends up destroying the source of profits, because, when the information differentials between the agents disappear, i.e., when agents *learn*, there will not be a snowball's chance in hell that profits will be made[?]. (Identification of a clear cause-effect relationship is not an easy operation, especially in social sciences. Iosif Vissarionovich Dzhugashvili, yet to become Stalin, asked, in vain, for a job as a night porter in a hotel in Ancona: how legitimate is it to attribute, for example, Stalin's gulag to the refusal of Paolo Pallotta, the doorman of the Dorico Hotel? He refused to offer Stalin the job because he found the boy too shy.)

But the main reason why economics is not a science is the lack of interaction between the theoretical level and the empirical one, due to the fact that, in economics, there are no repeatable experiments: here, the two levels are rarely intersected to create real scientific knowledge. Unfortunately, stylized observations and statistical analysis have discredited some of the basic assumptions of the formal theory. And scientific falsification has not produced a significant revision of the theory, perhaps to protect the *status quo* (Blaug 1998).

Empirical research in econometric studies has widely used economic data to develop more advanced methods of mathematical statistics, without contributing much to the substance of economic theory: the creation of a scientific illusion of empirical macroeconomics (Summers 1991). Econometrics seemed to possess that method that makes it possible to discover laws in economics, very similar to the analysis of observational astronomy data. Unfortunately, it is not so, because the already mentioned "anything is possible" theory also applies in this case, and what is being tested is, in reality, the set of assumptions (normality of errors, linear relations, representative agent).

Despite having all of the essentials of a *soft* science, economics is *not* a science, because, although economic theory and empirical data do exist, they do so in parallel: they don't intersect. As Kaldor summarized (1972, p. 1239, footnote 1), "in economics, observations which contradict the basic hypothesis of prevailing theory are generally ignored: the 'theorist' and 'empiricist' operate in two isolated compartments and the challenge of anomalous observations is ignored by the theorist as something that could be taken into account in the stage of 'second approximation' without affecting the basic hypothesis."

Reality is even worse: the dominant model is not even able to be empirically validated. Resistant to falsification, its axioms challenge evidence, and often also approach the ridiculous. Verifiability of axioms in economics should be a mandatory methodological choice, almost a necessity if it is intended to be useful in the real world.

Economics must therefore cease to be treated like a scientific theory or defended as if it were a religion. For economic theories to be really *useful,* economists must be prepared, if necessary, to modify or abandon them, on the basis of observations. To systematically apply the scientific method, what economics needs is a scientific revolution that is capable of linking internal and external consistency within the boundaries of a social science that has many regularities, but few laws.

The reason why this revolution is more urgent than others is that economics deeply affects our lives: it dictates the times of work-rest-fun, and it frees us from mere survival, but it has reduced us to the role of hamsters. This is a big difference in regard to, for example, cosmology: whether space is homogeneous or fractal, whether the universe accelerates or not, this doesn't directly affect human existence. Instead, our lives depend on rules of economic policy derived from a mental model. In short, an incompetent cosmologist will, at most, ruin their family's wealth, but a bad economist who is taken seriously can ruin entire countries with their phony claims. Finding an analytical solution can reinforce the model, but it is in no way decisive concerning the virtue or not of the model.

To sum up the problem, in economics, the mainstream model assumes—with a lot of different epicycles—the existence of heterogeneous non-interacting agents, perfectly rational in an ergodic environment with incomplete information of agents in a situation of general equilibrium. The fact that almost every datum contradicts the preliminary hypothesis is considered a minor problem, compared to the advantage of the fact that these assumptions can be treated mathematically and make it possible to derive analytically closed forms. Which are useless in the real world. Unless you want to make economics a science, which studies only the aforementioned hydrogen atom (the only one analytically solved) arguing that it's the only existing agent in nature.

There are alternative systems, which, although not yet completed and structured, provide a more promising research strategy that can offer insights as to what has happened in this and other crises. The following chapter illustrates the research paradigm.

Chapter 3
A Rather Unusual History

As we have seen, the marginal revolution of Jevons, Menger and Walras is based on Newton's physics, that is, on mechanistic determinism, in which cause-effect relationships are believed to be true, while statistical physics takes its first steps (the economists' equilibrium is consequently a state of quiescence in which every single agent is in equilibrium and not, as in statistical physics, a statistical equilibrium in which the single entities may not be, but the totality is). It's the affirmation of methodological individualism, namely, of the methodology that sees every agent acting in its own individual interest, without bothering about what the other agents do. In economics, this is known as the *lack of strategy principle*. In real life, as stupidity. Is it possible to be so autistic? Yes, if we are all equal, and therefore have the same information. If everyone has the goal of maximizing usefulness and information is common to all—including that on the true model of economics—economic agents behave in the only way possible: as if they were atoms. So, we can apply the physics analogy to economics. But this is possible if and only if these conditions are all valid. Having identical agents is therefore not just a way to aggregate or to have analytical solutions. There is more: if we have equilibrium in the micro, we will also have it in the aggregate—while the opposite is not true; if there is no strategic behavior, economic agents are atoms, and not agents.

Poincaré points this out to Walras: if there is non-linearity—and there always is—the axiom of selfish-rational behavior is "acceptable in first approximation," while "greater caution" requires that of perfect prediction (after Lorenz, this refers to the "butterfly effect"). Indeed, it is not only butterflies that disturb economists, even history—with a small "h"—disturbs them. [AU: This edit only applies if "the economist" is being used here as a representative figure, and not in reference to a specific person.] Edgeworth is dubbed a "pirate" by Marshall, for having hypothesized that exchanges can take place at misleading prices, i.e., not in equilibrium. If this happens, equilibrium will depend on history, just like in ergodic systems (Davidson 1982).

Who guarantees that balance has been reached and is stable? The market, as the axiomists say, and vainly hope. Walras' general equilibrium model describes

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exchanges between agents—in a sort of top-down ABM—in which their coordination is due to the work of an external body that processes all of the necessary information. Walras hypothesized the presence of a central authority who would collect demand and supply from the various agents present in the market. The auctioneer behaves like a benevolent dictator, that is, the State coincides with the market and individual incentive no longer drives the optimal allocation. So then, the problem of economics—how to coordinate millions of agents—is not solved by the market, but by the state? Is this the death of methodological individualism and liberalism, of the market as optimum? Of course, the blow inflicted by the SMD is hard. Strictly speaking, general economic equilibrium in the simplest version—the static one—does not work.

But just like the Ptolemaics who did not surrender to evidence and added epicycles upon epicycles so as not to change the Ptolemaic paradigm, so too go the axiomatics. In the early 1980s, the idea appears of replacing the Walrasian auctioneer, after the *de profundis* announced by SMD, with the hypothesis of *rational expectations*. The first models of RBC were conceived as dynamic offspring [the AD model could not give stable solutions, because, so it was believed, it was structurally incapable of giving any, being that it was static] of the AD model, but were eventually replaced by the DSGE, which soon became the models of the New Neoclassical Synthesis. DSGE models are very non-linear. To study them, one must linearize them around the steady state, a procedure commonly adopted in many other disciplines to make sure that the steady state is stable. In economics, however, this analytic procedure is not neutral, as already illustrated. Add to this the fact that the only stability possible is given by the saddle path.

The "optimal" trend, obtained as a solution to the Ramsey model, is a saddle path and can only be followed starting from very precise and unique initial conditions. Outside these, the path does not lead towards a state of equilibrium, but moves away until it reaches absurd configurations, so much so that mathematicians do not consider saddle paths to be stable. If some shock, say the DSGE's, pushes the system's path out of the optimal one, the operators, on the basis of rational expectations, make decisions that, in a short time, have the effect of changing these conditions so as to make them compatible with the balance of the saddle path. "The system's performance is therefore hypothetically stabilized from the beginning: operators on average do not make bad decisions" (Cozzi 2011). [DSGE supporters object that information market forces operate effectively as stabilizers. But the fact that a capitalist economy is stable doesn't mean that a mathematical model that does not foresee stability is correct. In fact, quite the contrary.]

The hypothesis of rational expectations states that individuals use efficiently, without making systematic errors when forming expectations. All available information is used in the best possible way (it is assumed that agents know the true model). It is not required that agents should know all future prices (assuming that prices coordinate supply and demand), but rather the "real" model from which to derive expectations. A questionable assumption at the very least, if one only thinks about how many updates—read epicycles—have been made to the DSGE model. [Not due to the structural dynamics of economics, which, in itself, constitutes a requiem for REH.]

Moreover, in DSGE models, the postulate of always being within a Walrasian equilibrium is applied to the whole temporal sequence—from the present to infinity—and the resulting equilibrium path is derived. The only possible sources of the cycle are found in stochastic shocks that adjust over time. In reality, the equilibrium, not being based on a constructive derivation, cannot be calculated, and its existence can only be proved thanks to mathematically implausible/incoherent hypotheses such as the uncountable infinity of agents and goods or their arrangement in a continuum that goes from 0 to 1, which allows us to treat them as points with infinitesimal mass on the real line. Hence, mainstream modeling can be compared to a map whose point of arrival is uncomputable and that cannot identify workable directions. This approach is still dominant, both for the lack of an equally structured alternative and for a widespread acceptance of the idea that income distribution is a "natural" consequence of production conditions.

In these models, it is assumed that an individual can make mistakes, but not the community. [Note that, in the hypothesis of rational expectations, economic policies become ineffective because they are neutralized by the behavior of agents. Individuals will react quickly to the choices of economic policy and policymakers have to "surprise" the markets.] So, there can be neither involuntary unemployment nor non-neutrality of monetary policy, that is, this cannot systematically influence production or unemployment. There is now a lot of empirical and experimental evidence that has belied this hypothesis, nevertheless accepted by the mainstream [Simon's (1959) limited rationality hypothesis offers an alternative to it]. In reality, the DSGE seems to provide false predictions, because "it confuses knowledge of the economic system with knowledge in the economic system. It's the same Hayekian distinction between scientific knowledge (understood as culture, the heritage of theoretical knowledge) and practical knowledge, of circumstances of time and place (von Hayek 1948). On the basis of the first type of knowledge the NMC arrives at an immediate and continuous equilibrium of the market; but the significant knowledge is the second, and needs time and correction of errors" (Sabatino 2012).

Rational expectations cannot work if there is heterogeneity between agents that produces direct interaction, as the system produces market failures or structure dynamics of the same (via network or entry–exit), and if there is asymmetric information, then agents tend to use it strategically, including through learning and imitation: in short, they interact outside the markets. [Not to mention the fact that interaction produces non-linearity, feedback effects and network relationships.] On the other hand, they require knowledge of the "true" model to use data rationally—which, in itself, is a dogma, rather than an axiom. And finally, while, for Walras, the information required from agents is almost negligible—they only need to know their costs and usefulness [if it were infinite, markets would not exist]—in rational expectations, this may be limited—in other words, there is interaction, then the Greenwald and Stiglitz (1986) theorem is valid [The theorem states that efficient market allocations cannot be achieved without government intervention if there are information imperfections and/or incomplete markets. The importance of the theorem is due to the fact that, in the axiomatic literature, it is assumed that markets are always efficient, apart from some rare and well defined exceptions. The theorem shows that exceptional cases are those in which the market is perfect, while the rule presupposes imperfect markets. The conclusion that is drawn is that, whenever markets are incomplete and/or information is imperfect, and this is the typical condition of all markets, the markets themselves do not move toward the Pareto-optimal, a position that can only be reached with government intervention]. In short, markets are unable to coordinate anything if information is asymmetric, or—if incomplete—knowledge of the model is required in order to obtain results that can be improved by public intervention.

Moreover, "if an economic model presents chaotic dynamics assuming that economic agents are rational, then by definition of deterministic chaos they can in no way reach in their predictions the infinite precision required to avoid the effects of the extreme sensitivity of chaotic dynamics. In other words, if we start from a model with rational expectations and we discover that it generates deterministic chaos, then the predictions cannot be rational by definition of chaotic dynamics. A corollary that contradicts a hypothesis of the theorem!" (Bischi 2012; Benhabib 1982; Davidson 1982; Boldrin and Montrucchio 1986; Grandmont 1985). Boldrin and Montucchio (1986) in particular show that economic agents who make decisions solving optimization problems over infinite time horizons do not behave regularly and predictably, because the trend over time of the optimal accumulation of capital may present chaotic trends. They show the way in which to obtain dynamics of all kinds (periodic or chaotic), provided that consumers consider future consumption to be much less important than that of the present.

It is time to reconsider that part of macroeconomic history that emerged during the years of "high theory." It is my belief that Keynes wrote the *General Theory* as a way of overcoming the neoclassical theory founded on the "Commodity-Money-Commodity" barter-view, in favor of a monetary theory of production, "Money-Commodity-Money plus," [see Keynes (1933/1973)] and the tools of rational mechanics—and not only as a reaction to the 1929 Crisis. Statistical physics is, in fact, perfectly compatible with Keynes's macroeconomics, circumscribed—the former—to the short period and where Laplace's demon found no room. According to the Bayesians, statistical inference can be applied over a long time horizon, but in the *Treatise on Probability* and in the subsequent *General Theory*, uncertainty is replaced by risk and equilibrium is only aggregate. The long period therefore cannot be modeled, because we will never have—even though we are not "amateurs," and thus know about the "true" model—the infinite information needed to solve a complex system. Note that even the assumption that fluctuations depend on shocks is not neutral, because, in fact, it is assumed that the economic system is always in a steady state and that, after the disturbance, it returns to the original state. In fact, the possibility is precluded of having path-dependency and that the system always reacts in the same way to similar shocks—independently, for example, from different financial fragilities or high and low unemployment.

Instead of reducing axioms to testable hypotheses, economics has chosen a different path: axioms have become dogmas and scientific rigor has been identified with mathematics. This operation is not neutral. By privileging the form over the substance—that is, mathematics over empirical evidence, and moreover, by using the mechanistic analogy with Newton's physics—economics has become self-referential.

This is based on the obsolete vision of mechanism and individualism, which led us to underestimate the common goods, to live and pollute by over-producing as if humanity (and the economy) were not part of Nature. Capra and Mattei (2015), p. 8: "Today, all political debates are firmly anchored in the powerful academic disciplines of economics, which, by successfully claiming to be an exact science, determines policy making and legislation. Unfortunately, economics still applies to short-term reductionist, linear, and quantitative bias typical of traditional scientific thought, in consequence of the mechanistic paradigm. So-called economic laws produce major distortions because they are based on the assumption that it is natural and desirable for an institution to set a growth target that induces extractive individual behavior while discouraging virtuous practices." The theory of complexity ends the time of certainty when scholars believed that every effect corresponds and is proportional to one precise cause. This subtle problem has effects on the dominant economic theory, which is based on the assumption of equilibrium and linearity, but also on the hard sciences—physics and chemistry—in the first place. As shown by Anderson (1972), the aggregate is not the sum of its components, but rather results from the interaction (which involves non-linearity) between its components. It involves the abandonment of the very idea of "natural law" and mechanism, of proportionality between cause and effect, and that the dynamic of a system can be reconstructed by summing up the effects of single causes acting on single components (Nicolis and Prigogine 1977). By focusing on systems in equilibrium, economists implicitly accept that the number of possible states a system may attain is limited (and computable) and that search time dynamics is short and convergent, compared to the "equilibrium" time. The mainstream approach in economics is very quantitative, reducing the value of human life to the value of the goods and services produced, and is, according to Capra and Mattei (2015), p. 115, "the current form of the Cartesian mechanistic vision. [...] Private-sector incentives and legal structures [e]ncourage exploitative and shortsighted corporate behavior determinates the institutional, legal, and intellectual structure of the present extractive economic orders we call the mechanistic trap." The mechanist trap is well evidenced by those like Irving Fisher, who, in 1891, built a hydraulic machine for calculating equilibrium prices. Years later, in 1950, William Phillips invented the MONIAC, a hydraulic computer that simulated the British economy. The ability to describe the economy as a machine is a fruit of the tradition of classical physics, well able to describe a complicated subject, but not a whole, that is, capable of evolution. [Economics lay in the center of her investigation an abstract individual, an isolated atom, which exists apart from the others (social atoms in Buchanan 2007). This view is far from being neutral, which does not take into account the feedbacks from other agents and nature.]

The use of representative agents makes it possible to apply the analytical method to economics, but at too high a price. In the meantime, if it is true that the aggregate can thus be reduced to the micro—which gives us the idea of a false microfoundation—by definition, one gives up the possibility of analyzing distribution and the effects of composition. Kirman (1992) finally highlighted the analytical limits of the Representative Agent that does not represent anyone.

If we look closely at the hypothesis of maximum-minimum (utility-cost), it derives from classical physics and is only functional for reducing the behavior of agents to that—without strategies or learning—of atoms. And, being functional, it is ad hoc. This made it possible to transform a social science like economics into a quantitative one. The use of mathematics provides economics with an authority that risks becoming a presumed objectivity and that, in any case, makes it difficult to identify its ideological conditions [see Schumpeter (1954) and his discussion of pre-analytical ideological vision]. This setting of economics has been a decisive factor for the definitive affirmation in mathematics of formal systems, since, for the first time, the axiomatic-deductive method was applied outside of the traditional contexts of geometry or physics. But, unlike physics, the behavior of human beings is more difficult to describe through mathematical models, since it is not enough to adapt the methods and reasoning of physics to model the economy because economics is a moral science. [Keynes: “It has to do with reasons, expectations, psychological uncertainties. [. . .] It is as though the fall of the apple to the ground depended on the apple’s motives, on whether it is worth falling to the ground, and whether the ground wanted the apple to fall, and on mistaken calculations on the part of the apple as to how far it was from the center of the earth”. And Bischi (2012) sarcastically comments: “. . .how and to what extent the apple is conditioned by the behavior of other apples, the expectations that the apple has on the results of its fall, the information that the apple has on the decisions of other apples and on the conditions of the soil on which it will fall.”]

According to this interpretation, rationality is only a piece of methodological advice. In the most benevolent interpretation, maximization is an ad hoc hypothesis. The modelling of complex agent systems makes it possible to obtain a plethora of stylized facts using a single model (Delli Gatti et al. 2005; Dosi et al. 2010) and not a hypothesis in a model to “explain” a fact (Stiglitz 1992), and thus to build complex evolutionary systems in which the structural dynamics—due to innovation—are combined with the interaction of heterogeneous agents and credit can connect different time periods. Not to mention all the non-market relations (contagion, domino effects) and the impact on the—beyond GDP—measurements of Chap. 1.

3.1 From Axioms to Hypotheses

The mainstream pursues the same utopia as Hilbert’s program in mathematics, which aimed to prove that all mathematical laws could be explained by a consistent system of axioms. Gödel’s incompleteness theorem, however, demonstrates the impossibility of this program, because even the axioms are based on statements that are impossible to prove in regard to whether they are true or false with nothing but the tools derived from the axioms themselves. In the general equilibrium framework—and in its modern developments—topological approaches are used to derive the existence of a fixed point, such as the Brouwer fixed point theorem or the more general one by Kakutani, but these are pure theorems of existence, not constructive, which do not provide any indication as to how to find the fixed point.

Regarding the incompleteness theorem, (Gödel 1931) says: "In any formal system S endowed with a logical (ie, non-contradictory) set of basic axioms which are sufficiently complex as to be able to encompass arithmetic, it is possible to construct propositions that the system can't determine: they can neither be proved nor disproved, on the basis of the axioms and rules of system deduction." Basically, Gödel shows that we can construct a proposition P that succeeds in affirming: "P cannot be demonstrated in S," as in the paradox of the liar: "I'm lying." The same happens for the axiomatic system of Debreu, in which the SMD theorem proves the undecidability of the same.

To overcome the impasse of the GET and DSGE (Landini et al. 2018), it is necessary to solve the problem of axiomatic systems—not verifiable internally—and thus subject to Gödel's theorems, and "validate" the hypotheses, as the ABM can do. The paradigm of Walras was based on an analogy with classical physics, but it was not sufficient to solve the fundamental problem in the general equilibrium framework, that is, proving the existence of the equilibrium. Mathematical economics from Walras' *Elements* to the end of the 1930s of the last century was basically an analogical representation of economic facts with the classical mechanics models of physics (Mirowski 1989; Ingrao and Israel 1991). This mathematization of economics consists in changing the language from ordinary (e.g., English) to artificial (mathematics) and finding analogies between economic and physical phenomena to formulate economic theories.

The mathematical economics between the 1940s and the 1950s is the formalization of the methods for analyzing the economy. Formalization of economics consists in the mathematical specification of economic problems. Von Neumann (1937) formulated the equilibrium problem replacing the analogy with physics with a mathematical analogy (Gloria-Palermo 2010). In this mathematical economics of the second generation, the problem ceases to be economic, becoming a mathematical problem (Blaug 2003). [It is certainly not mathematics that is in crisis today—given the axioms it started with, it has done a great job—but rather the use that the mainstream paradigm makes of it.] The switch from the first to the second generation of mathematical economics is a consequence of what happened in mathematics in the 1920s–1930s: the foundational crisis, the controversies about set theory and the notion of infinity, the debate among the competing foundational schools of mathematics, the formalistic Hilbert program, the Gödel's theorems, and their consequences.

The major part of the imbalance between theoretical and applied economics is due to the axiomatization of the discipline according to the paradigm of Hilbert introduced in economics by von Neumann (1937), and later by Samuelson (1947), Arrow and Debreu (1954) and Debreu (1959) [see Blaug (2003)]. This is because, according to the economists, the axiomatic mathematization of a theory is believed to be a sort of "scientific accreditation" that guarantees the consistency of the theories, even when there is no empirical validation. Let us disambiguate that we do not consider a theory (economic or otherwise) to be scientific only if it is consistent; indeed, a theory might tell us something false without contradiction. A theory is scientific if predictions follow from its premises without contradiction and if the consequences of its predictions are in agreement with the facts, at least up to an acceptable degree of approximation. This means that a theory is scientific if it is logically sound and somehow empirically falsifiable according to the scientific method. Moreover, beyond falsification, there is validation (Colander et al. 2008). An *applied* theory should be validated in terms of its effectiveness in explaining facts, without certainty of having found a law that is confirmed by experience. A *pure* theory should be validated in terms of the consistency of its reasoning and inferential or deductive method in solving (mathematical) problems without contradiction. The optimal situation for a theory, which has both pure and applied approaches, would be that the two planes of discourse intersect while reinforcing each other, as happens in physics, contrarily to economics. Sornette et al. (2017) highlight the strict relationship among the validation, hypothesis testing and statistical significance test of mathematical statistics while proposing (algorithmic) validation as a constructive iterative process.

The axiomatic mathematical form of economics is privileged to substantially assert propositions, without the possibility of falsification, similar to theology, but differently from the scientific disciplines. This worrying trend is not without its implications. No plausible critique is possible from the outside, say, from the empirical evidence: the methodology strictly follows the late procedure of adding new *epicycles* to fit the data. As it became clearer and clearer during the late Middle Ages that the Ptolemaic theory of the Sun going around the Earth was not predicting celestial mechanical dynamics well, its advocates kept adding small “epicycles” to the predicted main cycles to get it to explain the data. In analogy with this, we use the *epicycle* argument to mean that if a consistent theory is not powerful enough to prove a statement (incompleteness) that has been formulated within the theory, or to match with the facts (incorrectness), one might be tempted to assume additional hypotheses so as to reduce the level of incompleteness/incorrectness: if such hypotheses are assumed without proof, they play as axioms, hence one is adding *epicycles*.

Landini et al. (2018) show that augmenting a consistent set of axioms by means of new axioms has two drawbacks: (1) it restricts the scope of the theory and, to prove the augmented set of axioms is still consistent, (2) it takes a more powerful theory based on a different set of axioms. Contrastingly, tested hypotheses may be assumed in the theory, which becomes falsifiable, without modification of the axiomatic set; in this case, the drawback is that the theory is less general but also less incorrect. If economics is not falsifiable, the only possible critique is to prove the logical weaknesses of the theoretical approach (Kirman 1989). Landini et al. (2018) also show how the Gödel-Rosser theorems undermine the GET-DSGE in terms of coherence and incompleteness, and they offer an alternative approach: ABM (agent-based modelling) as a tool for dealing with complexity and falsifiability. In order to be calibrated, all models must first be validated to be empirically relevant (Bianchi et al. 2007; Grazzini et al. 2017; Richiardi 2018; Fagiolo 2018).

Developing an axiomatic formal theory is like playing chess against the *Incompleteness Theorem*: the most reasonable way to try to win is doing our very best not to lose. As, in a chess game, our opponent may move a piece for enticement, the *Incompleteness Theorem* may seduce us in terms of consistency while hiding the winning move of incompleteness, which stimulates us to introduce new axioms, thus compromising coherence: if this happens, the *Incompleteness Theorem* gives us the checkmate. Therefore, so as not to be entrapped in the coherence-incompleteness recursion, the most reasonable move we can play is not to push beyond our limits with ever newer axioms, but rather to open up the already existing axiomatic system to reality.

For the purpose of not losing the game, we should introduce effective hypotheses that can be tested, case by case: whenever it is possible, nothing that can be proved is to be assumed without proof. This is not a general strategy for perpetual victory, but simply generic tactics for proving what is to be proved. If the theory turns out to be inconsistent or ill-matched with facts, the theory is to be revised. But if no inconsistency is found after having introduced the previously tested hypothesis, then coherence is preserved and, above all, the implications of the theory will be pretty close to the facts.

The advantage of this strategy is evident: we will end up with theoretical proposals whose implications are in agreement with data, and we also have a theory to explain the reasons of "how" something happens when something else happens. Of course, we would never have a "general" theory, but rather a "generic" theory that works fine in all cases that are consistent with the empirically tested hypotheses, those in accord with "the world as it is." Clearly, this is a price no formalist is prone to pay; it is not a matter of faith, but a matter of method: opening up the axiomatic system to testable hypotheses means losing something in terms of theoretical apparatus, but, at the same time, also means gaining something else in terms of the applicability of the theory.

So, the question becomes, more generally, how to move beyond the formal limits of general equilibrium theory while still engaging in serious and substantive quantitative modelling of economic systems? We advocate the use of modelling methods that do not rely on optimization requiring axioms that place the analyst in the situation presented here. Agent-based models (ABMs) are one such approach, in which no overall equilibrium is necessary, even if some such models do lead to such an outcome. ABMs can embody behavioral assumptions for the agents that are empirically sound, as argued above. But these behavioral assumptions do not need to be derived from axiomatic foundations. Rather, they reflect real world estimated data. An important source of such data may well be experiments from either lab or field settings, preferably from both, with each confirming the findings of the other. In his detailed review and systematization of the reasons why general equilibrium became (and remains) dead, Ackerman (2002) explores some "Alternatives for the Future," and finds the ABM to be a valuable route for simulating worlds dominated by chaos and complexity. Bookstaber (2017) supports the idea of ABM as a new paradigm: "It [ABM] operates without the fiction of a grand leader, or a representative consumer or investor who is unerringly right as a mathematical model can dream. [. . .] agent-based economics arrives ready to face the real world, the world that is amplified and distorted during times of crisis. This is a new paradigm rooted in pragmatism and in the complexities of being human."

A behaviorally-based ABM approach also opens the door to a greater possibility of modelling the evolutionary dynamics of a system. The contrast between evolutionary and equilibrium approaches was at the foundation of Veblen's (1898) critique of neoclassical equilibrium theory and his proposal to replace it with the study of the evolution of economic institutions. The lack of imposing an equilibrium outcome on the system allows for changes to emerge from the lower level interactions of the agents in the model, hopefully based again on sound empirical findings. It is reasonable that, in moving beyond the axiomatic formalism of a GET-DSGE framework, approaches that emphasize the possibility of ongoing change in an evolutionary manner should be made possible. Rather than all-knowing and optimizing agents bound to obey problematic axioms, boundedly rational agents attempting to improve their situation in interaction with the other agents around them can provide a stronger foundation and framework for understanding real economic dynamics in a complex world economy.

3.2 Models with Heterogeneous Interacting Agents: An Escape Route from Axiomatic Economics

Rosser (2009) argues that "during a period of upheaval, when an established orthodoxy has died and is being replaced, the mainstream can and will step aside from it and pursue this effort, not being tied to any particular paradigm necessarily."

As we have seen, the situation is similar to what occurred when the Ptolemaic system went into crisis, but there's still no alternative system like the Copernican one. Its abandonment was not abrupt. Aristarchus and heliocentric models were forgotten, while the Ptolemaic system won and ruled for centuries. After all, the planets continued to spin independently from our theories on their motion. Epicycles were continuously being added to the geocentric system (similarly to what the dominant economics does, by including banks, heterogeneity and various imperfections), and while the pyres intended for heliocentric heretics illuminated the squares of Europe, the earth continued to revolve around the Sun, unaware of Ptolemy. But if it is true that it is easier to change the laws of physics than to change people's minds (or, as Einstein said, "it is easier to break an atom than a prejudice"), the question becomes particularly relevant when it involves economics, which directly affects the life of every human being. And, anyway, it's worth mentioning that the Ptolemaic system eventually collapsed because it was no longer able to reconcile theory and reality. The same will happen in economics: the theoretical system is already imploding and a new paradigm is urgently needed.

In my opinion, the re-foundation of economics requires a fundamental shift: from *homo oeconomicus* to the social agent who learns from its own and other agents' experience. It is therefore a question not only of abandoning the method of reductionist and mechanistic physics, but of going beyond physics itself, acknowledging that economic agents are atoms that think and learn. The "anything is possible" theorem constitutes the formal nucleus of the *pars destruens* of mainstream economic theory. Research on agent-based models is the *pars construens*, a toolbox still in the making, but already crucial compared to *mainstream* optimality. Agent-based models have the potential necessary to face the challenge, but their development is still not ready to offer a new and complete paradigm.

The simplest formulation of these models is that, due to imperfections, especially informative ones, agents interact, an endogenously formed heterogeneity occurs among them (size, technology, debt, credit and commercial networks, etc.) that changes over time and macro relationships *emerge* from the interactions themselves. As I have explained above, axiomatic economics adopts the reductionist and mechanistic approach of Newtonian physics, applying it to the single agent. Extending this to all economics is justified by the hypothesis that the agent is representative: if all agents are equal to each other and there is no externality (the action of one agent has no effect on others), macroeconomic behavior will be identical to individual behavior, only bigger. So, it will be sufficient to multiply what a single agent does by the total number of agents.

Since models with many heterogeneous interacting agents are complicated, economists assume the existence of an RA: a simplification that makes it easier to solve for the competitive equilibrium allocation, since direct interaction is ruled out by definitions. Unfortunately, as Hildenbrand and Kirman (1988) noted: "There are no assumptions on isolated individuals, which will give us the properties of aggregate behavior. 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."

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), Gallegati (1994) and Caballero (1992) show that RA models ignore valid aggregation concerns, by ignoring interaction and emergence, committing a fallacy of composition (what, in philosophy, is called a fallacy of division, i.e., to attribute properties to a different level from which 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 RA is not just an analytical convenience, but both unjustified and resulting in conclusions that are usually misleading and often wrong (Kirman 1992). 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 who have to collectively make a decision cannot show the same rationality as an individual (Mas-Colell et al. 1995). Moreover, the 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 macro econometrics becomes a central topic, since some issues (e.g., cointegration, Granger-causality, the impulse-response function of structural VAR) lose their significance (Forni and Lippi 1997). All in all, we might say that the failure of the RA framework points out the vacuum of the mainstream microfoundation literature, which ignores interactions: no toolbox 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). Cohen (1960) is the first to discuss the potential of computational models for modeling complex economic dynamics. For instance, Cohen points out that computational approaches would avoid aggregation issues, as macroeconomic data would simply be obtained by summing up individual ones. So, when estimating the relationships between macro variables obtained thanks to the aggregation of AR, two hypotheses are evaluated at the same time: (1) the existence of AR and (2) the relationship between macro quantities obtained through a misleading aggregation process.

Currently, the focus is on[?] microfoundation macroeconomics, that is, the attempt to explain how economics is faring based on the behavior of a single form of agent (households, banks and firms) or heterogeneous without interaction. Actually, microfounded literature may follow two approaches: DSGE equilibrium and ABM. The DSGE model uses the representative agent or more classes of heterogeneous agent, provided that their number and proportion does not change over time (remember that, in the general equilibrium model, there is no role for endogenous innovations) and that there is no direct interaction between agents. [Interaction, outside of completely unique and unrealistic cases, generates non-linearities, and we know that "standard" aggregation works only with linear relationships. It is important to note that if two agents, A and B, interact directly with each other, they give rise to a new type of agent C, which is different from the other two that have generated it: you can no longer use the representative agent a priori, and so the micro–macro bridge collapses. It is worth emphasizing that, without interaction and heterogeneities, there are no coordination and crisis problems, but there is no trade or markets either.

The ABM, instead, has two approaches: a computational one and an analytical one. The latter provides a theoretical foundation based on "mean field" dynamics ["Mean field interaction" is a form of indirect interaction that interprets micro behavior in a probabilistic way. This interpretation of interaction derives from the analysis of complex systems according to the statistical mechanics perspective and allows us to explain the transitions of agents among states as a result of an uncontrollable myriad of interactions that occur at a micro level but cannot be directly observed unless the system is brought back to a family of groups, each one consisting of individuals similar to each other "on average" in some characteristics. Assuming then that two or more groups begin to interact, this perspective allows us to estimate the probability that a certain number of individuals will leave each group and that a certain other number of individuals will enter it, all of this depending on a microfounded phenomenology and on some macroscopic quantities (at, in fact, the field level) that orient the system], derived from statistical physics and made popular by the Santa Fe Institute: it analyzes economic agents as "social atoms," i.e., atoms that relate to each other. It is, therefore, an approach based on heterogeneous agents who interact directly with each other, and therefore move in a context of partial information with limited rationality [Judd and Tesfatsion (2006) and Dawid and Delli Gatti (2018) provide a comprehensive and detailed overview of its applications in many fields of economics (from innovation to work, from financial markets to credit); while Farmer and Foley (2009) focus, above all, on the inability of DSGE models to explain reality because they use hypotheses that are too abstract and unrealistic, and demonstrate the need and urgency to adopt the ABM. Numerous research centers on ABM exist in Japan and in the United States (Ashraf et al. 2016, 2017), but in Europe most of all: Amsterdam in the Netherlands; Sussex, Oxford and the Bank of England in England (Haldane 2016; Haldane and Turrell 2018); Bordeaux (Salle et al. 2013), Nice (Seppecher 2012; Seppecher and Salle 2015) and Paris in France; Genoa (Cincotti et al. 2010, 2012; Teglio et al. 2012; Raberto et al. 2012), Milan, Cattolica (Assenza and Delli Gatti 2013; Delli Gatti and Desiderio 2015; Delli Gatti et al. 2008, 2011), Pisa (Dosi et al. 2006, 2008, 2010, 2013, 2015, 2017), and Ancona (Riccetti et al. 2013, 2015, 2016a, b, 2017, 2018; Russo et al. 2007, 2016; Caiani et al. 2016a, b) in Italy; and Bielefeld (Dawid et al. 2008, 2009, 2012, 2014, 2018) and Kiel (Alfarano et al. 2005, 2007; Lengnick and Wohltmann 2011, Lengnick 2013) in Germany. [On the Italian ABM schools, see Dosi and Roventini 2017.]

But what are ABM? "Agent-based models" are abstract representations of reality, in which:

– a wide variety of agents interact with each other and with the environment;
– the agents are independent, i.e., there is no central control of their behavior;
– agents can be very heterogeneous, and it is assumed that they behave accordingly (characteristically, income and wealth distribution can be compared to a situation in which the vast majority of agents moves at 3.5 m per second, 1% at 100 km per second and 0.1% at the speed of light).

The ABM methodology is bottom-up and is focused on the interaction among many heterogeneous agents, which might produce a statistical equilibrium (Miller and Page 2006; Epstein and Axtell 1997; see also Wooldridge 2001, and Flake 1998). ABM is a methodology that allows us to construct models with heterogeneous agents, based on simple behavioral rules and interaction, in which the resulting aggregate dynamics and empirical regularities are not known a priori and are not deducible from individual behavior (Nicolis and Nicolis 2007). The bottom-up approach models individual behavior according to simple behavioral rules; agents are allowed to have local interaction and to change the individual rule (through adaptation), as well as the interaction nodes. By aggregating, some statistical regularity emerges, which cannot be inferred from individual behavior (self-emerging regularities): this emergent behavior feeds back to the individual level (downward causation), thus establishing a macrofoundation of microbehavior. As a consequence, each and every proposition may be falsified at the micro, meso and macro levels. [The general principle of holism was concisely summarized by Aristotle in his Metaphysics: *The whole is more than the sum of its parts.*]

The agent-based methodology can also be viewed as a way to reconcile the two opposing philosophical perspectives of methodological individualism and holism. Having agents as a unit of analysis, ABM is deeply rooted in methodological individualism, a philosophical method aimed at explaining and understanding broad, society-wide developments as the aggregation of decisions by individuals (von Mises 1949).

Methodological individualism suggests—in its most extreme (and erroneous) version—that a system can be understood by analyzing its constituents separately, Agent-based computational economics (ACE) being the area of computational economics that studies economic processes, including whole economies, as dynamic systems of interacting agents. As such, it falls into the paradigm of complex adaptive systems. In corresponding agent-based models, the agents are "computational objects modeled as interacting according to rules" over space and time, not real people. The rules are formulated to model behavior and social interactions based on incentives and information. The theoretical assumption of mathematical optimization by agents in equilibrium is replaced by the less restrictive postulate of agents with bounded rationality adapting to market forces. ACE models apply numerical methods of analysis to computer-based simulations of complex dynamic problems for which more conventional methods, such as theorem formulation, may not find ready use. Starting from initial conditions specified by the modeler, the computational economy evolves over time as its constituent agents repeatedly interact with each other, including learning from interactions. In these respects, ACE has been characterized as a bottom-up culture-dish approach to the study of economic systems. The outcome of interaction is numerically computed. Since the interacting objects are autonomous, they are called agents: Agent-based Computational Economics is the computational study of economic processes modeled as dynamic systems of interacting agents (Tesfatsion 2002, 2006; Gintis 2007; Chen 2012). Here, *agent* refers broadly to a bundle of data and behavioral methods representing a constitutive part of a computationally constructed world. The availability of high-speed processors and the possibility of handling large amounts of data have undoubtedly contributed to the success of ACE models. One of the problems detected is related to parameter setting: with many degrees of freedom, as is often objected, every result becomes possible. The process of aggregation, in physics, takes away these degrees of freedom. The procedure of microfoundation in economics is very different from that used in physics. The latter starts from the micro-dynamics of the single particle, as expressed by the Liouville equation, and, through the Master equation, ends up with the macroscopic equations. In the aggregation process, the dynamics of the agents lose their degrees of freedom and behave coherently in the aggregate. In mainstream economics, while the procedure is formally the same (from micro to macro), it is assumed that the dynamics of the agents are those of the aggregate. The reduction of the degree of freedom, which is characteristic of the aggregation problem in physics, is therefore ruled out: a rational agent with complete information can choose to implement the individually optimal behavior, without additional constraints.

The main contributions of ASHIA are:

To provide a solution to the problem of aggregation in HIAs by using methods inspired by the statistical mechanics against the usual classical mechanics involved in RA-based models;

To propose a dynamic stochastic model for sub-populations of many HIAs interacting in an endogenous evolving network (see Delli Gatti et al. 2009, 2010a, b);

To develop an analytic solution in which the model is defined as a deterministic ordinary differential equation describing the dynamics of a network.

The dynamic stochastic aggregation is able to provide a complete and consistent analytical representation of the system, using numerical simulations only as a further verification of the results of the model. Economic agents are not atoms, however: they have many more choices according to their preferences and endowments, but mostly according to rationality and information. There is only one way to match homo oeconomicus with the atom: perfect information and complete rationality [Note the irreconcilable approach between physics and its *Laplace's demon* problem and the mainstream economy in which *Lucas's angel* can predict the future]. A person without a sound mind can behave in a totally unpredictable way, while even the poorly informed can hazard a guess. In this process of "trial and error" lies the process of learning, often modelled by complexity theorists, such as CAS. Apart from the equivalence between atom and homo oeconomicus, we must consider some consequences, among which, in my opinion, the following three points are the most relevant: With learning, the contribution of ASHIA profoundly changes: it is no longer the mere transposition into economics of an instrument borrowed from statistical physics, since it is [It is worth noticing that this approach overcomes another limit of the RA modelling, as the equilibrium is no longer a fixed point in space, but rather a probability distribution: a system can be in equilibrium, even if its constitutive elements are not] transformed in the direction of scientifically studying the society in which individual behavior changes and it is changed by the aggregate context; to appreciate the systemic aspect of an economy, one has to analyze the individual, as well the global characteristics of the system, by analysing the individual nodes as agents and their links in the network; the social aspect of the economic atom is expressed in networks: the links between agents are established (e.g., to form credit linkages and/or to increase the information set) and are changed according to fitness (see Barabasi and Albert 1999; Bianconi and Barabási 2001; Tedeschi et al. 2012).

According to the mainstream approach, there is no direct interaction among economic units [for a pioneering, though neglected, contribution, see Föellmer (1974); see also Kirman (2000)]. In the most extreme case, any individual strategy is excluded [the principle of excluded strategy, according to Schumpeter (1954)] and agents are homogeneous. Small departures from the perfect information hypothesis are incoherent with the Arrow-Debreu general equilibrium model, as shown by

Grossman and Stiglitz (1980), since they open the chance of having direct links among agents (Stiglitz 1992). In particular, if prices convey information about the quality, there cannot be an equilibrium price as determined by the demand-supply schedule, since demand curves depend on the probability distribution of the supply (Grossman and Stiglitz 1976: 98).

In other words, ABM are tools used to study economics as an adaptive complex system, a dynamic one, as, in fact, it is, that is, composed of many interacting agents that adapt to an environment that changes as a result of their actions. The basic units of ABM are agents (from individuals to social groups organized to carry out economic tasks, like households, firms and banks). They can also be aggregated to other agents such as industries or countries and are characterized by persistent and significant heterogeneity. Within an ABM framework in which agents are heterogeneous, aggregate variables that are the focus of macroeconomic analysis, like consumption, savings, investment, and disposable income, are calculated from the bottom up, i.e., summing the values produced by the action of all agents. Seeing that the information available to agents is limited, their choices may no longer be optimal, as in the axiomatic theory, but still *satisfactory*.

ABM can be falsified at an individual, sector or aggregate level and assumptions about individual behavior (and about the various interactions) can be modified. As they are models built from the bottom up, they *model*, in fact, the behavior of individual agents. For example, the type of work and remuneration depend on what is considered satisfactory, but also on the remuneration of colleagues. This relationship can be falsified through economic experiments or econometric tests, and then replaced by another, more robust one, maybe coming from other social sciences or from behavioral economics. Note that falsifiability is true at the individual level, but also for sectors, at all levels. Modelling individual behavior in ABM implies that the whole is not equal to the sum of its parts, as in the reductionism of axiomaticists. For these new paradigms, aggregate behavior can be obtained by observing the behavior of individual agents. While, as we know, reductionism is implicit in the representative agent paradigm, i.e., the dominant one that holds that the whole of society can be analyzed in terms of the behavior of a single representative, it is instead completely incompatible with ABM methodology due to direct interaction between agent and agent, and no longer mediated only by the market. Interaction creates the kind of externality that generates what *holism* describes, namely that the properties of a system cannot be explained by the sum of its components. Instead, it is the characteristics of the system as a whole that determine the behavior of the individual [As such, holism is closely related to organicism, a biological doctrine that emphasizes the importance of the organization rather than the composition of organisms].

This approach earned renewed popularity in the last decades of the twentieth century as "complexity science." Delli Gatti et al. (2010a, b) conjugate complexity and ABM, and show that these models are characterized by the fact that aggregate results (the whole) are calculated as a sum of the single characteristics (its parts). However, the resulting aggregate behavior is often different from the behavior of individual agents, a fact that leads to the discovery of emergent properties. In this sense, the *whole* is more than the sum of its *parts* ("*More is different*", as Philip Anderson, Nobel Prize in Physics in 1972, tells us).

While in traditional economic models, with representative agents, equilibrium is a state in which the demand (individual and aggregate) equals the supply, in ABM, the notion of equilibrium is statistical, i.e., aggregate equilibrium is *compatible* with individual disequilibrium. Statistical equilibrium does not require that each single element be in equilibrium, but rather that the distributions are stable, that is to say, "in a state of macroscopic equilibrium maintained by a large number of transitions in opposite direction[s]" (Feller 1957; 3rd ed. 1968, p. 356).

Thanks to the computational power of computers, we are today able to model economies on the order of hundreds of thousands of agents in many markets. The simulations used in many disciplines, as well as in sciences that are not social, such as biology, nonlinear mathematics or engineering, are paradoxically not used in economics, in which only mathematical formalization is considered as synonymous with rigor and scientificity [Leombruni and Richiardi (2004) show that "simulation is mathematics"]. Yet simulation also makes it possible to aggregate, to pass from the analysis of individual behavior to that of aggregate behavior, i.e., from micro to macro, in a perfect way: the dreams of axiomaticists are thus realized, in other words, to base aggregate behavior on that of each individual subject (the goal, however, is that, if there is an avalanche, we're not interested in knowing which snowflake is responsible for it, but rather, if anything, the probability of occurrence).

ABM are already used to analyze the most diverse aspects of macroeconomics, the crises and the cycles, the distribution of wealth, income and firm size, financial markets and the way in which the market structures respond to technological change. No axiomatic model comes close to reaching the empirical success of ABM (also because the former, which is dominant, in order to explain unemployment, needs one model with gullible workers, another model to explain the rigidity of prices, still another to obtain some motivation for credit rationing, and so on for all of the pathological phenomena).

A further field of ABM development has been to study the dynamics of learning and the experimental behavioral approach. Lastly, another area of current interest for ABM application is the analysis of networks (when two agents interact, they come into contact, and they are nodes that bind together: a network topology).

Research is still far from being complete, above all, where empirical verification of aggregate models is concerned, but it is already more effective in explaining reality than what has been done so far and continues to be done by the DSGE models that dominate the economic scene. Although ABM certainly do not constitute a panacea for the crisis, it is indisputable that they provide suggestions of economic policy unknown in traditional models. Freed from the straightjacket of equilibrium and a representative agent that only works with a single good and a single market, we can finally dedicate time to investigating the potentiality of interactive agents and their emergent properties.

3.3 The Cumbersome Political Economics of Complexity

Economics was all about[?] political economy first. According to classical economists, economic science has to be used to control real economies and steer them towards desirable outcomes. If one considers the economic system as an analogue of the physical one, it is quite obvious to look for natural economic policy prescriptions (one policy fits all). This is the approach of mainstream (neoclassical) economists. ABM complexity does add new views to the toolbox of mainstream economic policy analysis (Brock and Colander 2000; Fagiolo and Roventini 2017; Gaffard and Napoletano 2012; Haber 2008; Neveu 2013).

The complexity approach showed us that the age of certainty ended with the non-equilibrium revolution, exemplified by the works of Prigogine. Considering the economy as an evolving evolutionary system, we have to admit that our understanding is limited: there is no room for the Laplace's demon in complexity. Individual behavioral rules evolve according to their past performance: this provides a mechanism for an endogenous change of the environment. As a consequence, the rational expectation hypothesis loses significance. However, agents are still rational, in that they do what they can in order not to commit systematic errors (Hommes 2013; Palestrini and Gallegati 2015). In this setting, there is room for policy intervention outside of the mainstream myth of a neutral and optimal policy. Since emergent facts are transient phenomena, policy recommendations are less certain, and they should be institution-dependent and historically oriented (Finch and Orillard 2005). In particular, it has been emphasized that complex systems can either be extremely fragile and turbulent (a slight modification in some minor detail brings macroscopic changes) or relatively robust and stable: in such a context, policy prescriptions ought to be case sensitive.

Real economies are composed of millions of interacting agents, whose distribution is far from being normally distributed. The distribution of firms' trade-credit relations in the several sectors is characterized by the presence of several hubs, i.e., firms with many connections: the distribution of the degree of connectivity is scale-free, i.e., there are a lot of firms with 1 or 2 links, and quite a few firms with a lot of connections (see, e.g., De Masi et al. 2010). Let us assume the Central Authority has to prevent a financial collapse of the system, or the spreading of a financial crisis (the so-called domino effect). Rather than looking at the average risk of bankruptcy (in power law distributions, the mean may even not exist, i.e., there is an empirical mean, but it is not stable), using the latter as a measure of the stability of the system by means of a network analysis, the economy can be analyzed in terms of different interacting sub-systems and local intervention can be recommended to prevent failures and their spread. The structural characteristics of a network are relevant for quantifying vulnerability, isolation, and integration, to name a few. Networks can be hierarchical or modular (Caldarelli 2007; Jackson 2008). In those cases, the distribution of numbers of connections per node is skewed, and this number varies according to the cyclic phase, providing information on what will happen and on the economic policy to be followed.

Instead of a helicopter drop of liquidity, one can make targeted interventions to a given agent or sector of activity. In this perspective, notions elaborated from network theory become very relevant, like resilience, which depicts the behavior of network's structures following the removal of some nodes. In particular, whenever a vertex is removed from a network, the average distance among nodes increases, and, as this process goes further, some nodes will ultimately be disconnected. Nodes can be removed in many ways. They may be attacked randomly or according to some of their intrinsic properties (such as their degree). Depending on the rules used to remove nodes, the network shows a different level of resilience. For instance, Albert and Barabási (2000) show that social networks, usually highly right-skewed, are remarkably resistant to random attacks, but extremely vulnerable to attacks targeted at nodes with the highest degree (hubs). To prove this claim, the authors remove nodes in decreasing order of their connectivity, showing that, as a small number of hubs are removed, the average distance of the scale-free network increases rapidly. Network topology is relevant for systemic risk too. Credit relationships, which have acted as a major channel of contagion during the crisis, can be naturally conceived as networks in which nodes represent agents and links represent credit claims and liabilities. In particular, it becomes important to identify densely connected subsets of nodes within such networks, i.e., modules or communities. In fact, community structure is tightly related to the issue of diversification, because, in a nutshell, the latter may be attained only where the former is suppressed.

Since communities are instead likely to be ubiquitous in real economic networks, community detection provides a general approach to the analysis of contagious defaults. In fact, contagion is dependent on the geometric properties of the network [For instance, Fujiwara (2008) shows how to calculate the probability of going bankrupt singularly, i.e., because of idiosyncratic elements, or through a domino effect, i.e., because of the failure of other agents with which there exist credit or commercial links], with the adjacency matrix representing (possibly weighted) connections, which, for its part, is related to the community structure of the network (Bargigli and Gallegati 2012). Thus, a community detection algorithm provides a general recipe for detecting those areas of the financial system that are most likely to be affected when some nodes are initially hit by shocks, without the need to specify such shocks in advance.

In an environment of heterogeneous interacting agents, there is also room for an extension of the Lucas critique. It is well known that, since the underlying parameters are not policy-invariant, any policy advice derived from large-scale econometric models that lack microfoundations would be misleading. The Lucas critique implies that, in order to predict the effect of a policy experiment, the so-called deep parameters (preferences, technology and resource constraints) that govern individual behavior have to be modelled. Only, in this case, it is possible to predict the behavior of individuals, conditional on the change in policy, and aggregate them to calculate the macroeconomic outcome. But here is the trick: aggregation is a sum only if interaction is ignored. If non-price interactions (or other non-linearities) are important, then the interaction between agents may produce very different outcomes.

Mainstream models focus on analytical solvable solutions: to get them, they have to simplify the assumptions, e.g., using the RA approach or a Gaussian representation of heterogeneity. At the end, the main objective of these models is to fit the theory, not the empirical: how to explain, e.g., the scale-free network of the real economy by using the non-interacting network of the mainstream model? At a minimum, one should recognize that the mainstream approach is a very primitive framework and, as a consequence, the economic policy recommendations derived from it are far from being adequate prescriptions for the real world.

One of the traditional fields of applications of economic policy is redistribution. It should be clear that a sound policy analysis requires a framework built without the RA straightjacket. A redistributive economic policy has to take into account that individuals are different: not only do they behave differently, e.g., with respect to saving propensities, but they also have different fortunes: the so-called St. Matthew (13:12) effect (*to anyone who has, more will be given and he will grow rich; from anyone who has not, even what he has will be taken away*), which is the road to Paradise for Catholics, and the power-law distribution of income and wealth (Clementi and Gallegati 2016) for the econophysicists. [A "power law" distribution can simply be obtained by coupling a multiplicative shock with a repelling threshold (Levy and Solomon 1996). Note also that, without a representative agent, the analysis of agent distribution must be corrected using Zanardi's estimator (Clementi et al. 2018) and, strictly speaking, we would have as many multipliers as classes of income, as well as many welfare indices like the Atkinson ones, each deflated by its own consumption basket.]

Gaffeo et al. (2007) show that there is a robust link between firms' size distribution, their growth rate, and GDP growth (see also Gabaix 2011). This link determines the distributions of the amplitude frequency, size of recessions and expansion, etc. Aggregate firm size distribution can be well approximated by a power law (Axtell 2001; Gaffeo et al. 2003), while sector distribution is still right-skewed, but without scale-free characteristics. Firm growth rates are far from being normal: in the central part of the distribution, they are tent-shaped, with very fat tails.

Moreover, empirical evidence shows that an inverse function of firm age and size exists, and is proportional to financial fragility. In order to reduce the volatility of fluctuations, policymakers should act on the firm size distribution, allowing for growth of their capitalization, their financial solidity and wealth redistribution (Delli Gatti et al. 2004, 2005). Since these emerging facts are policy sensitive, if the aggregate parameters change, the shape of the curve will shift as well. Different from Keynesian economic policy, which theorizes aggregate economic policy tools, and different from mainstream neoclassical economics, which prescribes individual incentives because of the Lucas critique but ignores interaction, which is a major but still neglected part of that critique, the ABM approach proposes a bottom-up analysis.

According to the general consensus, a central bank must perform three different tasks: (1) it must provide a "nominal anchor" to the monetary unit used to sign contracts, to quote prices and to keep accounts, with the aim of controlling inflation and inflation expectations; (2) it must ensure that such an obligation is managed at minimum cost in terms of output fluctuations; (3) it must promote a secure and efficient payment system to prevent financial collapses and sudden shortages of means of payments. Standard macroeconomic monetary models insert tasks (1)–(2) into a rational-expectation general-equilibrium framework to obtain optimally designed policies (Clarida et al. 1999), while task (3) is simply ignored on the presumption of efficient markets and perfect arbitrage [Not to mention the possibility, suggested by Keynes in his *General Theory*, that the economy possesses multiple "natural" rates, many of which are compatible with involuntary unemployment].

The recent global financial crisis has dramatically proved how very wrong and misleading these assumptions could be. In the complex ABM system we are depicting here, endogenous uncertainty affects both the public and policymakers, and the very notions of rational expectations and rational learning are meaningless. In the absence of a Walrasian auctioneer, individual agents can fail to coordinate their choices, and macro-financial instabilities materialize as a marker of such failures. Traditional monetary policy (tasks 1–2) and the promotion of stability in the financial system (task 3)—including the general provision of liquidity to financial institutions and other unconventional policies in the wake of a financial crisis—are thus interlinked and must be devised inside a unitary framework. Several interesting research questions arise from this approach. A promising approach is the one rooted in the long tradition that goes back to the idea of a natural rate of interest elaborated by Knut Wicksell (1898) and the notion of forced saving developed by the Austrian school in the 1930s. Simply stated, the point is as follows. Suppose the economy possesses a real interest rate consistent with full employment and stable prices (and consistent private expectations thereof), and call it natural. In a world of radical uncertainty, a central bank that aims to peg the interest rate cannot know for sure where the natural rate is at any particular point in time, and a discrepancy between the natural and the market rates can easily occur and be maintained for quite a long time. When the market rate is lower than its natural counterpart, entrepreneurs are encouraged to borrow from banks in order to undertake investments that will add to the supply of goods for consumption in the future. However, that same discrepancy implies that consumers are not willing to sacrifice current consumption for future consumption (that is, to save) at the rate expected by entrepreneurs to make their investments profitable. As a result, an intertemporal coordination failure between saving and investment emerges due to an incorrect market signal: the economy builds up a stock of capital in excess of what is needed. Notice also that such a process can continue without overall price inflation if the economy is growing, and the rate of growth of available nominal money does not exceed that of the demand for real balances. The recent history of the U.S. and other industrialized economies—marked by exceptionally low interest rates, massive capital inflows from China and oil-producing countries, decreasing saving rates of households and a spectacular accumulation of office buildings, houses and excess productive capacity—can be interpreted along these lines. Mostly valuable for the issue we are dealing with, the grouping of large cumulating financial imbalances and missing (CPI) inflation has shown that the practice of inflation targeting, followed by many central banks around the world, has not only failed to engineer financial stability as a by-product,[?] but, in fact, has actively contributed to the creation of asset-price bubbles (Leijonhufvud 2009). Once again, the crucial point is that saving-investment imbalances are emerging properties of a macroeconomic system composed of heterogeneous interacting units, and cannot be deduced from the primitive characteristics of a representative agent. As we abandon rational expectations, one must ask how monetary policy must be conducted to prevent an economy from sliding along a cumulative destabilizing path characterized by increasing financial instability. The lessons for monetary policy, wonderfully summarized by Howitt (2006), are a natural starting point for new research along a new paradigm. In particular, agent-based explorations of how adaptive heterogeneous mechanisms of expectation formation interact with different assumptions as to the way in which prices and quantities adjust in real time can shed additional light on the viability of alternative interest rate rules in anchoring inflation expectations, or in solving intertemporal coordination failures.

A second strand of issues arises naturally as soon as one starts to think about the way in which monetary policies aimed at addressing tasks (1) to (3) should be designed and implemented in the presence of endogenous waves of optimism and pessimism. In a previous life, Governor Bernanke made use of a New-Keynesian DSGE framework to ask himself whether central bankers should respond to movements in asset prices, and the answer he gave was negative: “Changes in asset prices should affect monetary policy only to the extent that they affect the central bank’s forecast of inflation. To a first approximation, once the predictive content of asset prices for inflation has been accounted for, there should be no additional response of monetary policy to asset-price fluctuations” (Bernanke and Gertler 2001, p. 253). Notice, incidentally, that the same conclusion is still sustained by recent research (conducted, needless to say, by means of a structural DSGE model) at the IMF (International Monetary Fund 2009). [For a couple of examples to be interpreted as a starting point for additional explorations, see De Grauwe (2009), who discusses a simple New-Keynesian model in which reinforcement learning mechanisms can generate correlations in beliefs, with interesting implications for the role of monetary policy in stabilizing output fluctuations; and Canzian et al. (2009), who insert a social contagion mechanism inside a dynamic IS-LM model to provide an agent-based description of the behavioral traits contained in Keynes’ original description of the business cycle (Chap. 22 of the *General Theory*).] Finally, it could be interesting to extend the analysis put forth in Delli Gatti et al. (2005), in which some issues on the rules-versus-discretion debate are discussed in a fully decentralized macroeconomic agent-based model that mimics the learning processes of the central bank by means of a genetic algorithm. In particular, such a framework could be usefully employed in evaluating alternative proposals on new macroprudential arrangements, or innovative feedback adaptive rules, such as the “Taylor rule for capital adequacy” recently proposed by Ingves (2009).

As Ozdagli and Michael Weber (2017) demonstrate, monetary policy shocks have a large impact on stock prices through large network effects in realized cash-flow fundamentals. Their findings indicate that production networks might be an important mechanism for transmitting monetary policy to the real economy. A very important aspect regards the transmission channels that can be analyzed only with an ABM conjugated with consistent analysis of the stock flow (Caiani et al. 2016a, b).

Catullo et al. (2015) present an agent-based model that underlines the importance of credit network and leverage dynamics in determining the resilience of the system, defining an early warning indicator for crises. The model reproduces macroeconomic dynamics emerging from the interactions of heterogeneous banks and firms in an endogenous credit network. Banks and firms are linked through multiple credit relations, which derive from individual target leverage choices: agents choose the more convenient leverage level, according to a basic reinforcement learning algorithm.

Furthermore, it is important to emphasize that the complex ABM methodology allows us to analyze the complexity theory using two tools—dynamic systems and the network—to model the real world and "the economy in the business cycle and to measure vulnerability/fragility. When this knowledge is applied to the topology of networks of people and their social interactions, it becomes possible to quantify integration between social groups as well as isolation of minorities or other social subgroups" (Pijpers 2018, p. 16).

Catullo et al. (2018) propose an alternative regulation framework based on the so-called meso prudential policy, using an ABM to answer two different questions: (a) Are there any drawbacks when the financial stability authority has used a combination of micro and macro prudential policies to achieve its target?; (b) Does a prudential policy that also takes into account the credit network relationship work better in terms of output and credit stabilization than the one based on a traditional micro/macro framework? The following results emerge from their investigation: (a) the combination of micro and macro prudential policy reduces instability and the probability of an economic crisis with respect to the scenario that implements the micro prudential policy alone; (b) However, such instability does not disappear, but is rather transmitted to the banking system through the higher volatility of banks' equity; (c) The implementation of a meso prudential policy is effective in reducing systemic risk through tightening of the capital requirements of more connected banks only. Therefore, exploiting network topology, it is possible to better coordinate micro and macro prudential policy in order to increase the resilience of the economic system without impacting on the performance of the banking system.

Economic policy is no longer just a stabilizer of fluctuations, an entrepreneurial role (Mazzucato 2013) with a redistributive, "granular" and social-inclusive function. Only a complex ABM has the tools to answer the questions "how and who is growing?" What generally emerges is not a one-size-fits-all policy, since it depends on the general as well as the idiosyncratic economic conditions; moreover, it generally has to be conducted at different levels (from micro to meso to macro, or micro–macro-prudential rules and network-sensitive policies).

Chapter 4
Where Do We Go, to Go Where We Have to Go?

4.1 A Paradigm Shift

Since in a finite world like ours, resources are limited, we need research to show us how to steer innovations towards technologies able to save non-renewable energy and to redesign the environmental impact of products throughout their life cycle. Adopting this perspective can lead to the dematerialization of products, the use of relational goods [Relational goods consist of interpersonal relationships, dialogue, sharing, solidarity, answers to social utility needs, etc. They are different both from *material goods* (which are "satiable," because they are intended to meet survival needs) and from *positional goods*, intended for what is superfluous (and therefore "insatiable," because the demand can be induced and fed indefinitely)] and the idea of *sufficiency*.

Sustainability is certainly a complex, multidimensional concept and often difficult to define. Nonetheless, it seems to me that at least one certainty can be identified: the economic challenges that the developed countries face are quite different from those of developing countries. The latter have little pollution, but few resources to devote to green investment, and therefore "risk" using their sustainable resources, which they need in order to grow, in a non-renewable way. On the other hand, already developed countries have serious pollution problems and cannot reasonably disallow all of the others from growing as they have done, thus compromising the environment, which belongs to everyone (pollution invests the planet: we all have to participate in reducing it, because nobody can do it alone), or from consuming natural resources.

All of this indicates the only possible way to go: developed countries must innovate in order to save resources, growing in a different way from that which they have followed so far so as to allow the poor countries to grow. In *Something new under the sun*, John McNeill (2000) points out that, between 1890 and 1990, the world economy grew 14-fold, the world's population quadrupled, water use went up ninefold, sulphur dioxide emissions increased 13-fold, energy use rose 16-fold and

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carbon dioxide emissions went up 17-fold. The work of James Speth (2008), *The Bridge at the Edge of the World*, confirms this trend, updating the figures to 2005. The protagonist of this deterioration of the relationship between natural and social systems is the mechanism of economic growth that was triggered by the Industrial Revolution and pursued from then on, and that still directs the lives of we unwilling hamsters.

Who can believe in a world in which nine billion people—that's how many we will be in 2050, according to the forecast of the United Nations—can all reach the level of wealth of the OECD nations? Tim Jackson (2009), in *Prosperity Without Growth*, reminds us that, by that time, if we maintain our current standards, the economy would need to be 15 times the size of the current one (75 times that of 1950), and continue to grow exponentially until it is 40 times its present size at the end of this century (200 times that of 1950). This is obviously a paradox: but without changing the way in which we live, produce and consume, a shared and lasting prosperity is inconceivable.

Social sustainability depends essentially on the distribution of resources. If there is great inequality, we can create the distortions I mentioned in *The Economy of the Hamster* (Gallegati 2014), which affect participation in social life. Increased inequality in the distribution of wealth and income in a country can put its social cohesion at risk, and consequently that of national democracy itself. If this happens at the supranational level, between countries, it is not difficult to imagine that the increase of relative poverty could lead to massive migratory phenomena fleeing from unsustainable economic conditions, exacerbated and compromised, if we don't intervene, by environmental degradation. Deterioration in distributive equity may also permanently damage *social capital*, i.e., the set of shared values and rules that makes civil coexistence possible.

All of this implies a change of paradigm: we can no longer live to work and work to consume, believing (or pretending to believe) in the myth that, by consuming more goods, we'll be happier.

4.2 The House Is on Fire, But I'll Use the Only Bucket of Water Left to Have a Shower

In Chap. 2, I mention the work of Blanchard (2009) about the state of macroeconomics being good. This was an article published by the National Bureau of Economic Research written at the dawn of the Great Recession, which, some years later, the author has now corrected: "Until the 2008 global financial crisis, mainstream U.S. macroeconomics had taken an increasingly benign view of economic fluctuations in output and employment. The crisis has made it clear that this view was wrong and that there is a need for a deep reassessment" (Blanchard 2014; see also Blanchard 2018).

To understand how this point of view emerged, we have to go back to the so-called "revolution of rational expectations" of 1970. Which was actually a counterrevolution, launching 30 years of triumphant neoliberalism. The basic idea is that the behavior of people and firms depends not only on current economic conditions, but is also influenced by what we and the others expect will happen in the future. It follows then that the decisions I make now also depend on the predictions of others, and, in the same way, the expectations of others will depend on "my" expectations: the result is a vicious circle. Basically, the problem is that, even in this theory, economics is considered as a linear system, constantly subject to external disturbances that don't affect its perpetual return to equilibrium.

The idea that small disturbances can have large effects cannot be contemplated in the linear axiomatic economic world. However, even if, only a few years earlier, Robert Barro, one of the mainstream leaders, advocated the policy of "taking no prisoners"—whoever isn't faithful to the dogma of axiomatic theory is a loudmouth and should simply be ignored—Blanchard (2014) recognized that: "Turning from policy to research, the message (of the Great Recession) should be to let a hundred flowers bloom. Now that we are aware of nonlinearities and the dangers they pose, we should explore them further theoretically and empirically—and in all sorts of models. This is happening already, and judging from the flow of working papers since the beginning of the crisis, it is happening on a large scale."

And the fact that we have to change the DSGE models on which economics is currently built (those, we have seen, that claim to describe the global economic system based on the behavior of an average agent, as if one lived isolated from everyone and everything, without the interactions and emergent phenomena dealt with in Chap. 2) has, by now, been ascertained. But do we have to change the paradigm or continue with the strategy of adding epicycles onto epicycles, as the Ptolemaic astronomers did with astral anomalies?

The easiest part of the answer is that DSGE models should be extended to the financial system. And this has been done. There are now several DSGE that include banks. Moreover, they are enriched with heterogeneities, which must never entail direct interaction (because, as we know, this would represent an externality and would mean the failure of the "market" abandoning general equilibrium). The crisis has thus helped to produce richer, and therefore more realistic, DSGE models. But without having resolved the poor adherence of data to the model, or the logical problems used by the SMD theorem to pin responsibility on mainstream modelling of the unattainability of that much-vaunted equilibrium.

Blanchard himself asked whether these models should also be able to describe how the economy behaves in crisis, and the answer he gave was both disarming and ingenious: when things go well, we can still use the DSGE. But another class of economic models, designed to measure systemic risk, can be used to give warning signals when we are getting too close to a crisis and evaluate policies for reducing risk. Trying to create a model that integrates both normal and crisis times (and thus is suitable for all seasons) seems to be beyond the conceptual and technical capacity of the profession, at least at this stage.

Currently, we can only aspire to a model that explains how the sun rises and another one that explains how the sun sets (although, to be precise, we know from Copernicus that, if anything, it is the Earth that rises and sets). In other words, we must be content to continue using the map of the ideal city to visit all of the cities in the world. And when you get lost, maybe ask a policeman: where do we go to get where we have to go?

What the axiomaticists don't seem to have perceived is that an economy is a self-organized system (Bak 1997), i.e., a complex system in which nonlinearities are a product of direct interaction between agents who are constantly present, both close to and far from a crisis. Earthquakes are always attributable to the movement of tectonic plates, regardless of whether they have a magnitude of 0 on the Richter scale (eight thousand a day) or a magnitude of 9 (one every 20 years).

In short, the general economic equilibrium theory becomes inconsistent when its aims and the analytical results obtained meet: it isn't possible to rigorously deduce, and thus be certain of obtaining, those results (global stability and uniqueness of equilibrium) that are central to the paradigmatic core of the theory. On the other hand, even the evolution of the latter in DSGE models is unable to explain the real world and the behaviors deriving from its non-falsifiable axioms. However, DSGE also continues to be resistant to the criticisms of "dilettantes" and indifferent to the contradictions of the real world.

And what if the ABM theory were the new paradigm?

4.3 Dilettantes at Work

Each schematization, as long as it makes clear the logical scheme of the author, involves a loss of information. What I proposed is no exception, although it has, in my opinion, an immediate and intelligible interpretation.

Economic theory can be divided, for our purposes, into:

a branch that does not deal with direct interactions between agents, with the assumption of

1. A representative agent, or of
2. Heterogeneous agents without infra-group dynamics;

a branch that analyzes the issue of heterogeneous interacting agents using Agent-Based Models that are separated into two approaches:

3. Agent-based Computational Economics (ACE);
4. Analytically Solvable HIA (ASHIA) models based on statistical physics or Markov chains.

The difference between the two branches can be traced back to assumptions about information. If information is complete or incomplete, but not asymmetrically distributed, there is no room for direct non-market interaction, because agents do not need to increase their information through interaction and sooner or later will learn the true outcome of the model (see also Ellison 1993). Some consequences follow: there are no coordination problems, and thus no functioning pathologies.

However, interaction, once introduced, involves non-linearity and externalities and, more generally, one loses the proportionality between cause and effect: small shocks may lead to large effects. In my opinion, we must take into account the difference between atoms and human agents: this involves the transcending of the methodology proposed in statistical physics and the transition to the economics of complexity. The main consequence of learning, or of learning atoms, as stated in the quotation of Gell-Mann, reported by Page (1999), is that the tools of physics cannot be translated *sic et simpliciter* in economics.

The contributions of Foley (1994) and Aoki (1996) have introduced into economics the possibility of analytically treating the issue of many heterogeneous and interacting agents, and thus micro-founding aggregate behavior without resorting[?] to the heroic hypothesis of a representative agent. With this achievement, we depart from the economics of mechanical equilibrium of the Poinsot-Walras setting to the economics of equilibrium probability distributions, in which the single agent can find itself outside of equilibrium and the system becomes complex.

A crucial aspect of the complexity approach is how interacting elements produce aggregate patterns that those elements, in turn, react to. This leads to the emergence of aggregate properties and structures that cannot be guessed by simply looking at individual behavior. What determines the emergency are non-linear interactions. If and only if—a system is linear, the proportionality between cause and effect is preserved and analytical separation of the former is possible. If the independent variables are separable, the ceteris paribus analysis is possible. In the presence of non-linearity, in fact, small idiosyncratic shocks are sufficient—they spread rapidly through domino effects—to make future configurations unpredictable. Indeed, as we know, interactions—and non-linearities in general—show a marked dependence on initial conditions. Path dependence implies that the particular way in which events have developed over time influences future results [Note that, in the presence of interaction, even i.i.d. noise could cause path dependency phenomena].

It has been argued (Saari 1995) that complexity is ubiquitous in economic problems (although this is rarely acknowledged in economic modelling), since (1) the economy is inherently characterized by the direct interaction of individuals and (2) these individuals have cognitive abilities, e.g., they form expectations about aggregate outcomes and base their behavior upon them. In a nutshell, the passage from economics to economic complexity will coincide with the passage from an axiomatic discipline (what economics actually is) toward a falsifiable science (falsifiable at different levels of aggregation); an economic policy in which one size does not fit all.

In their introduction of the learning mechanism, Landini et al. (2015) present a model that goes beyond the tools of statistical mechanics, opening the path for its applicability to social science, and to economics in particular. After having derived analytic functions, they model learning agents as a finite memory Markov chain, and subsequently derive the corresponding master equation that describes the evolution of the population of the same agents. Economic agents differ from physical atoms because of their learning capability and memory, which lead to strategic behavior. Economic agents learn how to interact and behave by modifying their behavior when the economic environment changes (*self reflexivity*). They show that business fluctuations are endogenously generated by the interaction of learning agents via the phenomenon of *regenerative-coordination*, i.e., agents choose a learning strategy that leads to a pair of output and price that produce[?] feedback on learning, possibly modifying it. Mathematically, learning is modelled as a chemical reaction of different species of elements, while inferential analysis develops a combinatorial master equation, a technique, which is an alternative approach to modelling heterogeneous interacting learning agents. [On modelling ABM as a Markov chain, see Gintis (2012).] Note also that the possibility of interaction between agents can address the problem of coordination failures (that is, for example, crises and fluctuations). [See a review of applications of the complexity theory to economics in Rosser (1999, 2003); Arthur (2000); Beinhocker (2006); Miller and Page (2006); Kirman (2011, 2016).]

Agent-Based complexity theory should not be confused with general systems theory, a holistic approach developed in the 1950s and 1960s that, in its most radical form, argued that everything affects everything else: according to systems theory, phenomena that appear to have simple causes, such as unemployment, actually have a variety of complex causes—complex in the sense that the causes are interrelated, nonlinear, evolving and difficult to determine. Conversely, the complexity approach looks for simple rules that underpin complexity. The research program launched by the neoclassical school states that macroeconomics should be explicitly grounded in microfoundations. According to the mainstream approach, this implies that economic phenomena at a macroscopic level should be explained as a summation of the activities undertaken by individual decision-makers. The reduction of the degree of freedom, which is characteristic of the aggregation problem in physics, is ruled out: a rational agent with complete information can choose to implement the individually optimal behavior,

There are three main pillars of this approach:

The precepts of the rational choice-theoretic tradition;
The equilibrium concept of the Walrasian analysis; and
The reductionist approach of classical physics.

The first two assumptions, which constitute the necessary conditions for reducing macro to micro, are logically flawed (and empirically unfounded), while rejection of the third opens the road to complexity. Mainstream economics, like theology, is an axiomatic (dogmatic) discipline. According to the supporters of this view, such an abstraction is necessary, since the real world is complicated: rather than compromising the epistemic worth of economics, such assumptions are essential for economic knowledge. However, this argument does not invalidate the criticism of unrealistic assumptions (Rappaport 1996). While it requires internal coherence, so that theorems can be logically deduced from a set of assumptions, it abstracts from external coherence between theoretical statements and empirical evidence. Of course, this implies an important epistemological detachment from falsifiable sciences like physics.

ABM is a methodology that can be applied to any model. It is valid for the DSGE, as well as for “amateurs”: the Walras’ model is a model of agents arranged on a star network, while the DSGE [e.g., Smets and Wouters 2003] has identical agents, or non-interacting heterogeneous ones—that is, without networks. While the former do not show those aspects of complexity that are related to the real world, the present work is dedicated to the ones in which the HIA generate complexity.

4.4 By Way of Conclusion

As we saw in Chap. 3, “agent-based models” make it possible to overcome some of the many contradictions of the axiomatic model, whether it be reconciling reality and theory or making the construction a dynamic one: innovation, for example, becomes the engine of the economy, and not a stumbling block. Paradoxically, the axiomatic theory, instead of acknowledging the numerous cases of market failure, always prescribes further market expansion as a way to restore mainstream economics. Although this theory admits that, in reality, the market fails to be efficient, nothing is done to review the regulatory requirements that give the market itself the function to act as a tool to reach that “optimality” of which we spoke. Because, according to the *mainstream* theory, if the Pareto principle is an efficiency that cannot be obtained in reality, it is only because the markets aren’t widespread enough. An excellent example of confusion between dreams, reality and the wishes of numerous small make-believe Napoleons who are convinced they can fight the battle of Austerlitz again. Better not fall into the trap of discussing military strategies with them, because it would be like acknowledging that we really are in front of Bonaparte, as Solow (1984) says.

In this book, we have seen that economics is in crisis from at least two different perspectives.

The first is the crisis of the GDP growth concept as a means of spreading economic well-being by means of increased employment. *Jobless* growth is a phenomenon now common to all economies since the mid-1990s, and this has led to talk about *agrowth*. Furthermore—as Pijpers notes (2018: 3–4)—“Within complex systems there is a known phenomenon referred to by the term “self-organized criticality.” It appears that many systems have the property that, through the interactions of the elements within the system, they reach a critical state. As long as there is no external stimulus or disruption to this system, it appears to be in a stable equilibrium. However, a very small disturbance of the system in this critical state can cause very far-reaching changes. In this case a traditional approach, where the behavior over the recent past is used as an indicator of future stability or robustness, is clearly not suitable. Some small stimuli might cause widespread disruption, and others none at all. An arbitrary external stimulus of a system that is in such a critical condition will not as a matter of course produce an instability or other “catastrophic” behavior. Modelling is a means of assessing in what ways, i.e. for which incentives or stimuli, an economy is *vulnerable/fragile* and which stimuli are harmless, i.e. leave the economy *robust* or *sustainable*."

Thus, the economic crisis, which has been ongoing since 2007, with GDP slumps, bankruptcies, deflationary phenomena and levels of unemployment not seen since the Great Depression, raised questions about the relevance of the current mainstream. And it seems as if the only way to tackle it is with exceptional measures. This aspect is intertwined with the fact that the dominant macroeconomic model was unable to predict the crisis because it didn't contemplate a priori any possibility of a long, deep crisis like the one we are currently experiencing. This is why the crisis has also affected the paradigm, just like the Depression of 1929 did. That crisis was resolved with the New Deal and, at the same time, with the Keynesian revolution as well.

Perhaps it is not true that the future enters us, to be transformed within us long before it actually happens, but if we continue with the same demographic and production trends, in 2030, we will need the resources of two Earths. So, we must either prepare ourselves to colonize the Universe or to immediately start redistributing resources and thinking about sustainability.

The crisis of mainstream economics is well documented by academic works and central bankers' contributions. In my opinion, a fundamental feature of macroeconomic modelling resides in the ability to analyze complex evolutionary systems like economic ones. What characterizes a complex system is the notion of emergence, that is, the spontaneous formation of self-organized structures at different layers of a hierarchical system configuration. Agent-Based Modelling is a methodological instrument—one that can be fully employed by both neoclassical and Keynesian economists, or those of whatever theoretical approach. [Reconciling DSGE and complex ABM seems to resemble the calculation of Tycho Brahe, who proposed a model that replaced the Ptolemaic one among all of those astronomers who did not want to accept the Earth's movement. From a cinematic perspective, the tychonic model is identical to the Copernican one. The two models differ only by their chosen reference system: the Earth for Brahe, the Sun for Copernicus]—which is appropriate for studying complex dynamics as the result of the interaction of heterogeneous agents (in which a degenerate case would be a "representative agent" model for which the degree of both heterogeneity and interaction is set to zero, that is, a situation that reduces holism to reductionism in a hypothetical world without networks and coordination problems). Even when fluctuations of agents occur around equilibrium, which we could calculate using the standard approach, the ABM analyses would not necessarily lead to the same conclusions. This is because the characteristics of the fluctuations would depend on higher moments of the joint distribution and often on the properties of the tails, or three kurtosis of the distribution.

For the last couple of decades, ABM have seriously taken to heart the concept of an economy as a complex, complex system [Anderson et al. 1988]. Two keywords characterize this approach: *Evolving*, which means the system is adaptive through learning; and *ABM complex*, i.e., a methodology that allows us to construct, based on simple (evolving) rules of behavior and interaction, models with heterogeneous interacting agents, in which the resulting aggregate dynamics and empirical regularities are not known a priori and are not deducible from individual behavior.

Agents' behavioral rules are not fixed (this does not mean that it is not legitimate to build ABMs with fixed rules, for example, to understand what the dynamics of an economic system would be if agents behaved in an "optimal" way), but change by adapting to variations of the economic environment in which they interact. The traditional approach that assumes optimizing agents with rational expectations has been, and remains, a powerful tool for deriving optimal behavioral rules that are valid when economic agents have perfect knowledge of their objective function, and it is common knowledge that all agents optimize an objective function that is perfectly known. If agents are not able to optimize, or the common knowledge property is not satisfied, the rules derived with the traditional approach lose their optimality and become *ad hoc* rules. Research is still far from being complete, above all where the empirical verification of aggregate models is concerned, but it is already more effective in explaining reality than what has been done so far and continues to be done by the DSGE models that dominate the economic scene. Although ABM certainly do not constitute a panacea for the crisis, it is indisputable that they provide suggestions of economic policy unknown in traditional models (network, domino effects, resilience and fragility, etc.). Freed from the straightjacket of the equilibrium and representative agent hypothesis, which only works with a single good and a single market, we can finally dedicate time to investigating the potentiality of interactive agents and their emergent properties.

The complex ABM approach can offer new answers to new and old unsolved questions, although it is still in a stage far too premature to offer definitive tools. This book shows that this new tool has already yielded interesting results, and also that this approach does not say different things in simple situations in which the comparison with the standard models is possible. It enables analysis of complex situations that are difficult to analyze with the models most in use today.

We need a paradigm that knows how to conjugate economic, social and environmental aspects. A *secular* paradigm, free from that axiomaticism that is characteristic of the current economic *mainstream*. I don't want to affirm that *complex ABM* models will be the starting point for future economic theory. But nearly.

After all, our well-being will depend on the possibility of choosing the future.

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