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On the meaning of a black swan in a risk context

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ABSTRACT

In recent years there has been much focus on the so-called black swans in relation to risk management and decision making under uncertainty. A key issue has been the ability of risk assessment and probability theory to capture the black swans. In this paper we carry out an in-depth analysis of what a black swan means in relation to risk, uncertainty and probability: is a black swan just an extreme event with a very low probability or is it a more surprising event in some sense, for example an unknown unknown? We question how the black swans are linked to the risk concept, to expected values and probabilities, and to the common distinction between aleatory uncertainties and epistemic uncertainties. The main aim of this paper is to contribute to a clarification of the issue in order to strengthen the foundations of the meaning and characterisation of risk, and in this way provide a basis for improved risk management. The paper concludes that the black swan concept should be associated with a surprising extreme event relative to the present knowledge.

1. Introduction

In recent years I have heard numerous speeches and read a large number of papers which refer to the black swan logic in a risk context. The metaphor is intuitively appealing and has been very popular to illustrate the idea of surprising events and outcomes. The black swan concept was first introduced by the Latin poet Juvenal, who wrote "rara avis in terris nigroque simillima cygno" (a rare bird upon earth, and exceedingly like a black swan), but, according to Hammond (2009), that was imaginative irony. Juvenal's phrase was a common expression in 16th century London, as a statement of something impossible. Up to that point in time, all observed swans in the Old World had been white. Taleb (2007), p. xvii, writes:

> Before the discovery of Australia people in the Old World were convinced that all swans were white, an unassailable belief as it seemed completely confirmed by empirical evidence.

But then in 1697 a Dutch expedition to Western Australia, led by Willem de Vlarningh, discovered black swans on the Swan River, and the concept of black swans developed to mean not only something extremely rare (a rarity), but also that a perceived impossibility might later be disproven: a logical fallacy, meaning that if one does not know about something, it is therefore impossible. Taleb (2007) comments that in the 19th century John Stuart Mill used the black swan logical fallacy as a new term to identify falsification. John Stuart Mill wrote: "No amount of observations of white swans can allow the inference that all swans are white, but the observation of a single black swan is sufficient to refute that conclusion." It became a classic example in elementary philosophy (Hammond, 2009).

In 2007, Nassim Nicholas Taleb further defined and popularised the concept of black swan events in his book, *The Black Swan* (Taleb, 2007) (a second edition was issued in 2010 with a new section which among other things discusses various aspects of the probability concept). Taleb refers to a black swan as an event with the following three attributes. Firstly, it is an outlier, as it lies outside the realm of regular expectations, because nothing in the past can convincingly point to its possibility. Secondly, it carries an extreme impact. Thirdly, in spite of its outlier status, human nature makes us concoct explanations for its occurrence after the fact, making it explainable and predictable.

Taleb's (2007, 2010) book has inspired many authors; see for example the many references in Taleb (2011). However, some scholars are sceptical of Taleb's work. Professor Dennis Lindley, one of the strongest advocators of the Bayesian approach to probability, statistics and decision making, has made his view very clear in a review of Taleb's book (Lindley, 2008): Taleb talks nonsense. Lindley lampoons Taleb's distinction between the lands of Mediocristan and Extremistan, the former capturing the placid randomness as in tosses of a coin, and the latter covering the dramatic randomness that provides the unexpected and extreme outcomes. Lindley provides an example of a sequence of independent trials with a constant unknown chance of success – clearly an example of Mediocristan. Each trial is to be understood as a swan and success a white swan. Using simple probability calculus, Lindley shows that a black swan is almost certain to arise if you are to

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see a lot of swans, although the probability that the next swan observed is white, is nearly one. Lindley cannot be misunderstood: "Sorry, Taleb, but the calculus of probability is adequate for all kind of uncertainty and randomness".

The purpose of the present paper is to provide a thorough analysis of this issue: the concept of the black swan in relation to risk. What is the meaning of this term in a professional/scientific setting? I question to what extent the ideas of Taleb, and in particular the distinction between Mediocristan and Extremistan, can be given a proper scientific justification in view of existing risk theories and perspectives. Clearly, if Taleb has made some important points, Lindley cannot be right. More specifically, the paper studies several interpretations of a black swan, starting from these four:

1. A surprising extreme event relative to the expected occurrence rate (extreme event in the sense that the consequences are large/severe, this understanding also applies to the interpretations 2 and 3 below).
2. An extreme event with a very low probability.
3. A surprising, extreme event in situations with large uncertainties.
4. An unknown unknown.

The discussion will be linked to a set of issues, including:

(a) The common distinction between aleatory uncertainties and epistemic uncertainties. Does a black swan mean that chances (frequentist probabilities) cannot be meaningfully defined for this event? A frequentist probability exists as a proportion of infinite or very large populations of similar units to those considered. It represents the aleatory uncertainties.
(b) The ability of risk assessment to identify the black swans.
(c) The problem of establishing an accurate prediction model for the black swan.
(d) The situation being characterised by large consequences and high uncertainties ("post normal sciences"). Is the occurrence of black swans linked to or restricted to such situations?
(e) The situation being characterised by scientific uncertainties as in applying the precautionary principle. Again, is the occurrence of black swans linked to or restricted to such situations?

The remaining part of the paper is organised as follows. In Section 2 we discuss the meaning of a black swan – addressing the four interpretations 1–4 mentioned above. The discussion is based on some fundamentals concerning the concepts of risk, probability and uncertainty, which are presented in Appendix A. To be able to clarify the meaning of the black swans, it is essential to be precise on these concepts. As we know there are different perspectives and definitions of these terms, and in our analysis we need to distinguish between these to be able to carry out a thorough argumentation. The closing Section 3 provides some final remarks and conclusions.

2. Discussion of what a black swan means

In the following we will discuss the four interpretations 1–4 introduced in Section 1.

2.1. Is a black swan a surprising extreme event relative to the expected occurrence rate?

Let $N(t)$ denote the number of times the event under consideration (called A) occurs in the period $[0,t]$, and assume that the expected number of events per unit of time, $E[N(t)]/t$, converges to λ as t goes to infinity (the expectation here is with respect to a frequentist probability distribution, see Appendix A). We refer to λ as the expected occurrence rate of the event A. Suppose $\lambda = 1/100$ (year^{-1}), i.e. the event A is expected to occur once every 100 years.

Now, is the occurrence of A to be considered a black swan? It is clearly a rare event, but the probability that it occurs in a period of 10 years could be relatively high. Assuming that the occurrence process $N(t)$ is a Poisson process, we know that the probability of at least one event during 10 years is $1 - \exp\{-\lambda 10\} \approx 0.10$, and the occurrence of the event can hardly be said to be surprising.

If, however, the occurrence rate λ is equal to say 1/10,000, an occurrence of the event during the next 10 years is rather surprising as the probability is about 0.1%. However, say that we are facing not only one such event occurrence process, but many similar processes, for example 200. Then the occurrence of at least one event is about 20%. Hence the occurrence of one event in this period is not particularly surprising. Focusing on a specific type of event A, the occurrence may be surprising but not when considering a large number of such processes.

In a society we are facing a number of different types of extreme events. Let us assume for the moment that we know what these types are and what their occurrence rates are. Then we are in a situation as described above. Considered in isolation, one type of extreme events may be considered surprising but not if we open up for all types of events.

Of course in practice, the situation is not as idealised as this; we may not know all types of events and how often they occur. These situations will be discussed in the coming subsections. It is too early to conclude on the question of whether a surprising extreme event relative to the expected occurrence rate should be considered a black swan.

2.2. Is a black swan an extreme event with very low probability?

Let us return to the case presented by Lindley (2008) mentioned in the introduction section. In this example we consider a sequence of independent trials with a constant unknown chance of success. Lindley shows that a black swan (failure of trial) is almost certain to arise if you are to see a lot of swans, although the probability that the next swan observed is white (success of trial) is nearly one. This example is similar to the one studied above for the occurrence rate. When we focus on the occurrence rate of the first black swan we get a very low number, whereas if we consider the occurrence rate when studying a large set of swans the probability of occurrence of a black swan becomes large. But there are some differences between these two examples, and these are important. To reveal these, we need to dive deep into the assumptions of Lindley's example.

Lindley assumes that we are facing a sequence of independent trials with a constant unknown chance of success, and to obtain his probabilities he assumes a prior probability distribution over this chance, namely a uniform distribution over the interval $[0,1]$. This means that Lindley tacitly has assumed that there is a zero probability that all swans are white – there is a fraction of swans out there that are black (non-white). From this point on, his analysis cannot change this assumption. Of course then, the probability calculus will show that when considering a sufficient number of swans, some black ones will be revealed; see the Appendix B. By the assumptions made, the analyst has removed the main uncertainty aspect of the analysis. In real life we cannot of course exclude the possibility that all swans are white. The uncertainty about all swans being white is a key issue here, and Lindley has concealed it in the assumptions. This is the problem raised by many authors, including Taleb (2007, 2010) and Aven et al.