LIMITS TO GROWTH AND STOCHASTICS

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Introduction.
The aim of this article is to use probabilistic ideas to study predictive reasoning based on hypotheses and models, but without using Ito calculus, without writing any stochastic differential equations, in fact without writing any formulas at all. The aim is to extract from the study of stochastic processes those qualitative traits that have significant philosophical implications for the political decision-making process.

Indeed, we need to acknowledge that the impact of the economy on the environment is not a result of temperance or mitigation of natural variations but rather that the economy itself – in addition to the underlying trends due to growth – is a major source of perturbations arising from the random fluctuations in prices or values that are caused by the anticipations made by the agents. Consequently we need to understand the additional effects that randomness superimposes on arguments based on the finiteness of the world and its flows of energy.

I intend to conduct this discussion without technicalities since they only obscure the issues. However, while I have tried to limit the mathematical background required from the reader, I cannot avoid assuming a certain level of knowledge, since the concepts arise from that subject.

We begin by reviewing the analysis of the Club of Rome to provide the context for our main discussion.

I. On the Rome report: simple models and their refinements

The issue of perfecting models is a classic trap. On the one hand, simple models have the disadvantage of being far from the laws of physics, biology and economics, but the advantage of being easy to calibrate. On the other hand, complex models seem to better reflect our knowledge of the phenomena being studied, but they have so many parameters that it becomes impossible to fine-tune them properly. Furthermore, their perfectionism gives an illusion of completeness: one can never be sure that they have taken everything into account. Ultimately, the most appropriate choice of model depends on the social use to which the model is being put, the sort of knowledge available, and the possible actions that can be taken[1]. The case of the Club of Rome is here typically a global reference, something for "everyone".

The philosophical value of the work of the Club of Rome.
After the appearance of the first version of the report [Meadows et al. 1972] numerous critics highlighted various weaknesses in the style of reasoning it used. Firstly, it was too simplistic: how could the reality of the world be captured in an algorithm whose equations comprise merely a few hundred lines of code? Next, and above all, it was closed: it could not take into account innovation, progress arising from science or technology or, more generally, human creativity. All of this may change *completely*, even the meaning of the words used in the model, yet the projections are based only on current knowledge. For example, concerning nuclear power, it only takes into account the nuclear fuel resources, the difficulty of storing waste and the problem of areas rendered uninhabitable by accidents. It does not consider the success of fusion technology whose advantages and disadvantages are still not well understood[2].

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[1] Cf. [Bouleau, 1999] Partie III.
[2] Cf. the discussions about the ITER (*International Thermonuclear Experimental Reactor) project*.

The new version of the report, published 30 years later [Meadows et al., 2008] argued that the first version had not been contradicted by subsequent facts [Turner, 2008], and maintained, in the new model World3-03, the same methodological principles. Balance sheets drawn up by the Meadows team are relatively independent of subjective economic interpretations because they are based on measurements of quantities: energy received from the sun, quantity of arable land, population etc, which allows the authors to express themselves in terms of specific indicators: "human welfare" and "ecological footprint". Several scenarios are studied under different assumptions of economic policies. The general conclusion is well known: unless politicians are very vigilant, we will always get an "overshoot-collapse" situation, i.e., excessive growth followed by collapse.

The truth value of this report does not lie in the details but in the thesis – which offends most philosophies and many religious beliefs – that one may take seriously and scientifically the fact that the finiteness of the world and its resources means radical changes are required to prevent collapse. This is a change of scene from that in which economics and politics usually take place, and can be seen as a turning point for civilization. It allows us to see that many old ideas about progress are based only on a desire for instant power without taking into account the limits, which is then turned into a rational theory. At this level, obviously only a simple line of argument can persuade.

The power of simplicity applies to all models where there are conflicting interests.
Let us now consider climate change and the IPCC with its three groups studying the physical phenomenon, the impact and politics of reduction and adaptation, and economic models for mitigation. Although the work of the third group is *a priori* the most delicate and the furthest from the objectivity of the natural sciences, it is the conclusions of the first group about human responsibility for climate change that have been attacked by climate skeptics. There remains an on-going conflict between the wider scientific community and protestors who claim to be adhering to scientific principles in challenging the hypothesis that the increase in greenhouse gases is due to human activity.

Human responsibility cannot be proven with absolute certainty because one cannot state with mathematical precision what would have happened without human intervention. What the IPCC says goes against the economic interests of energy consumers. This case is epistemologically delicate and has shaken several recent philosophical doctrines. The 20th century has emphasized the links between knowledge and interest, already highlighted by Nietzsche, reworked by Habermas[3] on the one hand and by Feyerabend[4] on the other. A new conception of knowledge has now emerged, one that is definitely non-positivist, in which reality does not speak without being questioned and where the communities of researchers (Thomas Kuhn) and interest groups (Callon) are the ones who construct the concerns, representations and, ultimately, reality. Also the popularity of Science Studies (Latour, Callon, etc.) and its link with the mainstream of pragmatism that one can trace through Bentham, Mill, Bain, Dewey, Peirce, William James and Rorty, suggest that knowledge is a social construct and draws its relevance from social issues. The confrontation with the universalist and quasi-positivist collective discourse of the IPCC is not simple. Many texts of the new trends suggest – or at least do not rule out the idea – that economic negotiation is ultimately the key to the most positive patterns of behavior, i.e., those which are most efficient, persuasive and peaceful.

Yet, even without absolute proof, reason affirms the human responsibility claimed by the IPCC, even though this clashes with and opposes economic logic. Why? Is it because of the seriousness of the work by various teams around the world, based on different models? Is it because of the fact that among those who have contributed to the work there are many

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[3] J. Habermas *Erkenntnis und Interesse* (1968).
[4] P. Feyerabend *Dialogues sur la connaissance* (1991), Seuil, coll. "Science ouverte", 1998.

researchers based in rich countries whose interests are not well served by raising these issues and that many leading climate skeptics are linked to powerful economic interests? It certainly is not an argument of authority (the number of renowned scientists or the prestige that some of them have) or a return to a positivist view of truth. But the relativism of knowledge – which relates to the issues discussed – seems too subtle a concern, a second-order effect. Ultimately, what is most important is the simplicity of the argument: On the one hand, the graph of CO_2 emissions as a function of time, on a historic scale, with its clear sign of the post-industrial period, combined with the physical fact of the effect of CO_2 on the absorption of different wavelengths and, on the other hand, the graph of lower-atmosphere temperatures, with its step-change in order of magnitude just after the industrial age.

It is a mistake to complicate models of the environment.
Excess mathematization is a natural path in the academic world, as a result of numerous institutional factors[5]. It is the most convenient way, in the academic world, of avoiding any *commitment*. One speaks of self-organization, of complex systems that are sensitive to initial conditions and, by talking of multi-agent models and other possible thesis topics[6] … the ethical conclusion gradually, without anyone noticing, evolves into the belief that it is only scientific research that needs to be perfected. The productivism and selfishness of the privileged classes are forgotten. The economy is hit hard by this tendency.

Keeping the simplicity of the Club of Rome's arguments while reasoning probabilistically.
In the most recent version, the Meadows team considered several different scenarios (11 scenarios are discussed). In some ways this already represents the start of a probabilistic line of reasoning, but without considering the consequences of stochastics on current dynamics.

In these scenarios we find the general idea of an evolution first in exponential growth (30 pages in Chapter 2) which, after a certain time, becomes tempered by constraints arising from limits in material and energy in the planet (80 pages in Chapter 3). What happens after the peak is only sketched, the authors emphasizing that this time of decline causes social changes so great that they cannot be modeled sensibly. Simplifying to dimension 1, one could say that there is a logistic equation, more or less refined, that leads to certain horizontal asymptotes for the combined balance sheets of minerals and fossils, and certain bell curves, with a peak and then a decline, for the marginal trends and quantities, i.e., for the derivatives.

Our plan will naturally be the following: first we describe the new features of stochastic processes with regard to deterministic trends (part II), and then we review the consequences of uncertainty for the vulnerability of the environment subject to economic rationale (part III) and we conclude by highlighting the most important points.

II. Qualitative aspects of stochastic processes
While a deterministic quantity is completely described by the evolution of a number as a function of time, a stochastic process is, in some way, a piece of music for multiple voices.

Probabilistic "reasoning".
For all evolutions (growth, decline, convergence) we should specify whether we are arguing in distribution, in mean or path-by-path.

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[5] I've gone into this in more detail elsewhere: on the philosophical level cf "On Excessive Mathematization, Symptoms, Diagnosis and Philosophical bases for Real World Knowledge " *Real World Economics* 57, 6 September 2011, 90-105 (http://www.paecon.net/PAEReview/) and on the financial level "Mathématiques et autoréférence des marchés" (http://cermics.enpc.fr/~bouleaun/publications.htm).
[6] In this way one talks of "complex adaptative systems", "critically self-organized" systems, the "agent-based" or "self-generated" complexity, or of "highly optimized tolerance" etc. cf for example [Rosser, 1999], [Harris, 2007].

Arguments "in distribution" or "in the mean" (quadratic mean, or in spaces of summable p-th power), also arguments "in probability" introduce compensations that probabilistic calculus allows between the events where there is an increase and those where there is decrease. The evolutions thus described are in general fairly regular because the causes that attribute certain probabilities to certain phenomena usually have some degree of permanence.

But we are also interested in what happens for each trajectory that chance produces, because it is one of these trajectories that describes what actually occurs, or at least what the model suggests will occur. And the most fundamental information that the study of stochastic processes has given is that the behavior of trajectories can be very different from that which dynamics depicts from distributions or mean.

Trajectories in stochastic processes are erratic, often very erratic.
There are stochastic processes that are smooth, but only where chance applies to only the derivatives or higher derivatives of the quantity. In general stochastic processes are very irregular. A good image is given by share prices, or the silhouette of a mountain crag.

What happens in financial markets – forgetting for the moment the economic role of these institutions – is interesting because it shows how uncertainty, and the imperfect knowledge that agents have of the future, result in the frantic movement of the quantity on which they act. Where the evolution of a currency or an action is not certain – and thus financiers do not agree on the likely outcome – the quantity will not take a medial path that would represent some sort of averaging of the opinions. Instead it will become erratic, and much more erratic when the uncertainty is large. This wildness, which financiers call volatility, is considered to be the most objective measure of the uncertainty affecting the economic quantities being studied [Bouleau, 2004].

In other words, in general, a stochastic process doesn't possess any clear trend (no speed or derivative in the mathematical sense); from one moment to the next it will increase or decrease.
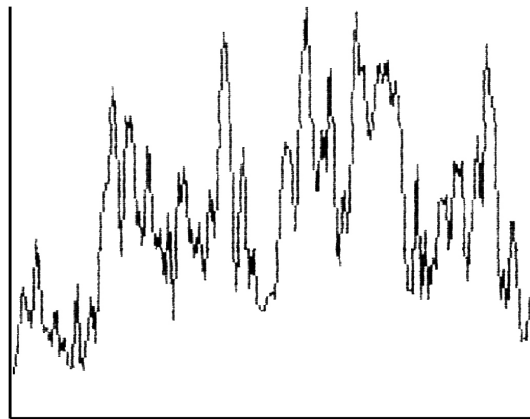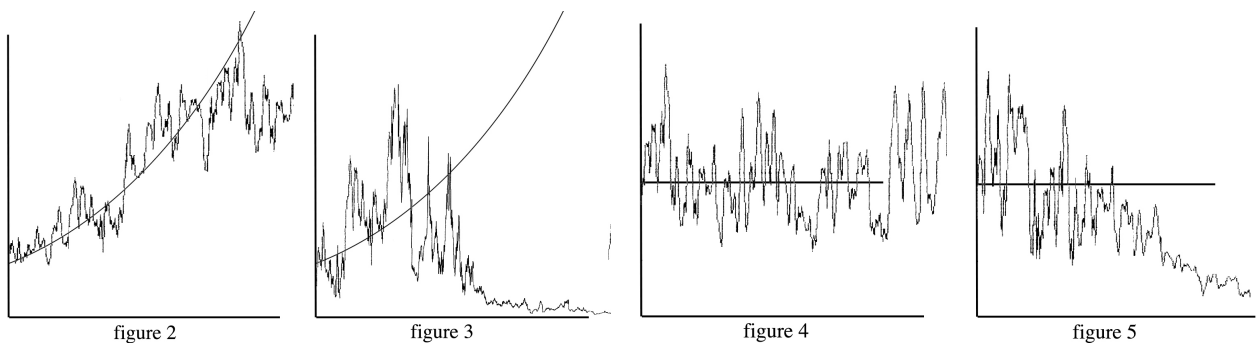

figure 1

Phenomenology of the exponential family.
The heart of the argument of the Club of Rome is to consider phenomena with relatively constant growth rates and to show that, sooner or later, they "go to the wall". These are quantities whose rate of change is proportional to their actual value, with a positive coefficient. In the case of many variables these can be put in a matrix calculus and the signs of the eigenvalues indicate which linear combinations of variables will vanish and which will increase explosively. This exponential growth cannot last and will necessarily by interrupted by some phenomenon whose role as a brake will increase progressively. Hence the appearance of an

additional term in the equation which leads, in the simplest case, to a logistic equation or similar, and results in a saturation and, for the Club of Rome models, to a collapse.

One fundamental phenomenological point is that this is completely different in the case where the quantity has a random element to it. If a quantity showing an exponential character is subject to some randomness that is constant proportionally to the quantity's size, then one of two things will happen. If the randomness is small, the general path of the trajectory will be as one would expect: an exponential curve with fluctuations, above and below, that gradually become larger; this case is illustrated by figure 2. But if the randomness exceeds a certain threshold (as often occurs in financial markets, for example) the behavior of the paths will be completely different from what our intuition suggests: they all end, after some oscillations, by tending to zero; this case is illustrated by figure 3.

This phenomenon is well known in the case of martingales, which are processes in which the mathematical expectation is constant[7]. There exist positive martingales for which all trajectories tend to zero (figure 5). In this case the study of phenomena "in distribution" or "in the mean" do not at all match what happens in reality. And this is not just some sort of mathematical pathology; such cases are extremely common, particularly in economics.

| figure 2 | figure 3 | figure 4 | figure 5 |

For example, if you put your money in a fund that pays 4.5% and you reinvest your dividends constantly, you will achieve exponential growth. If, however, there is some uncertainty which increases the volatility, and this volatility exceeds 3%, the oscillations are such that one will frequently approach very small values, and in the long run you are certain to be ruined.

As another example, if you put your money in at 10% and each year you gamble half your money, the cumulative effect of the gain and the uncertainty will lead you inevitably to ruin. The positive martingales which tend towards zero are typical in fair games and have major significance in terms of collapse.

The same remarks obviously also apply if we consider situations where there is some limit on the exponential dynamic which causes some braking, leading to an equation of the logistic type, with a bell curve instead of something that increases indefinitely.

The most important philosophical point of this phenomenology is that in the case where there is randomness, and it exceeds the threshold we discussed, *it is impossible to tell from the trajectory what would have happened without that randomness*[8]. In other words, *exponential behavior cannot be detected in what is objectively observable*. Thus an observation such as figure 1 does not allow us to infer an underlying exponential dynamic.

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[7] Figure 4 is how one intuitively expects a martingale to behave. It's the special case of a "uniformly integrable" martingale.
[8] The general question of knowing if one can understand the deterministic trends underlying a stochastic process has been written about at length. The negative response is a consequence of the theorem attributed to Girsanov, cf. [Bouleau, 2004] p37., and for a precise mathematical formulation cf. [Lamberton et al., 2008].

Stationarity does not mean "always the same".
A somewhat similar remark needs to be made about stationary processes. In most cases, and especially in the normal (Gaussian) case, they exceed, after a certain period of time, all levels given in advance[9]. Thus a situation which appears to be "sustainable" when considered "in distribution" may turn out not to be so for every trajectory. This is because the size is unbounded (its marginal distribution has no compact support) and that chance makes it "walk" everywhere.

One would think, then, that this phenomenon cannot occur in a finite world. However, we will see later that economic logic requires us to consider that prices are unbounded.

In an uncertain world there are rare events, and their probability is generally unknown.
We now turn to issues that are less descriptive, and more semantic in nature.

If knowledge comes from statistics obtained from experiments, then distribution tails are poorly known; this is obvious and frequently noted. If the quantity represents a level (of water, or of temperature, etc.) then extreme events are badly probabilized.

But we must go further than this. We must consider the role played by *meaning* in the concept of rarity; this is linked to the unprobabilizable uncertainty that was so dear to Keynes. What does it mean to talk of a "rare event"? An event is simply a (Borel) subset of the real numbers. Events whose description is complicated generally have a poorly understood probability, for the same reasons as those related to extreme events. And the central philosophical point is that our interest (in the most general sense of that which attracts our attention) is governed by the *meaning* of the event, i.e., by the impact of this event on the rest of the world. This impact is not in the model studied but in, precisely, that which is not modeled. Translating this concern into the probabilistic language of models is a difficult operation that usually we do not know how to achieve.

To precisely describe the mathematical form of events that we fear is particularly difficult for a stochastic process. An event is a region in path-space. Why talk of this one or that one? One speaks of those which are interesting, those that mean something in terms of consequences for what matters to us, on the economy or on the environment. But the interest that we bring to such and such phenomenon is not at all objective and is usually highly subjective. That is why the *forms* of families of temporal trajectories that have some meaning, that can be interpreted, generally have poorly understood probabilities, because the rarity ascribed to them is usually subjective, at least in part. It is linked to the fact that the event matters to us, or to others.

Let's clarify this tricky but important point. How does an event, which is perceived as rare by some people but not by others, come to have a poorly understood probability? The model is a summary and we extrapolate from it by different interpretations. The model's output is accurate about the things that are common to all these various interpretations, because the model only "speaks" clearly about this common ground. Except for some purely physical phenomena (emission of alpha particles, Brownian motion, etc.), for most of the interesting situations that we are concerned with (in the environment, in economics, etc.) the element of chance in probabilistic models is a way of representing our ignorance, some sort of convention that we stop at a set of facts and interpretations, and we do not go beyond this point, because that is where opinions start to diverge[10].

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[9] This is true even for processes that are *strictly* stationary, i.e. when their marginal distributions of order n are invariant under translation.

[10] One can read more about this in my book *Risk and Meaning, Adversaries in Art, Science and Philosophy*, (Springer 2011), especially chapters II (Cournot's "Philosophical Probabilities") and XI (Jacques Monod's Roulette).

III. Vulnerability of the environment when subject to economic "rationality"
Does this collection of striking features of the phenomenology of random processes have any consequences for our understanding of the work of the Club of Rome and, more generally, the question of the limits to growth?

The first issue is to determine whether or not there is randomness and, if there is, what creates it.

It is the economy that adds randomness.
All rated quantities – raw materials and prized materials, sources of energy, lands and real estate – all fluctuate in our liberal economy. We will go deeper into the reasons for this in a moment. But let's note already that to reason as the Meadows team did, without using monetary value, is to build a model that is disconnected from the forces that represent the interests of agents (or at least from those forces that the agents believe represent their interests). The key fact that *the economy exists* – particularly in the globalized neoliberal period we find ourselves in – means that the link between an economic interpretation of the world, which is very random, and the deterministic curves of the Meadows report, is not made.

The mechanism for finding a market price necessarily involves randomness.
We can first ask whether price formation in markets is truly stochastic in nature, or whether it is governed by some complex, chaotic mechanism. The question might be interesting to the *quants* on the trading floors, but for our purposes it is not very important. Both representations are simply models. What matters is that it moves and that one cannot tell in advance how it will evolve.

In organized markets, for a price to be established, market makers or an exchange systems must work constantly to produce the current spot price. Indeed, if the dealers are split into two groups: the bulls who think it will rise and that the current price is too low, and the bears who think the opposite, what will happen to the price if the bulls buy? The price will rise. And if we let the bears sell, then the price will fall. The organization providing the spot price will therefore sometimes let one group speak, and sometimes the other, so that both camps always have some members. Technically it will seek to maintain *good liquidity*, i.e., to minimize the bid-ask discrepancy (for details of how markets function, cf. for example [Cont et al., 2010]).

Thus we understand that when we say that volatility is the uncertainty in the evolution of the price of the quantity, we may as well say that this irregularity reflects the difficulty that the trading organization has in achieving the balance between buyers and sellers needed to maintain the permanence of the pricing.

The price of a scarce commodity does not follow the logistic curve of the Club of Rome; it follows a "punk hairstyle" instead
We'll now look at things in more detail. If we take the price of copper, or the price of teak, the primary characteristic of the trajectory over time is that it is jagged, and that no-one can say with any certainty whether it is about to go up or to go down, let alone predict its value in a year's time.

The best example is the price of fossil-fuel energy resources. Neo-classical economists in the nineteenth century proposed deterministic models. The best-known examples of this type of thinking are the Hotelling model and its improvements. Without going into detail about the equations, a model that takes account of randomness will give a price graph similar to figure 3. We note that the prospect of depleted resources, combined with the fact that dealers use their arsenal of futures products on the derivatives markets to anticipate future prices, render these

models meaningless unless they incorporate a *significant* random component. Without that, expectations would make the price explode. For this not to happen, it is essential that the agents believe that there is a positive probability that the price may go down again. And this can only happen if the prices are randomly excited. This is what happens in financial markets for most quantities, for similar reasons. We can even understand that this is not just a little bit of randomness – a light breeze that gently shakes things – but rather *it is a massive disturbance that will completely obliterate the underlying deterministic curve*. This reinforces the need to reason as if we do not have any idea at all when the "peak oil" will occur [Helm, 2011].

The "price signal" of exhaustible resources works very poorly.
The consequence of this is that the "wise response" to the depletion of resources, that of raising prices so as to encourage agents to develop alternative energy sources and substitutes for the missing minerals, will not occur spontaneously, purely as a result of the price, because there is too much variation in the price signal[11]. The fall in the price of an energy resource, from a very high price to a low price, will kill the long-term investment in new technologies.

Indeed, it is clear that the magnitude of the financial uncertainties that we face prevents us from taking new directions. Using the IPCC estimates, for a stabilization target of 550ppm[12] CO_2 equivalent, the marginal cost reduction in 2030 would be between $5 and $80 per ton, i.e., a spread of 1 to 16. In these conditions, a businessman interested in the carbon emissions of his enterprise must evaluate investments whose profitability, even with some subsidies, is extremely uncertain, when compared with the long-term interest rate that the financial markets can provide today. Instead of stepping out and being the first among its competitors to begin this adventure, the business is almost obliged to wait until that spread is reduced.

This also explains why a system of tradable rights, as in Europe, or a tax on petroleum products, can only be effective at creating decarbonization and energy-efficiency technologies if it leads to the publication of a quasi-deterministic forecast of how the price will vary over a sufficiently long period[13].

Local agricultural methods are disrupted and driven to destructive practices.
In agriculture and livestock, in addition to meteorological variations, globalization has added significant randomness to prices [Daviron et al., 2011] which, since the winner takes all, ends up destroying traditional, sustainable practices and encouraging methods that are destructive and short-sighted. These survival techniques may also draw on ancient agricultural and farming customs but these are then carried out using the available mechanized technologies (burning of forests, fishing and hunting endangered species)[14].

The economic valuation of non-marketable common goods will relentlessly erode them.
A major consequence of the random nature of economic prices is that all the theoretical logic of cost-benefit analysis is lost, when applied to the environment.

To preserve the environment, economists usually say we must give a value to its preservation, i.e., put a price on it. This presents various kinds of difficulties, technical, political or legal. On a purely technical level, cost-benefit analysis (CBA) gives a price to non-

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[11] A study [Boyce 2011] about petrol, carbon, and 78 minerals, showed no correlation between the variation in the price and the variation in the quantity extracted. The impact of the variation in the price of petrol on the economy is also complex and variable, cf. for example [Lescaroux et al. 2010].

[12] ppm signifes parts per million, CO_2 equivalent signifies the equivalent amount of carbon dioxide.

[13] The graphs shows that neither the TIPP in France, nor the Italian tax that has significantly increased pump prices, satisfy this criterion.

[14] On the complex interplay of interractions, cf. [Warren 2011]. Furthermore, being unable to occupy space with sustainable activities, poor regions are also led to accept poorly-recycled waste from countries that are more technologically advanced.

marketable goods in such a way as to be comparable with marketable goods[15]. CBA methods are usually explained in textbooks[16], so we will not go into detail here. However it is done, cost-benefit analysis can only determine a price *based on information from the past and the present*. Yet prices fluctuate. There will necessarily come a time when randomness in the evolution of prices will mean that the service provided by the collective good will be valued lower than the substitute marketable goods that it could be replaced by. Certainly we can see that preserving the environment is of growing importance in public opinion and in this regard, a proper CBA needs to be updated to take this into account. But this concerns non-marketable goods – by definition, there is nothing to sell. The price estimate of the ecological service is inevitably calm and quasi-deterministic. It can only follow a smooth curve (a convolution) and thus a time will come, sooner or later, when the service provided by artificial means will be cheaper.

This is particularly serious for biodiversity. A typical approach employed by free-market economists is to divide species into two categories[17]. On the one hand there is the *remarkable biodiversity*, comprising those species considered by various *ad hoc* bodies to be *threatened*. For them we calculate the cost of maintaining them as we would for, say, a historic building. On the other hand, for *ordinary biodiversity*, i.e., all other species, we calculate their value by the *ecological service* they provide, from prokaryotes (bacteria) to eukaryotes (higher species) using standard methods of cost-benefit analysis. We can then buy and sell every part of nature or exchange against goods or services already quantified economically.

It is clear that on each specific question, on the way to preserve such and such species in its current condition, the fluctuations in cost legitimize artificial substitutions and the irreversible destruction of habitats. Consider a specific marshy wetland area that is in destructive competition with a deposit of fossil fuels. The two rarities do not evolve in the same way. On the one side there are real and random fluctuations in the price of fossil energy (due to speculation) and on the other there are gradual adjustments in the calculation of "ecological services". The fuel deposit will, some day, end up priced above the carefully calculated estimates for the marsh. *For the environment, this method is the bulldozer of substitutability*.

Taking economic value as a moral compass when faced with uncertainty is to play roulette with the environment, and will lead, sooner or later, to ruin.
Market value is still considered, not only by mainstream economists but also by policy makers, as a reflection of what people are willing to concede for the use of goods, after taking account of personal criteria and the collective game of social exchange. In the background is a picture of a harmonious world, in an equilibrium that slowly evolves with improvements in business performance and changes in consumer tastes. This image is a legacy of the neoclassical thinking of Léon Walras and others of the 19th century, who saw the economy in terms inspired by the minimal action principle in mechanics, and who described equilibrium states by mathematical methods of optimization. It is completely superceded by current practices which, while still relying on that philosophy, have great difficulty in thinking of economics without growth [Jackson, 2009], particularly in the case of the credit and securities market and because of the "debt-based monetary system" [Sorrel, 2010].

But in addition to this, prices fluctuate. In these conditions the competition between a non-marketable good and a commercial commodity is not equal. Under the blows of the waves, even large fragments of a cliff can fall into the sea, but they do not rise again when the sea is

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[15] Serious shortcomings in this method, when applied to the environment, have already been identified, cf. [Hanley 1992] and [Ackerman et al. 2002]. But the point made here is, in our opinion, even more serious.

[16] For these methods, without any critical discussion, see [Pearce et al. 2006].

[17] Cf for example in France "Approche économique de la biodiversité et des services liés aux écosystèmes, Contribution à la décision publique", *Centre d'Analyse Stratégique* April 2009.

calm[18]. The key point here is that in the long term the present economic organization, with its financial markets that govern the most important prices, is incapable of setting limits to prices that fluctuate. *In other words, the whole world is finite and bounded, except for prices.*

From quoted prices in financial markets to prices in everyday life.
We first make a remark that complements the arguments above. Stock prices, currency rates and commodity prices fluctuate in financial markets, as we have said. But the way the economy works in society in reality means there are certain "valves" which ensure that certain quantities stay stable or grow randomly, but never go down. This is generally true of real estate prices in city centers in Europe, and of salary levels for certain professions, etc. Without going into the mathematical details, the reader will understand that the existence of steps and rises creates a situation that is random and unpredictable, whose consequences are similar to those of a process which rises and falls, in so far as we never know how much it will increase in a given time period[19].

It thus appears that the primary source of turbulence that spreads through the economy comes from the financial markets[20]. This leads us to the conclusion that this turbulence, which has such devastating effects where the economy and the environment meet, is there to allow financial markets to exist. Given that, should we conclude that we should get rid of them? Yes, so long as we measure how much this idea necessarily disrupts free trade from top to bottom. Because even if capital markets are the principal source of randomness, they are not the only ones (there is also randomness in business, in transport, in economic policy decisions, etc.). Until we know how to think, globally and in the details, about a sustainable economics that does not unduly restrict our customary freedom, in which the evolution of prices over time is smooth, it is essential to regulate and vigilantly resist the attacks of randomness that come from economic logic.

Conclusion
Randomness hides trends. It is precisely for this reason that there is randomness in financial markets. For if the trends were clear, they would be immediately exploited, and their clarity would disappear. In hiding these trends, randomness weakens the arguments that one can derive from the finiteness of the world and its limits. This is one reason why the warnings given by the Club of Rome were not acted upon: *bell curves – quasi-exponential growth, overshoot, peak, decay and collapse – we do not see these in prices.* We genuinely feel, when watching commodity and share prices, that the economy is still broadly in the same situation. So long as agents' behavior is governed by the economic climate rather than by moral considerations, *business as usual* will continue.

For the ancient Greeks, chance was on the side of nature; they feared the wrath of Poseidon so much that they were ready to sacrifice a young girl. Until the 18th century it was the "elements" that were random; humans actually occupied only a tiny part of the planet. Now the situation has changed: a great disaster, such as the Tōhoku tsunami, may kill 20,000, i.e., three millionths of the world population, yet this is far lower than the number who die in car accidents each year. Humans occupy the majority of the planet and it is they, by economic reasoning and free-market logic, that is the main source of randomness. *The economy is now the*

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[18] Recent examples include the exploitation of oil sands in Canada, coal in Australia, and the Belo Monte dam which has just been signed off by the president of Brazil, and which will flood 400,000 hectares of forest, and displace 40,000 inhabitants.
[19] One way to understand such reasoning, often used by economic correspondents in the media, is to consider the graph of relative changes, where the randomness of the increases is more obvious.
[20] Specifically, the turbulence comes from the fact that if a market shows a clear trend that sets it apart from a risk-free investment, then it is unstable, since buying and selling will, respectively, cause the price to increase or decrease.

environment that the environment finds itself in. Neoliberalism has become the storm, against which the world needs protection. That clearly means that it is not enough to relay information about the current and future physical states of the world; this will not convince an economic agent who sees prices fluctuate. It is essential to attack the problem at its root, which is the way that the market economy "speaks" by imposing a screen of volatility over the determinism of the collapse.

Appendix

A) *On the origin of the volatility of market prices.*

Robert J. Schiller begins his 450-page book *Market Volatility* [Schiller, 1989] with the phrase "The origin of price movements are poorly known in all speculative markets for corporate stocks, bonds, homes, land, commercial structures, commodities, collectibles and foreign exchange".

In its simplest version, finance theory says that an asset cannot have a foreseeable evolution unless it is deterministic and varies as the core investment, without any risk: the "bond". It also says that under certain hypotheses, often framed in terms of perfect information – although the notion of information is simple to express mathematically, but not at all simple in what it represents – the uncertain assets are martingales, i.e., processes which have the "centre of gravity property" [Bouleau, 2004]. We know mathematically that these processes are very irregular. Thus we have a theory that explains the irregularities we see in stock prices. But this is not the real explanation of the behavior, of course, because markets usually function with only incomplete, partial information.

All studies conclude that there are two types of reason. On the one hand, the effect of real shocks that change the landscape of the activity: technological innovation, consumer tastes, social or political change, fundamental changes in currency rates, etc. On the other hand, there are psychological factors arising from differing opinions, changes in confidence, differing levels of risk-aversion, etc.

In this article we have outlined a simplified form of the non-arbitrage principle: the value of an asset cannot be predicted if its evolution is different from a bond, because if not, then it would enable risk-free profits and this would change its value. This argument does not explain the phenomenon beyond saying that the variation in the price of an asset (its volatility) is even larger when the evolution of the asset is more uncertain.

To discuss this latter phenomenon would require a definition of uncertainty different from that given by volatility. This is a genuine research program with a high risk of subjective interpretations. We are therefore reduced to recording that volatility is, often (for instance for currencies), lower in the more highly diversified and highly structured economies of advanced countries, and greater concerning the assets of developing countries where there is more uncertainty about the future.

B) *We choose two graphs* from among the many possible, to serve as a visual aid to complement this article.

Real price of oil

Price in dollars 1973 and price in Euros 1973, normalized by the level in 1973.

Source : EIA, US department if Energy.

World food prices, UN Conference on Trade and Development (UNCTAD) and Food and Agriculture Organization (FAO), *Sources:* UNCTAD and FAO.
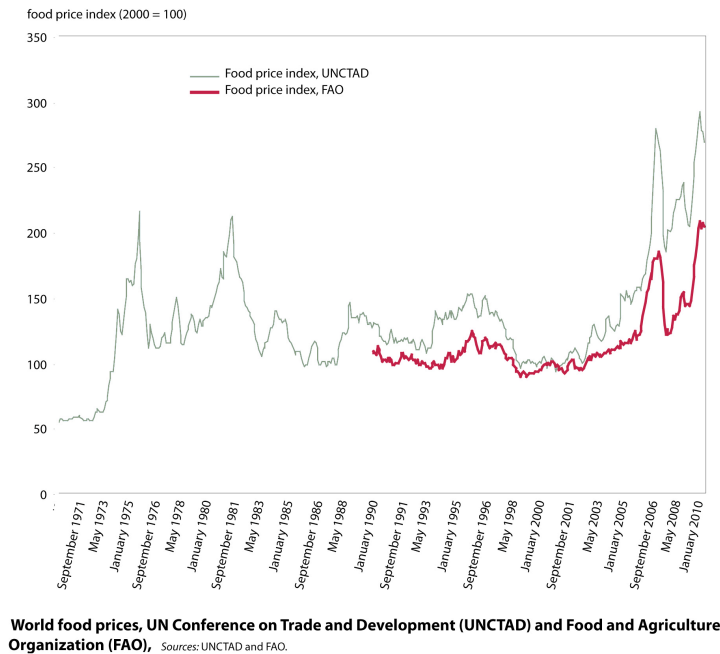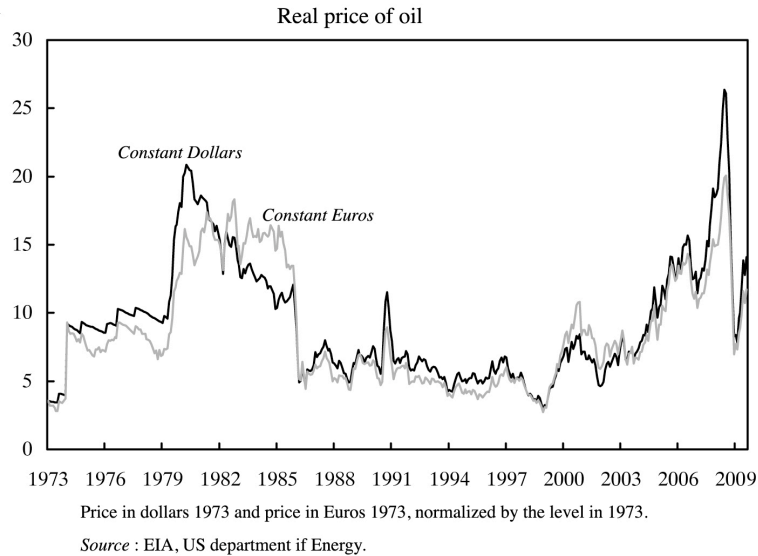
figure 7

C) If one compares the above reflections on the compulsory agitation of markets to recent events concerning political strategies on the environment such as the strength of the climate-skeptic current, one might legitimately ask whether there would be some structural economic link, by the mere incentives of liberalism, that *push to contradict even the most scientific predictions*, see [Michaels 2008] [Oreskes et al. 2010].

I do not currently have the sociological analyses that would bring the facts about it in Europe or the U.S., it's why I leave this comment out text in the appendix as a hypothesis. This hypothesis would give a stronger meaning to the term "merchants" in the title of Naomi Oreskes' book since we would then talk about "market doubts."

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