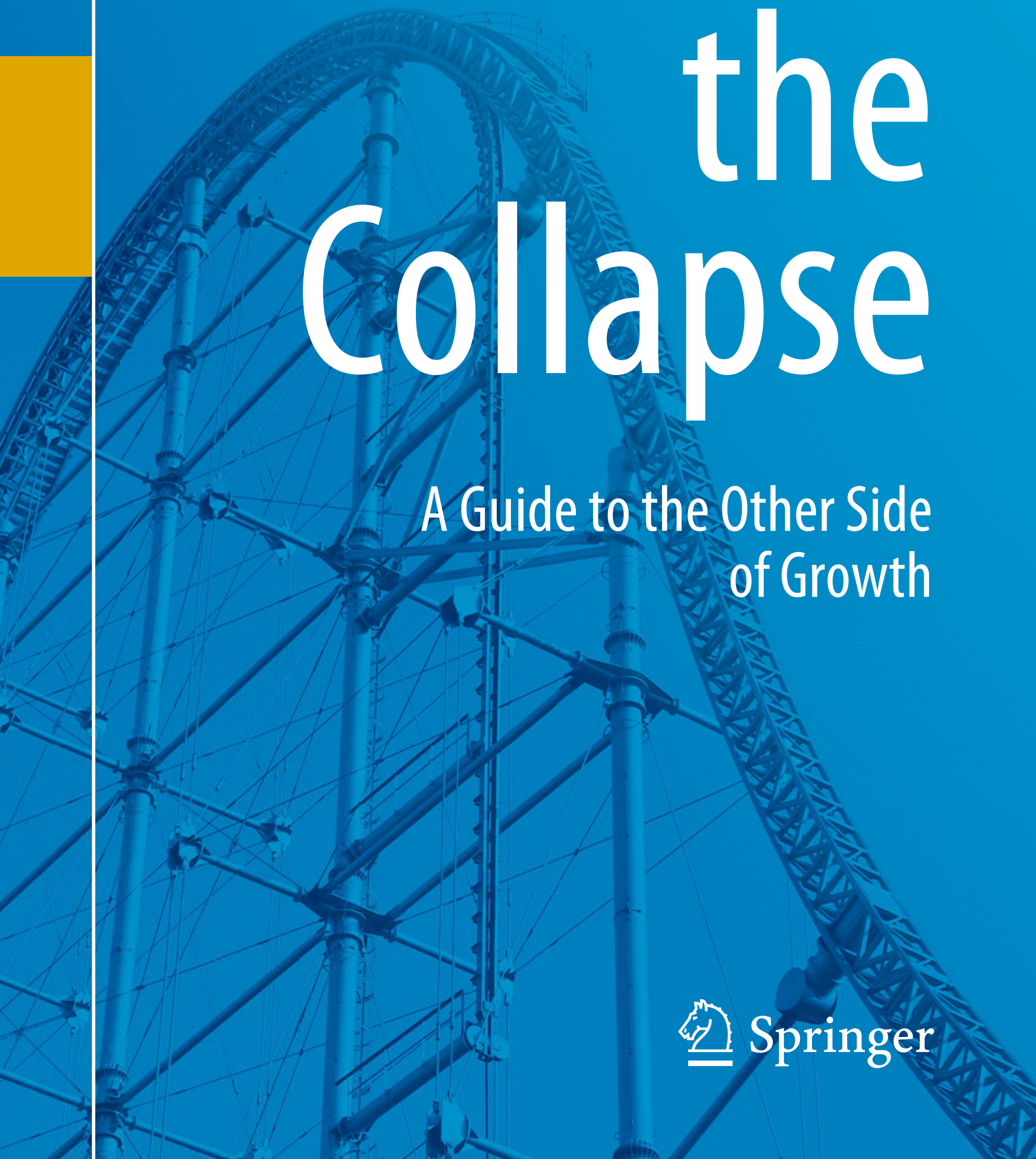
Ugo Bardi

Before the Collapse

A Guide to the Other Side of Growth



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Dedicated to my two granddaughters, Aurora and Beatrice, who were both born while this book was being written and who will live in the future that we can only dimly perceive today.

Foreword by Susan Kucera

I met Ugo Bardi for the first time when I interviewed him in Florence for my 2014 movie “Breath of Life”. More recently, he was featured in my 2018 documentary “Living in the Future’s Past” and in 2019 we met again in a medieval castle in the hills near Florence for a new film in production. It was a fitting environment to discuss how our future is mirrored in our past. Discussions with Ugo are always fascinating: you find yourself finding parallels between worlds that you would have thought to be so different as to have no points in common. For example, Ugo has such a breadth of knowledge that he can always tell you about how ancient civilizations, from the Sumerians onward, had so many points in common with our world. In particular, Ugo is interested in a comparison of our situation with that of the age that we call “Late Antiquity” or “early Middle Ages”.

In those ancient times, people were facing similar problems to those we face today: how can we maintain the achievements of what we call “civilization” in a condition of decline of our material wealth? According to Ugo and his coworker, the young Italian medievalist Alessia Scopece (whom I also met in that medieval castle in 2019), the early Middle Ages were far from being a “dark age”. Rather, they were a period of creative adaptation to a difficult economic situation. People living in the Middle Ages developed flexible and inexpensive solutions to problems that were unsolvable within the old paradigms, for instance, lacking precious metals, they developed cultural methods of exchange that replaced conventional methods. According to Ugo, the holy relics that were such a typical feature of the Middle Ages were in many ways to be seen as “money”, something that facilitated commerce and travel in Europe.

Ugo is not just interested in the past: he projects into the future and his studies on the great energy transition tell us whether it will be possible to abandon fossil fuels to build a society entirely based on renewable energy. He told me that, "it is obviously possible because it is unavoidable". The problem is not whether we'll get there or not, but how fast and with how much hard work and sacrifices. But just as the Middle Ages were the unavoidable destiny of the declining Roman Empire, a renewable-based society is the unavoidable destiny of our declining civilization.

In this book, Ugo Bardi distils much of his thoughts and his reflections he developed over the past years. It starts from the past, from a thought of the Roman Philosopher Lucius Annaeus Seneca who was perhaps the first in history to note that decline is always faster than thought—"Ruin is rapid", as Seneca wrote. Out of this simple sentence, Ugo builds up a wide-ranging discussion of how we find ourselves in the current plight, desperately trying to fight against forces that we ourselves set in motion and that we are now unable to control. Climate change is the paradigmatic problem of our civilization, one that may very well bring us to that "Seneca Cliff" that Ugo describes in this book.

However, this is not a pessimistic book, it is not a book about doom and gloom, and Ugo is not here to scare us or to tell us that we have no hope to survive. On the contrary, it is a book that gains strength and breadth from the ancient Stoic philosophy of which Seneca was an adept. Stoics understood that the world always changes, sometimes fast, and sometimes so fast that, from our viewpoint, we see the change as a disaster. But all changes happen because they have to happen, and if we'll see big changes in the future it will be because they are necessary. Indeed, the connecting line that goes through this book is what Ugo calls the "Seneca Strategy"—the realization that change is necessary and that in most cases opposing it simply leads to a faster ruin. So, from ancient Stoics, we may learn the wisdom we need to face our uncertain future.

Hawaii Susan Kucera

Preface: The Seneca Effect: Why Growth is Slow, But Collapse is Rapid

It would be some consolation for the feebleness of our selves and our works if all things should perish as slowly as they come into being; but as it is, increases are of sluggish growth, but the way to ruin is rapid.
Lucius Anneaus Seneca, Letters to Lucilius, n. 91—translation by Richard M. Gummere

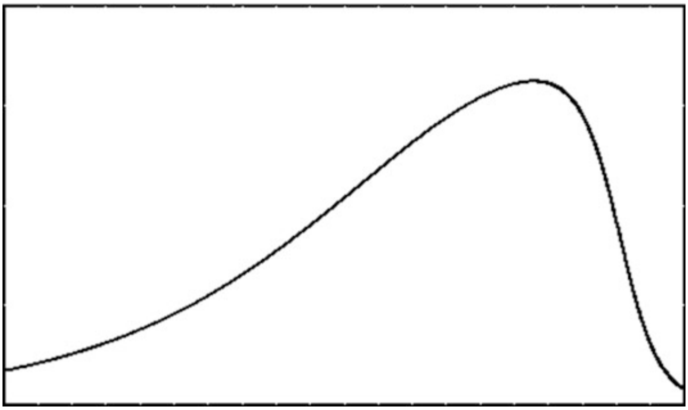

Fig. 1 The "Seneca curve" showing the time evolution of a system. Growth is slow, but the decline is rapid enough that it appears to us as a collapse

Normally, our life is quiet. As ordinary people, we may enjoy moderate prosperity, reasonable happiness, and expected events. But life is also full of surprises and when things start to fail, they tend to fail fast enough for us to use terms such as "collapse", or "ruin", as the Roman philosopher Lucius Annaeus Seneca noted already long ago when he said "increases are of sluggish growth, but the way to ruin is rapid" [1]. And when collapse comes, it often finds us woefully unprepared, that's why we should prepare in advance (Fig. 1).

It may be difficult to define collapses in rigorous terms, but we all can recognize one when we see it. Collapse is a rapid, uncontrolled, unexpected, and ruinous decline of something that had been going well before. It can strike individuals: you may lose your job, or get sick, lose a close friend or a family member. And it can happen very fast, sometimes by chance, sometimes by a mistake: think of the case of Roseanne Barr who, in 2018, saw her career of TV anchor ruined in a day because of a single racist tweet she wrote.

Collapse also affects larger systems. The average lifetime of a commercial company, today, is of the order of 15 years, but small companies tend to come and go much more quickly: it is the "fail fast, fail often" strategy, well known in Silicon Valley and supposed to be a good thing to eliminate the weaklings in the struggle for survival. True, a startup may become a "unicorn", a term coined by venture capitalist Aileen Lee to describe the rare case of a successful startup that reaches a value of over $ 1 billion. For these and even larger companies, demise may be a more difficult and painful affair, sometimes with possibilities of getting back in business as it happened to Evernote, a survivor of the early days of the Web that refuses to go away [2]. But, in most cases when a company goes down it goes *fast,* even for companies that were seen as the very image of solidity. Think of Lehman Brothers, the large financial company that went down in a few days at the time of the great financial crisis of 2008. That was when we discovered that there is no such a thing as a company that's "too big to fail".

While companies come and go, whole economies can experience disastrous crashes and, in that case, recovery may take a long time and sometimes never happens. Over history, economic collapses often accompany the decline and disappearance of empires and entire civilizations. Humankind has also seen abrupt population collapses caused by famine and pestilence and the same is true for the production of mineral resources that has seen entire regions experience production collapses, one of the most recent cases being that of the oil production from the North Sea. Today, we are facing the dire possibility of the ruin of our civilization and, perhaps, of the whole Earth's ecosystem. Climate change and resource depletion are the twin aspects of the troubles ahead.

Collapses are bad enough in themselves but they have a further quirk: they tend to arrive unexpected. Unless you are a firefighter, a physician, maybe you manage a large-scale electrical grid, or are engaged in some similar job, collapses are not part of your everyday planning. There is no "science of collapse" taught in universities or in business schools, and most of what we do is based on the idea that things will keep going on more or less as they have been doing in the past. The economy is supposed to be growing forever simply because it has been growing up to now. The same is true for the human population, the production of crude oil, or life expectancy at birth: they have been growing in the past and they are expected to keep growing in the future. The agencies and institutions that prepare forecasts in these fields work mainly on the basis of extrapolations of the historical data of the past few decades and tend to present a rosy picture of the future. It is a general problem we have with managing the future: nobody wants prophecies of doom! Yet, as we all know, growth cannot continue forever in a finite world (as we should know unless we are madmen or economists, a quote attributed to Kenneth Boulding). So, we should be prepared for the other side of growth well before collapse.

But what causes collapses? In ancient times, it seems that people tended to fault supernatural entities, Gods or evil magic, for the disasters befalling them. The first to note that collapses are a natural phenomenon, a fact of life, was perhaps the Roman Philosopher Lucius Annaeus Seneca in a note in on one of his letters to his friend Lucilius, written during the first century CE. Much later, during the seventeenth century, Galileo Galilei was the first scientist who tried to provide a mathematical explanation of collapses in the study of the fracture of solid objects.

Seneca's observation remained qualitative, while Galileo lacked the mathematical tools that he would have needed to build a complete theory of fracture. So, a true understanding of the physics of collapse came only in recent times with the development of the science of complex systems. The results of decades of work tell us that rapid changes are part of the way the universe works, a manifestation of the principle that rules everything, from living cells to galaxies: entropy, the basis of the second principle of thermodynamics. The science of complexity is possibly the most fascinating field of modern science and surely one that has significant consequences for our everyday life.

Out of this rapidly evolving field of science, there came the concept of the "Seneca Effect". It saw the light for the first time in 2011 in the form of a post in my "Cassandra's Legacy" blog [3]. Later on, I published a more detailed mathematical model in "Sustainability", a scientific journal [4]. Then, in 2017, I published a book that I titled "*The Seneca Effect*" [1]. I don't think that it is a difficult book to read, but it is also true that it was conceived as an academic book, with all the appropriate formulas and mathematical models. But the science of collapse is not just for academics: it is a science that everybody should know and use at least in its main features. That is the origin of this book, not a simplified version of the first Seneca book but a completely new one, with new examples, new discussions, new fields of application—also largely based on my personal experience.

So, this book is dedicated to how to confront collapses by being prepared before they arrive. That does not mean resisting collapse at all costs, desperately trying to maintain things as they are. Doing that means, typically, gaining some time in exchange for a much faster and abrupt collapse: by all means a bad deal. There are many examples of this concept and you can surely think of examples from your personal experience and perhaps the most evident one involves debating on social media. The more you try to contradict your opponent, the more you will find he or she will resist and respond to your arguments. That will often lead to the phenomenon called "flaming" that makes the discussion degenerate into an exchange of insults and personal attacks: a collapse of the debate!

Instead, the way to deal with collapses is to use what I call here the "Seneca Strategy". It is a view that derives from an interpretation of Seneca's work as a Stoic philosopher but that is also perfectly compatible with the modern field called "system dynamics" that Jay Forrester developed in the 1960s. The basic idea of the Seneca strategy is that the attempts to stave off collapse tend to worsen it [5]. It is also an idea with elements in common with some martial arts, such as Jiu-Jitsu or its modern incarnation, Judo, where practitioners aim at manipulating the opponent's force against themselves rather than confronting it with one's own force. So, the Seneca strategy consists in not opposing the tendency of the system to go in a certain direction but steering it in such a way that the collapse need not occur. The key of the strategy is to avoid that the system accumulates so much strain that then it is forced to vent it in an abrupt manner. Think of the story of the straw that broke the camel's back: collapse would not have occurred if the owner of the camel had avoided to overload the poor beast with heavy stuff.

But it is not always possible to avoid collapse, even though you may be able to detect it before it comes. Sometimes, it is just too late: the system has grown beyond its limits and it is now hovering somewhere in the unstable condition we call "overshoot". In this case, the system has to return to its acceptable limits, a condition sometimes called "carrying capacity". The best you can do is to soften the impact and prepare for landing. You will go through what I call the "Seneca bottleneck" with a view of restarting afterward and doing something better and wiser. That may be called the "Seneca Rebound". A good example is the fossil fuel industry: we can see its impending collapse and we *want* it to collapse in order to avoid a climate catastrophe, but not so fast that its fall will kill billions of people by depriving them of the energy they need to survive. The oil industry must keep extracting just the minimum that will be needed in order to create the renewable energy infrastructure that will replace the fossil one after the unavoidable collapse. This is what I called the "Sower's Way" [6], and it is a variant of the Seneca strategy.

Another useful skill derived from the Seneca strategy is how collapse can be exploited to get rid of old and useless structures, and organizations. I am sure that you know plenty of examples of irredeemably twisted and corrupt organizations that you have been thinking should be erased and rebuilt from scratch. You probably have in mind your government, but it is also possible to think of much smaller systems: plenty of people try to keep their marriage together beyond what's reasonable to do and in many cases divorce, the collapse of a marriage, is the best option. But a company may also become unfit to survive in the market, burdened by obsolete products, outdated strategy, an unmanageable organization. Bankruptcy is the way we call collapse in this case and, again, it is a way to start again from scratch. There are many other cases of collapses that result in something new and better emerging from the ashes of the old.

Finally, there is a further application of the science of collapse, one that Seneca would surely have disapproved of but that I cannot avoid mentioning: destroying one's enemy or competitor. It can be a military strategy: normally, a conflict ends when one of the two sides collapses and is not able to keep fighting any longer. It may happen because its military apparatus has been damaged beyond its resistance limits during the conflict but also as the result of the dark and dire things that, today, go under the name of "psyops" (psychological operations). Then, of course, nothing prevents people from using similar methods in business to cause the collapse of a competitor: think of "dumping", also defined as "predatory pricing". And even in love, perhaps the most competitive human enterprise, there exist objectionable but effective ways to get rid of competitors. Do you remember Hamlet saying, "Be thou as chaste as ice, as pure as snow, thou shalt not escape calumny"?

To summarize, the basis of the Seneca strategy can be described in four main points,

1. *Attention*. Remember that collapses occur and they do not just strike other people: they may strike you. Prepare in advance for a possible collapse!
2. *Avoidance*. You can avoid collapse if you start early enough by acting on the elements that put the system under stress. Detect collapses before they come!
3. *Mitigation*. If it is too late to avoid collapse, you can still reduce its damaging effects if you take appropriate precautions. Don't try to avoid collapse at all costs, but you can always soften it!

4. *Exploitation*. In some cases, you can use collapse to get rid of obsolete structures or to damage your competitors. And, therefore, welcome collapse!

I hope you will find this book useful for your life and your career but note that it is more than a manual for managing collapses. Since it starts from a sentence of a Stoic philosopher, it has a certain approach based on Stoic philosophy. The Stoics had understood a lot of things already two thousand years ago, the main one being, perhaps, that you cannot predict the future, but you can be prepared for it.

Firenze, Italy Ugo Bardi

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Contents

1

The Science of Doom: Modeling the Future

Forecasts are not always wrong; more often than not, they can be reasonably accurate. And that is what makes them so dangerous. They are usually constructed on the assumption that tomorrow's world will be much like today's. They often work because the world does not always change. But sooner or later forecasts will fail when they are needed most: in anticipating major shifts in the business environment that make whole strategies obsolete.
—Pierre Wack [1]

I will not die one minute before God has decided.
—Mike Ruppert, *Crossing the Rubicon* [2]

Predicting the Future: The Russian Roulette

Fig. 1.1 The Author giving a talk in Florence, in 2018. Note the gun in his hand: it is a harmless toy used to focus the attention of the public on the fact that knowledge, or lack thereof, may be dangerous. This may happen with guns, but also with much larger entities such as climate change (*photo courtesy* Ilaria Perissi)

U. Bardi, *Before the Collapse*,
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When I give public talks, sometimes I take a toy gun with me and I show it to the audience. I ask them this question: imagine you had never seen a gun, how would you know what it is and what it is for? Usually, the people in the audience immediately understand the message: the gun is a metaphor for climate change. How do we know how the Earth's climate works? And how can we know the kind of damage it can do to us? It is all about the field we call "epistemology," how do we know the things we know? Whether we deal with firearms or with climate change, ignorance can kill and epistemology can be a tool for survival (Fig. 1.1).

The idea of an unknown artifact that turns out to be a weapon is a typical trope of science fiction. When the hero of the story happens to find a ray gun or a phaser left around by aliens, he usually manages to understand immediately what it is for and to use it against his extraterrestrial enemies, it is a theme seen recently in the movie "Cowboys and Aliens" (2011). Rarer is the case of aliens stumbling onto a human-made weapon, but the theme was explored by Gilda Musa [3] in a delicate and intelligent story written in the 1960s where human explorers introduce a handgun to a civilization of peaceful aliens. Tragedy ensues, as you may imagine.

So, let us follow this idea. Suppose you are an alien and that, somehow, you find this strange object. You have never seen anything like it before and you only know that it was left by those weird Earthlings. They are a tricky race, so you may suspect that it is a dangerous object—maybe a weapon. But how to tell? Framed in these terms, we have a very pragmatic question that does not lead us to ethereal philosophical reasoning. What we need to do is to build a *model* of the unknown entity that can tell us how to deal with it and—in particular—if it is dangerous or not to deal with it.

Some people tend to belittle models as something purely theoretical, as opposed to the real world. But that's a completely wrong view: models are necessary and we build them all the time in our everyday life. On this point, it is worth citing Jay Forrester, one of the greatest model builders of the 20th century, the person who developed the method of calculation used for "*The Limits to Growth*" study [4].

> Each of us uses models constantly. Every person in private life and in business instinctively uses models for decision making. The mental images in one's head about one's surroundings are models. One's head does not contain real families, businesses, cities, governments, or countries. One uses selected concepts and

> relationships to represent real systems. A mental image is a model. All decisions are taken on the basis of models. All laws are passed on the basis of models. All executive actions are taken on the basis of models. The question is not to use or ignore models. The question is only a choice among alternative models.

Models can be complicated or simple, they may be based on equations, analogies, or just intuition. But they are always the same thing: entities existing in our minds that help us plan ahead and avoid the many disasters that could await us. Models are often useful, especially if they are tested by experience, but may also be disastrously wrong. Returning to the example of the gun as an unknown object, there are various ways you can make bad (actually, deadly) models about it. For instance, you know of the "Russian Roulette" game. It involves loading the cylinder of a revolver with a single live round, spinning it at random, and then pulling the trigger while the barrel is pointing at one's head. The origins of this game (if we want to define it in this way) are fictional—its first mention goes back to a novel by the Russian writer Lermontov *Hero of Our Time* (1840). But some people do play the game for real. We don't have good statistical data but a 2008 paper [5] reports 24 cases of Russian Roulette deaths in Kentucky from 1993 to 2002. Extrapolating these data to the whole US, we could roughly estimate that every year around 10–20 people die of the Russian Roulette and, possibly, a hundred or so play it and survive.

For most of us, it is evident that the only way to win at the Russian Roulette is by not playing it but, evidently, some people have a wrong understanding of statistics and use it to make very bad models. That must be not so uncommon, otherwise nobody would ever play any roulette game, not just the Russian version with a gun. But people do engage in gambling, sometimes using dangerous strategies such as the "Martingale" that nearly guarantees disastrous losses [6]. Compulsive gamblers face sometimes the same kind of Seneca ruin that the Russian roulette can generate but, in their case, the cliff may start from one of the windows of an upper floor of the casino building [7].

Some people, apparently, tend to see the world as dominated by forces that cannot be quantified in statistical terms. They seem to believe that, if your destiny is decided by God's plan, there follows that the Russian Roulette cannot kill you: you will die only if He decides that you have to, otherwise you will live. Of course, few people trust God to the point that they risk shooting themselves: after all, God is supposed to be benevolent and merciful but His patience is also known not to be infinite. Nevertheless, it is not rare to encounter a similar attitude in discussions on climate change. Some people are so convinced that the Earth's climate is in the hands of God that it is evident for them that nothing mere humans do can alter it, surely not by increasing the concentration of a greenhouse gas of a few hundred parts per million. And, for this reason, humankind seems to be engaged in playing a deadly game of Russian Roulette with the Earth's climate as a loaded gun.

Can we build better models than these examples that put our life at risk? Of course, we can. Generally speaking, there are two ways to build models: the "top-down" approach and the "bottom-up" one. The top-down method is sometimes based on statistical data and consists in treating the system as a "black box." You look at what the system does and you build up a model on the basis of what you see, without worrying too much about the inner mechanisms of what you are examining. A modern version of this heuristic approach is called the "Bayesian Inference Method." The idea is that you first assign a certain probability to the hypothesis (this is called the "prior",) then you update it to a new value (called the "posterior") in the light of new data or evidence. Then you iterate, until a certain stable value is obtained or, in any case, adapt your estimates to a changing system. This is a variant of the general "heuristic" model of using statistical data to predict the future.

The other method, the bottom-up one, is sometimes called the "reductionist" approach and is the basis of the scientific method. It consists in separating the system into subsystems and examining each of them separately, then building a model of how the whole system works. As you know, this method is relatively new in human history. It was formalized in the way we know it only a few centuries ago and is still being tested and refined.

Both methods have limits. In particular, they require specialists and appropriate tools for a thorough examination that is expected to provide a complete understanding of the system you are studying. And that also requires time while, in the real world, often you have neither the resources nor the time needed to apply these methods in full. Especially when dealing with things that could be dangerous, you cannot wait to have scientific certainty, assuming you can ever have it.

In particular, the statistical inference method, also in its Bayesian version, can lead you to dangerously wrong models. A classic mistake here is "the law of small numbers," identified for the first time by Twersky and Kahneman in

1971 [8]. The law says most people tend to build models on the basis of too few data. In particular they may engage in (1) gambling on the basis of small samples without realizing the odds, (2) having undue confidence in early trends and in the stability of observed patterns, (3) having unreasonably high expectations about the replicability of significant results, and (4) always finding a causal "explanation" for any discrepancy.

Let us apply the law of small numbers to the example of the gun. Assume you are one of the aliens of Gilda Musa's story and that you are tinkering with the strange object left by Earthlings, trying to understand how it works. You note the presence of a metal thing that looks like a lever. You test it by pulling it with your finger and, yes, it is a lever: it acts on the cylinder, making it spin. It seems to be a trigger that acts on another small object on the opposite side of the cylinder: it goes up and down, making a clicking noise. You pull the trigger a few times and the result is always the same: nothing more than that clicking sound: maybe it is a musical instrument? The Bayesian inference method tells you that the probability of the object being a weapon goes down every time that you pull the trigger and nothing happens. At the same time, the hypothesis that the object is a musical instrument becomes more and more probable. Then, to hear the clicking sound better, you place the object close to your head—the barrel-like protrusion on one side directly touching your ear. You pull the little lever once more and…

We can clearly see the problem of small numbers at work, here. Testing a revolver just a few times cannot tell you if there is a live round in one of the chambers of the cylinder. And a devilish result of the Bayesian inference process is that the more times you try and nothing happens, the more likely it seems to you that the object is harmless. The problem is there also with such things as climate change, oil depletion, resource depletion, poisoning of the biosphere, and more. We do have data for these systems, but often not for sufficiently long time spans: for instance, climate change is a very slow process that may turn out to be disastrous, but only in a relatively remote future. So, there arises the idea that since nothing horrible has happened to us so far, it never will—it is a wrong application of the Bayesian method. One of its forms is, "people have been saying that crude oil would run out on some already past date. That didn't happen and there follows that oil is not going to run out in the future." And, as you know, the words "so far, so good" were the last ones pronounced by the guy who was falling from the 20th floor of a building.

A good example of the limitations of heuristic methods when used alone can be found in the debate about "The Limits to Growth", (1972) [9], a study that attempted to describe the evolution of the world's economy. It was not a heuristic model: it did not treat the world's economy as a black box. The authors disassembled the economic machine taking into account the available natural resources, the effect of pollution, the growth of the human population, and more. This approach turned out to be incomprehensible to many economists trained in the statistical approach called "econometrics," a set of techniques used to derive a model directly from the historical data. In the well-known textbook by Samuelson and Nordhaus, *Economics*, (published for the first time in 1948 by Samuelson alone) econometrics is described as a tool "to sift through mountains of data to extract simple relationships."

On the basis of this approach, in 1972, William Nordhaus, who would later obtain the Nobel prize in economics, published a paper titled "Measurements without data" [10] where he harshly criticized the approach of "The Limits to Growth" study (even though he actually targeted an earlier, similar study by Forrester [11]). Nordhaus stated that the model:

> …..contains 43 variables connected to 22 non-linear (and several linear) relationships. *Not a single relationship or variable is drawn from actual data or empirical studies*. (emphasis in the original)

Note how Nordhaus is thinking in terms of econometrics, that is, one should extract relationships from the data rather than use physical considerations. It was the start of a degeneration of the debate that veered into a clash of absolutes and eventually consigned the "Limits to Growth" report to the dustbin of the wrong scientific theories from which it is only now slowly re-emerging. It is a story that I told in detail in my 2014 book "*The Limits to Growth Revisited*" [12].

The clash was created by a deep epistemological divide between two different approaches. In his papers, Nordhaus contrasted the "Limits to Growth" model with a model of his own [13] that he had developed on the basis of an earlier model by Solow [14], based on the fitting of the previous trends of the economy. It was a nearly completely heuristic model: it was based mainly on past data, and, since no collapse had taken place during the period considered, the model could not and did not foresee a collapse. Nearly 50 years after the debate, we can say that both Nordhaus' model and the "base case" scenario of

The Limits To Growth were able to describe the trajectory of the world's economy with reasonable approximation [15]. The two models diverge with the third decade of the 20th century and the optimism of Nordhaus and other economists could turn out to have been another case of the mistake that comes from the law of small numbers described by Twersky and Kahneman.

In general, the emphasis on only looking at data without even trying to build physical models can be seen as related to the approach called "Zetetics" [16] from a Greek word meaning "I search." Zetetics is an extreme form of the experimental method: zeteticists assume that data are all the need to understand the world. The term "zetetic" is often applied to the modern "flat-earth" movement whose adherents seem to think that since the Earth looks flat, then it must be flat. They refuse to see the Earth as a sphere because the evidence for a spherical shape is a theory, not a direct experimental observation. As a method of inquiry, zetetics may have some good points but, if it is applied in a literal manner, it can be suicidal. In the example of the gun, zeteticists would refuse to believe that a gun can kill anyone until they saw it actually killing someone and, possibly, they would maintain that this proves only that the specific gun having been tested is dangerous. On a much larger scale, the zeteticist's position "bring me experimental proof" could lead the whole humankind to an apocalyptic disaster caused by the consequences of climate change (but it must be said that Flat-Earthers, to their honor, do think that human-caused climate change is real [17]).

So, just looking at statistical data can easily lead us astray with models of complex and potentially dangerous systems such as the Earth's climate. How about the other possible method, the "bottom-up," reductionist approach? Is it better at making good models than the statistical approach? In some cases, yes, and, indeed, it is the basic tool of the "hard" scientific method. In fields such as physics and chemistry, scientists are used to performing carefully contrived laboratory experiments where they separate and quantify the various elements of systems that may be very complex. In engineering, for instance, the capability of a certain element of a structure, say, a plane or a bridge, is studied by performing separate tests on the materials that compose it. It is assumed that the behavior of a metallic alloy in the form of an hourglass specimen in a testing machine will be the same as in a real structure. Normally, that turns out to be correct, even though it is a conclusion that has to be taken with plenty of caution.

Applying the reductionist model to the example of the gun as an unknown object implies dismantling it. The experimenter should be able to determine that the object that goes up and down, pushed by the lever at the bottom, can hit and ignite the chemicals contained inside a small brass cylinder which, in turn, would propel out of the object a chunk of a few grams of lead at a speed of a few hundred meters per second. By all means, the reductionist method can tell us that this thing is *very* dangerous.

Within some limits, the reductionist approach is possible also for more complex systems, for instance the Earth's climate. We can identify several subsystems of the Earth's atmosphere, then study each one separately. The fact that carbon dioxide (CO_2) absorbs infrared radiation has been known since the early experiments by John Tyndall in 1859. Then, in 1896, Svante Arrhenius was the first to propose that CO_2 had a warming effect on the Earth's atmosphere and that the burning of fossil fuels would cause an increase of the atmospheric temperatures [18]. It was the origin of the idea of global warming caused by the effect of "greenhouse gases" and the "greenhouse effect," even though Arrhenius did not use these terms. Over the years, more and more sophisticated models were developed to tell us what kind of temperature increase we can expect if we continue to dump greenhouse gases into the atmosphere.

But, of course, neither Arrhenius nor anyone else could make a laboratory experiment proving the concept of greenhouse warming of the Earth's atmosphere. Some enthusiastic amateurs try to do just that at home using glass jars or Coca Cola bottles. Most of these experiments turn out to be poorly made or simply wrong [19]. Even when they are done correctly, all they can show is that an irradiated glass vessel gets a little warmer when it contains more CO_2 inside. But that proves nothing more than what Tyndall had already demonstrated one and a half centuries ago. The problem is that the properties of the atmosphere cannot be exactly reproduced in a laboratory: just think of the variable density of the atmosphere as a function of height, you cannot reproduce that in a Coca Cola bottle!

It is a problem that's especially acute with some models of the atmosphere. You may have heard of the "biotic pump" theory developed by two Russian researchers, Victor Gorshkov and Anastassia Makarieva [20]. The theory aims to explain the fact that rainforests manage to attract a high amount of rainfall and is based on a physical phenomenon, that when water vapor condenses it creates a negative pressure. The idea is that the biotic pump keeps the forest wet by continuously pumping moisture from the oceans. It is a fascinating theory but how can we prove it is correct? You can't create a rainforest in a lab and the only way to test the theory is by means of model-building and comparison with real-world data. It will take time before an agreement on the validity of this theory will be reached by the scientific community.

Does that mean that the idea of human-caused global warming is not supported by experimental data? Not at all, but you must understand how the scientific method deals with this kind of systems. The basic physics is known, the parameters of the system can be measured, the interaction among parameters can be simulated in computer models and that is enough to arrive at a number of well-known conclusions, such as that, at present, CO_2 is the main driver of the observed warming of the Earth's atmosphere.

As we all know, not everybody accepts this conclusion. In most cases, the denial of the basic features of the global warming phenomenon is based on purely political considerations. Some people state that the whole story is a hoax created by a cabal of evil scientists who wanted more money for themselves in the form of research grants. Of course, it is not possible to rigorously prove that this is not the case, even though it may be reasonably argued that the existence of such a cabal is, at best, a highly unlikely assumption. But, sometimes, denial is based on a zetetic approach: it is often claimed, for instance, that there is "no proof" that CO_2 warms the Earth. In this kind of epistemological approach, in order to "prove" that CO_2 warms the Earth, you would need a controlled series of experiments where you control the concentration of CO_2 in the atmosphere while measuring the effects on temperatures and also where you check the effects on the planetary ecosystem. An experiment to be done at a planetary scale and, obviously, a little difficult to do, especially for the part that involves the collapse of the ecosystem.

Overall, we can say that there are many ways to see the world but that none gives us absolute certainty of what the future could be. We always try to do our best, but we are not always successful. Sometimes we err because of an excess of caution, in others because we are careless or overoptimistic. Nevertheless, it is a good idea to use models to understand the world around us and build models for what we expect from it. The scientific method, while not a panacea, can help us a lot in the task. Trusting God may also help but, as the old saying goes, try to keep your powder dry.

How Good Can a Model Be? Nightfall on Lagash

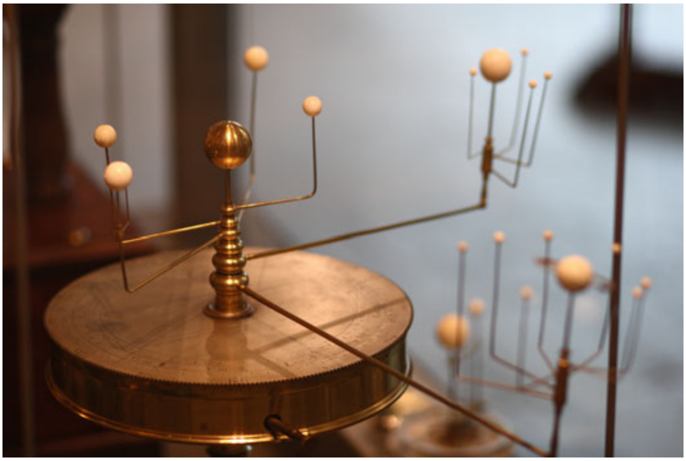

Fig. 1.2 A mechanical planetarium ("Orrery") made by Benjamin Martin in London in 1766, presently at the Putnam Gallery in the Harvard Science Center. This mechanical model is possible because the solar system is not a complex system and the planetary orbits are stable and exactly predictable (Figure courtesy of Sage Ross. https://en.wikipedia.org/wiki/Orrery#/media/File:Planetarium_in_Putnam_Gallery_2,_2009-11-24.jpg)

In 1941, Isaac Asimov published one of the best-known science fiction stories of all time, "*Nightfall*." It told of a remote planet called "Lagash," inhabited by a species of intelligent aliens. In the story, Lagash is constantly illuminated by at least one of the six suns of its multiple star system but, every some thousand years, an eclipse of the main sun causes the side of the planet where the Lagashians live to fall into complete darkness. They are completely unprepared for sudden darkness, the shock causes them to go mad and they start burning everything at hand, just to have some light. That is the cause of the cyclical collapses of their civilization that Lagashian archaeologists had noted but had been unable to explain.

The drama in Asimov's story is related to how a group of Lagashian scientists has been able to predict the coming nightfall by studying the motions of the suns of the system and then extrapolating their trajectories. Here is how the prediction is told by one of the scientists in the novel,