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The Concept of Antifragility and its Implications for the Practice of Risk Analysis

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Nassim Taleb's antifragile concept has been shown considerable interest in the media and on the Internet recently. For Taleb, the antifragile concept is a blueprint for living in a black swan world (where surprising extreme events may occur), the key being to love variation and uncertainty to some degree, and thus also errors. The antonym of "fragile" is not robustness or resilience, but "please mishandle" or "please handle carelessly," using an example from Taleb when referring to sending a package full of glasses by post. In this article, we perform a detailed analysis of this concept, having a special focus on how the antifragile concept relates to common ideas and principles of risk management. The article argues that Taleb's antifragile concept adds an important contribution to the current practice of risk analysis by its focus on the dynamic aspects of risk and performance, and the necessity of some variation, uncertainties, and risk to achieve improvements and high performance at later stages.

KEY WORDS: Antifragile; black swans; risk management

1. INTRODUCTION

In his new book *Antifragility*, the author Nassim Taleb[1] provides some strong views on risk and performance. Many of them relate to predictability and risk management. He writes:

> It is far easier to figure out if something is fragile than to predict the occurrence of an event that may harm. Fragility can be measured; risk is not measurable (outside the casinos or the minds of people who call themselves "risk experts"). This provides a solution to what I've called the Black Swan problem — the impossibility of calculating the risk of consequential rare events and predicting their occurrence. Sensitivity to harm from volatility is tractable, more so than forecasting the event that would cause the harm. So we propose to stand our current approaches to prediction, prognostication, and risk management on their heads.[1, pp. 4–5]

This quote is the point of departure for this article. According to Taleb, prediction and risk management should be replaced by processes moving us from fragility to antifragility, but is there in fact a conflict? Do we not need prediction and risk management in this process to move us in the right direction? The main objectives of this article are to argue for the confirmation of the latter question and the thesis that the concept of antifragility represents a useful contribution to the practice of risk analysis. However, we need to see beyond the perspectives on risk management addressed by Taleb.[1] The main goal of risk management is not to accurately estimate rare event probabilities, but to reveal and assess uncertainties, and make adequate decisions under uncertainty. Before we contrast risk management and the concept of antifragility, and the related concepts of fragility and robustness, and discuss practical implications for risk analysis, a brief review of this concept is provided.

The discussion in this article focuses on Taleb's antifragile concept, but it also applies to some extent to his black swan concept,[2] whose occurrence, according to Taleb, cannot be predicted, and our only available option is to strengthen the robustness and responsiveness of our society so that the shocking effects of a shocking event are not that shocking.[3] These black swan theses are studied by many authors,[3–5] and provide input also to the

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present discussion, although their perspectives are different from the one adopted here.

Taleb is undoubtedly an excellent writer and thinker. His ideas are drawn from a variety of fields and although many of them are well known, he has an impressive ability to make his case a convincing one. This article acknowledges Taleb's work as an important contribution to the risk and uncertainty field, in particular his thinking concerning the link between uncertainties and variation on the one side, and improvement and learning processes on the other. As for all theory, it needs, however, to be challenged and discussed, and this is exactly what this article is aiming at.

2. THE ANTIFRAGILE CONCEPT AND THE RELATED CONCEPTS OF FRAGILITY AND ROBUSTNESS

To explain the antifragility concept as defined by Taleb, Fig. 1(a)–(c) is illustrative. Fig. 1(a) shows a robust/resilient system. The system is subject to shocks and stressors, but the consequences are relatively small. The system is characterized by a rather narrow distribution. We can say that the system is under control, the uncertainties are small. Think of a production system in which the failure of a unit is quickly fixed in order to resume production.

Fig. 1(b) shows a fragile system. This system is not under control. Here we may experience large negative consequences, the frequency distribution of events has considerable mass on negative values. In the example of the production system, the result of a failure could be a complete shutdown of the process lasting several months.

Fig. 1(c) shows an antifragile system. The extreme consequences are now only positive—the frequency distribution places heavy weight on large positive values. The antifragile system is rewarded with good results and protected from adverse events. In the production system example, failures are fixed, but there is also an improvement process leading to better performance.

In the following section we will look more closely into these ideas and relate them to fundamental concepts and principles of risk management.

3. RISK MANAGEMENT AND ANTIFRAGILITY

The above description should make it clear that an antifragile system does not produce severe negative consequences, only positive. Look at Fig. 1(c). Here we see small perturbations around the reference value (typically zero value), and one extreme positive outcome. This is a realization of an antifragile system. It is hard to think about any system in real life that is like this, that guarantees no extreme negative results. A real system is antifragile to some extent, and we can think about processes to improve the system in the direction of being more antifragile. This leads us to the question of how we can measure antifragility.

Taleb argues that we can estimate and measure fragility and antifragility, as they are part of the current property of an object.[1,9] He gives a number of examples related to fragility, for example, that you can state with a high confidence that a structure is more fragile than another should a certain type of event occur.

3.1. Fragility, Vulnerability, and Resilience

Fragility is commonly understood as "easily broken," "damaged," or "destroyed," and for the example referred to above we easily get a feel for what fragile means and how it can be described or measured. It is more difficult for more complex systems, for example, an offshore petroleum installation. Yet for such systems, we can also have a lot of measurements that provide information about the fragility, for example, accidents showing how relatively minor events (such as a small gas leakage) have resulted in total installation losses.

In the professional risk management context it is more common to address the vulnerability and resilience of the system than its fragility. From a practical point of view it is hard to see what the fragility concept covers that is not also captured by the vulnerability and resilience concepts. Vulnerability and resilience also relate to consequences of stresses. If a system is easily broken, it is vulnerable and not resilient. As we will show, the opposite also holds under some conditions. If the consequences of some stresses are (likely to be) severe, that is, the system is vulnerable, the system is also easily damaged from this stress; it is fragile with respect to this type of stress. A person can, for example, be vulnerable in relation to people talking about his hair, which means that his mind is fragile to this type of talk. The concept of fragility is not in general, however, associated with specific types of stress, and this leads us to the resilience concept. If the system is *not* resilient it is *not* able to sustain its function in case of a

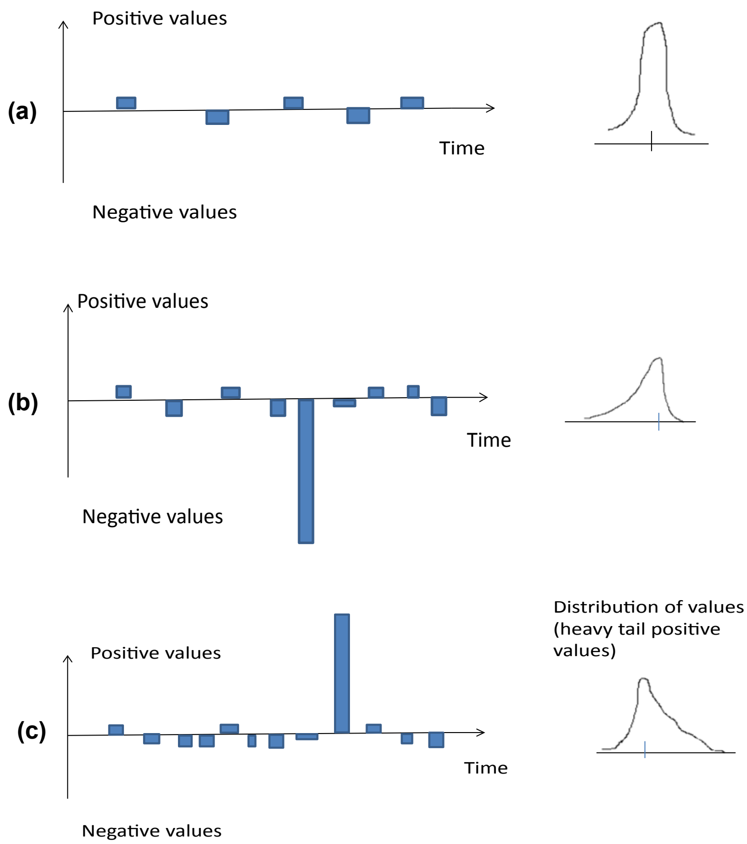

Fig. 1. Illustration of the (a) robust/resilient system, (b) the fragile system, and (c) the antifragile system (based on Taleb[1]).

stress—any type of stress. The body can be not-resilient toward different types of viruses, but does this mean that the body is easily broken, it is fragile? The answer depends on which types of stresses we include. If our focus is on these viruses, this not-resilience situation implies fragility but not so much if these viruses are extremely unlikely and we take an overall body health perspective. We are again back to the issue of which types of stress to include in the considerations. For all these three concepts we have to specify with respect to which set of stresses (known or unknown). If the set is the same, we can simply refer to one concept, for example, vulnerability.[6]

To formalize these concepts, a general setup[7] is needed. Let A be the stress (coming from a set S of stress types, which could be known, unknown, or both) and C the associated consequences (reflecting, e.g., the magnitude of the damage). Then we define vulnerability (in this wide sense) as (C,U|A,S), that is, as the combination of the consequences C of A and associated uncertainties U (what will C be?), given A and S.

To describe or measure the vulnerability, we select suitable characterizations C' of C (e.g., the number of lost lives), and a measure (in a wide sense) Q of the uncertainties. In general terms, we can then describe vulnerability as (C',Q,K|A,S), where K is the knowledge that C' and Q are based on. The most common measure Q is probability, but others also exist, including imprecise probabilities and qualitative approaches.

An assessor will judge the vulnerability given A and S as high if he/she finds (C',Q,K|A,S) to be high.

We may define fragility in this framework by a suitable specification of the various elements. In the simplest case of a structure subject to stress, the degree of fragility is linked to the time of failure (more precisely the expected failure time or more generally the probability distribution of this time) given specific loads. If the times to failure are typically low, the structure is judged as fragile. We see the resemblance with vulnerability judgments. The fragility measure is also a measure of vulnerability.

Robustness (and resilience) is commonly considered the antonym of vulnerability.[6,8,9] However, according to Taleb and Fig. 1(a), a robust system has no extreme consequences. In line with the perspective adopted in this article, we have high robustness if the vulnerability description (C',Q,K|A,S) is judged as low. This does not, however, exclude the fact that extreme consequences could occur—we cannot exclude scenarios, not thought of by the analysis group or given little attention because of low assigned probabilities, possibly being a reality in a complex system, although it is considered robust. Fig. 1(a) is problematic as it ignores these types of events. The distribution of values seems to represent a true variation also applicable for the future, but this is not possible in complex situations. The variation can be based on a substantial amount of historical data, which may be highly relevant for the future and capture most contributors to variation. But it could also be based on mainly expert judgments and be strongly influenced by those who perform the analysis. In any case, we need to consider it as a subjective (or intersubjective) measure of uncertainty and variation. Surprises may occur relative to these data, this analysis, and these judgments.

Taleb warns us against the experts' risk estimates —they cannot be accurately derived; the black swans are not reflected. However, surprising events (which may be also referred to as black swan type of events) may also occur in relation to the judgments made of robustness (and vulnerability and fragility). The point being made is that uncertainties and surprises need to be incorporated in the concepts and measurements of fragility, vulnerability, and resilience to make them meaningful in a practical context. It is not sufficient to use frequency distribution to describe these concepts as in Fig. 1.

3.2. Antifragility

We will now consider the antifragility concept and reflect on how to measure the degree of antifragility. This concept is more complex than the other three studied above, as it involves a development over time: by loving randomness, variation, and uncertainties, the system performance will be improved and we are to reach a situation as described by Fig. 1(c). The idea is well known and a fundamental principle in physical training. To become good, you have to impose stressors.

This idea means that we need to think of both positive and negative consequences C. Vulnerability and fragility focus on the negative consequences. Let the stresses be $A_1, A_2, \ldots, A_n$, on the system, and the associated consequences $C_1, C_2, \ldots, C_n$. These consequences will typically be minor, and the more antifragile, the higher the probability of large positive consequences and the lower the probability of negative consequences. Using the (C,U) nomenclature, a high level of antifragility is seen if judgments of (C',Q,K) for future activities are high for positive C' and low for negative consequences C'. The triplet (C',Q,K) can be viewed as a description of risk.[7] Making such judgments over time will reveal a possible trend toward antifragility, where no severe negative consequences occur. The K will include information concerning past A_i events and consequences C_i. Alternatively, we may consider the triplet (C',Q,K) a description of vulnerability given these stressors.

No nontrivial system can be fully antifragile; it can only be antifragile to some degree. Its measurement depends on judgments such as (C',Q,K). As for fragility, vulnerability, robustness, and resilience, we need to incorporate the uncertainties and surprises in the antifragile concept and measurement to make it meaningful in a practical setting. An example related to the operation of an offshore oil and gas producing installation will be used to explain this in more detail.

3.3. Example: Offshore Installation

The main goals for the operator of the installation are to maximize values and avoid severe incidents, including accidents. A lot of minor events occur, for example, gas leakages, and the production capacities also vary due to different operational measures, in particular maintenance activities. These events and activities can be viewed as the stresses $A_1, A_2, \ldots, A_n$, and we refer to the associated consequences as $C_1, C_2, \ldots, C_n$ as before. The observed variation in outcomes has been small, as the initiating events (leakages) have not escalated to accidents. However, there is a possibility that the next leakage could result in a major accident, such as the Piper Alpha (in 1988) and the Deepwater Horizon (in 2010) disasters. Fire and explosion scenarios may happen, leading to loss of lives, and environmental damage, as well as economic loss. In an antifragile system such disasters do not occur. However, as stressed repeatedly, for any real-life system, we cannot ignore the possibility of a major negative event occurring. The issue is then how we can analyze the degree to which the system is antifragile and possible trends, and, more importantly, how to make the system more antifragile.

First, let us reflect on the concepts of fragility and vulnerability. How fragile is the installation? A number of vulnerability analyses are carried out for such installations, for example, when studying the effect of gas leakages. These analyses, which are input to the risk assessments, describe potential scenarios starting from the leakage that can lead to a major accident, with an associated assessment of probability and uncertainties. From such analyses we can make judgments about how easily the system could break, that is, its fragility and its vulnerability. Several gas leakages occur every year on the installation, but if the computed probability for a major accident is relatively low, it seems reasonable to conclude that the fragility is rather small and the vulnerability is low.

The assessments are based on a number of assumptions and simplifications. Many scenarios (starting with a leakage) could have been excluded because they are not thought of by the analysis group, or they are ignored because they have very low judged probability. Fragility and vulnerability also relate to these events. There is clearly not an objective description of the fragility level. It is strongly dependent on the analysis carried out, with its methods and the analysts involved.

At any time we may make a judgment of the level of antifragility, by looking at the historical performance, as well as using judgments of the robustness of the system (as defined above based on (C',Q,K|A,S)) and its ability to learn and make improvements. The robustness of the system is studied in risk assessments, typically by means of historical data, event trees, and physical modeling of the phenomena involved, for example, of gas dispersion and fire development. The physical phenomena are well understood, and we can ignore strict unknown unknowns, that is, events occurring that are completely unknown to the scientific environment. However, black swan types of events as mentioned above could occur: Events that were not on the list of known events from the perspective of those who carried out the risk analysis (or another stakeholder), but known to others (unknown known—unknown events to some, known to others); or events on the list of known events in the risk analysis but judged to have a negligible probability of occurrence, and thus not believed to occur.[10]

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- events on the list of known events in the risk analysis but judged to have a negligible probability of occurrence, and thus not believed to occur.[10]

The level of antifragility must in some sense reflect the risk related to such events. In an antifragile system these events do not occur, but in real life we cannot exclude them, and any measure of the level of antifragility must address this risk. In addition, judgments need to be performed of the ability to learn and make improvements. Here, many issues could be highlighted to improve the overall understanding of risk and in particular the awareness and sensitivity to discerning the details important for obtaining a high level of performance and avoiding disasters, for example, the concept of (collective) mindfulness, linked to high reliability organizations (HROs), with its five principles: preoccupation with failure, reluctance to simplify, sensitivity to operations, commitment to resilience, and deference to expertise.[10–12] Judgments of issues like these provide a way of measuring how the system with its personnel are able to deal with events and situations occurring, and also how they are able to learn and improve.

Taleb[1] refers to a test to detect antifragility (and fragility) using asymmetry: "anything that has more upside than downside from random events (or certain shocks) is antifragile, the reverse is fragile." In Table I, some examples of random events are provided for this offshore case, with associated judgments of upside and downside. A lot of events occur where the system is stressed. In all cases up to now, an accident has been avoided, although in one situation it was close. The risk management has a special focus on situations that could lead to accidents. Surely, there is risk present, and the challenge is to manage this in the best way. This also includes to improve the understating of risk by identifying signals and warnings and acknowledging uncertainties and the importance of knowledge.

Taleb [1, pp. 268–271] also presents another test for fragility and antifragility: for the fragile, shocks bring higher harm as their intensity increases (up to a limit), and for the antifragile, shocks bring more benefit (equivalently less harm) as their intensity increases (up to a point). For this test, it is clear that the leakage record shows a rather high number of

Table I. Examples of Events (Situations) in the Offshore Case and Associated Judgments of Upside and Downside

Events /Situations	Effects (Upside, Downside)	Overall Judgment + Upside Dominating − Downside Dominating
Technical degradation leading to a leakage.	The safety barriers worked efficiently and the gas leakage was quickly stopped.	+
Error during planning of an operation, too low bolt torque specified, and a gas leakage occurred.	The safety barriers worked efficiently and the gas leakage was quickly stopped.	+
Large gas leakage occurring during testing after a period of maintenance.	The leakage was stopped after one hour. Under slightly different circumstances, there could have been a leak into the air at a significantly bigger rate, leading to the build-up of a large, explosive gas cloud that would have represented significant potential for a large accident.The operator implemented several measures to give better (more reliable and robust) systems in the future.	−
Relatively high production rates over a long period.	No increase in the number of leakages identified, in a short- or long-term perspective.	+

leakages that all have been stopped and further escalation avoided. In this sense the system has shown to be robust. There are also signs of antifragility, as more frequent leakages and a large one have resulted in considerable efforts aimed at reducing the leakage rate (as reported in Røed *et al.*).[(13)] On the other hand, some major leakage events in recent years have caused the Petroleum Safety Authority Norway (PSA-N) to question whether the industry does enough to pursue improvement processes and ensure lessons are learnt from previous incidents.[(14)] Many of the leakage scenarios that have recently occurred in the oil and gas industry have been of the unknown known type—the analysis team did not identify the event though it was well-known in other parts of the organization.[(15)] Anyway, there are risks involved—a major accident can occur—and the system is of course antifragile only to some extent.

It is immediately clear from this brief analysis that the tests are to be seen as nothing more than crude indicators of the level of antifragility. We will return to these tests in Section 4.

4. IMPLICATIONS FOR THE PRACTICE OF RISK ANALYSIS

In line with the argumentation and conclusions made in Section 3, the main features of the antifragility concept can be summarized as follows.

A system that is antifragile is exposed to stressors (uncertainties, variation, and risk at rather moderate levels) to obtain improvements and high performance at a later stage. The more antifragile the higher probability and "risk" related to positive performance and the lower probability and "risk" related to negative performance (such as accidents). Here "risk" relates to the consequences addressed, the uncertainty judgments (typically using probability), and the background knowledge that these are based on (i.e., (C',Q,K)). High "risk" related to positive performance is, for example, obtained if it is likely that the consequences will be very much desirable, and the background knowledge is strong.

To measure the degree of antifragility, "risk" needs to be described (key elements are: consequences of various stressors related to both positive and negative performance, uncertainty judgments, background knowledge).

The first symmetry test indicated by Taleb and briefly studied in Section 3 can be extended and conducted in line with these ideas by considering this risk description—comparing the positive "risk" with the negative "risk." A highly antifragile system is characterized by high positive "risk" and low negative "risk."

The second symmetry test of Taleb is related to the degree that the positive "risk" increases by increased stressors. Doubling the stressors should lead to an even higher effect on positive "risk." This test is, however, problematic to use, as indicated in Section 3. The idea can only work for some level of stressors, and it is often difficult to make comparisons in the level of increase for the stressors and the risk.

Then, we may ask, given this understanding of the antifragility concept, what does it add to risk analysis practice compared to robustness and resilience? The key contribution is the antifragility concept's idea of linking variation, uncertainties, and risk at the stress level to the positive and negative "risk" related to future performance. Robustness and resilience address both the stress dimension, but do not see these in relation to future developments that extend beyond established functions. Take the offshore example. The issue is not only about ensuring that a specific leakage is not ignited and an accident is avoided. Equally important is the process of developing over time and reaching higher levels of performance both with respect to production and safety. The design may be difficult to change in operation, but there may be a potential for operational and organizational improvements. The antifragility concept emphasizes the importance of not being satisfied with performance compliance at specific points in time. What is coming next needs always to be highlighted. The dynamics of the system is crucial for the proper understanding and management of the system (as also highlighted in system analysis and systems engineering).[16] If training programs are implemented with the purposes of increasing the understanding of risk in the operational team when carrying out critical operations, like well operations, the result may be a temporary increase in accident risk as the procedural compliance thinking is somewhat challenged, but it could lead to considerable reduced risk over time. In a design stage of an installation, the use of different types of equipment and arrangements for meeting a specific function can lead to variation and more or less strong performance, but the different experiences this gives could be decisive for the development of next-generation units with considerably better performance and reduced negative risks.

No one can disagree with Taleb when he says that "it is far easier to figure out if something is fragile than to predict the occurrence of an event that may harm" (Section 1). However, fragility and antifragility are also difficult to measure as vulnerability, fragility, and antifragility could capture situations with a poor knowledge basis and where the future performance is subject to large uncertainties. In the previous section we have shown how the concepts of vulnerability, fragility, and antifragility are closely linked to risk, when suitably interpreted. Measuring all these concepts is dependent on judgments, and important contributors can be lost in the representations. Black swan types of events are also present at the vulnerability and fragility level, as surprising sequences of events and conditions. Taleb states that risk is not measurable for real-life situations. Yes, it is not measurable in the sense of accurate estimations as if a truth were possible to find. Risk can, however, be described, and that is where the benefit of risk assessment lies, and such descriptions capture much more than the assigned probability numbers of rare events as we have underlined many times already. For sure, in the case of black swan type of events, it is not the probability numbers for the events that are of interest, but the proper understanding of risk, the signals and warnings, the awareness and sensitivity to operations, resilience, etc., as discussed in the previous section. Taleb proposes "to stand our current approaches to prediction, prognostication, and risk management on their heads" (Section 1), and when looking at much of the current thinking with its focus on probability modeling and estimations, Taleb's view is understandable. However, risk management is required to find the proper measures to confront potential events occurring. There are always limited resources available for this purpose, and the risk assessment provides decision support. The decisionmakers need to be informed about the issues discussed above, related to the precursors, the uncertainties, the collective mindfulness principles, etc. In a particular case, a decisionmaker may need to choose between investments in some measures that are effective in the case of some events, but not for others, and investments in some other measures with the reverse effect. Accurate predictions and estimates cannot be provided but, for sure, in most cases, informative risk descriptions can.

The weight on improvements has been made also by other environments, in particular the quality field, with its emphasis on an understanding of variation and its focus on learning.[10,17] Combining ideas from this tradition and risk analysis as here described, it is possible to develop a perspective on risk that highlights some of the same aspects as the antifragility concept, including the improvements over time and confronting black swan type of events.[10] This perspective includes vulnerability and resilience as key concepts, and by adding the antifragility concept, a further emphasis on the improvement dimension has been obtained.

This perspective is considered implemented for the offshore case, to further reduce leakage risk over time.[10,15] It can be argued that such an implementation is demonstrating antifragility. The occurrence of some unknown known types of events, as was mentioned in Section 3, have made the industry more aware of the black swan events, and a suitable framework is introduced to deal with this risk. The stress induced by these events leads to better future risk management and a higher safety level. Also, the general practice of risk analysis is improved.

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