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The cautionary principle in risk management: Foundation and practical use

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ABSTRACT

The precautionary principle is well known among scientists, politicians and the public in general. However, the closely related and broader cautionary principle is not so often referred to. Whereas the precautionary principle is typically invoked in cases of scientific uncertainties, the cautionary principle applies to the more general situation of risk and uncertainties. The present paper summarises and extends the argumentation adopted to justify the cautionary principle and presents and discusses some real-life examples of its use, covering both safety and security issues. The aim of the paper is to clarify the rationale of the principle in risk management, by reasoning and using these examples to illustrate the ideas and argumentation. The paper also refers to a new concept, the 'anti-cautionary principle', which stimulates actions and measures that can produce highly positive values.

1. Introduction

John has a nice house. He has implemented many measures to ensure that the probability of fire is very low. Yet, he has purchased a fire insurance policy. A fire could occur, and he will not take the risk of losing everything. He applies what is commonly referred to in risk management as the cautionary principle. This principle expresses that "If the consequences of an activity could be serious and subject to uncertainties, then cautionary measures should be taken, or the activity should not be carried out" [12].

As another example of the use of the cautionary principle, consider the German decision to phase out their nuclear power plants by the end of 2022 [18]. This decision was made following the 2011 Fukushima nuclear disaster. There are risks related to both potential nuclear accidents and nuclear waste. Judgements were made that the risks are unacceptable. Half of the German Ethics Commission, which paved the way for the German phase-out decision, argued that "Nuclear energy is not acceptable because of its catastrophic potential, independent of the probability of large accidents occurring and also independent of its economic benefit to society" [12]. They can be said to have given very strong weight to the cautionary principle. The other half argued using a cost-benefit type of reasoning: other means of electricity generation were feasible with almost the same benefit as nuclear power but with less risk [32]. Weight is also given to the cautionary principle in this case, although the argumentation is different. In most cases in life, trade-offs between different concerns must be made, and the cautionary principle then must be balanced against other attributes like costs and value generation.

As a third example, think of a car in which the driver considers passing another car on a rather narrow road. The driver may abandon the passing or choose to carry it out, increasing concentration and awareness when passing the car. The driver gives weight to the cautionary principle.

As a final example, consider the risk related to hydrocarbon leakages on offshore installations. According to the Norwegian petroleum regulations, it is a regulatory requirement that the living quarters should be protected by fireproof panels of a certain quality, for walls facing process and drilling areas [30]. This is a standard adopted to obtain a minimum safety level. It can be considered justified by reference to the cautionary principle.

All these examples refer to the cautionary principle and not the more common precautionary principle. Following SRA [33], the latter principle states that "If the consequences of an activity could be serious and subject to scientific uncertainties, then precautionary measures should be taken, or the activity should not be carried out" (see also [12]). Thus, the key difference between the cautionary and the precautionary principle is that the latter refers to 'scientific uncertainties', whereas the former just refers to 'uncertainties'. In none of the above examples do we face scientific uncertainties, and, hence, the precautionary principle does not apply. The point is that in these cases we understand the phenomena involved. We are able to develop accurate models of what is happening. We face scientific uncertainties when this is not possible, for example if we study the long-term effects on human health of a new type of chemical. The concept of scientific uncertainties has been thoroughly discussed in the literature; see for example Aven [2], Cox [16], North [27] and Vlek [38]. As scientific uncertainties make up a category of uncertainties, we see that the precautionary principle is a special case of the cautionary principle.

The present paper aims to clarify the motivation and rationale for the cautionary principle, and how it differs from the precautionary principle. A main goal of the work has been to demonstrate that the cautionary principle is a useful principle in risk management, closely

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linked to the key risk management strategies of robustness and resilience. In particular, the paper aims to show what the cautionary principle adds compared to the expected utility theory and similar decision analysis approaches. In many situations, such as for security issues, the extent to which we face scientific uncertainties is open to discussion, although we are clearly confronted with potential severe consequences, and uncertainties. The cautionary principle is thus applicable, and the issue of whether the problem is a precautionary one or not need not be addressed.

The remainder of the paper is organised as follows. Section 2 discusses whether the cautionary principle is a decision rule or not. Clarifying this is important in order to understand what this principle really means and does, compared to, for example, expected utility theory. Section 3 clarifies the scope of the principle – when it is applicable - and relates it to different features of the risk concept and how risk is characterized. Section 4 discusses the rationale of the principle - how it is justified. Finally, Section 5 provides some conclusions. The present paper summarises existing works on the topic (including [12]) and refines and extends the current insights and results. The fundamental idea of the cautionary principle and related approach – to be cautious – is probably as old as human life itself. Although not explicitly stated as a principle or approach, it has always been reflected in some way when considering risk in a decision-making context. To the best knowledge of the present author, HSE [22,23] is among the first to explicitly refer to the principle/approach. These HSE guidance documents on risk and safety management have inspired further developments, as reported in, for example, Aven and Abrahamsen [7] and Aven and Renn [11,12].

For terminology and definitions of key concepts, see the Glossary developed by the Society for Risk Analysis [33]. The risk concept will be discussed in detail in Section 3. The term uncertainty is used to capture the idea that a person or a group of persons does not know the true value of a quantity or the future consequences of an activity, as a result of imperfect or incomplete knowledge. Probability ('subjective probability') is a tool used to express uncertainties. Knowledge refers to justified beliefs, founded on data, information, modelling, testing and argumentation.

2. Is the cautionary principle a decision rule?

The cautionary principle provides guidance on how to handle risk. It is certainly not a decision rule, interpreted in a narrow sense, which maps an observation to an action. There is not necessarily an observation to consider when addressing risk. What we are facing are potential observations, events and their effects. We formalise the setting studied by considering an activity interpreted in a wide sense, for example the operation of a process plant, an investment, or the life in a country or on the globe. This activity can lead to some consequences C when looking into the future, for instance the coming year. As C is unknown – is subject to uncertainties U – we cannot define a decision rule based on C. We need to take into account uncertainties. This leads us into theories like subjective expected utility theory, which compare options using the expected utility, E[u(C)], where u is a utility function reflecting the decision-maker's preferences. Using this theory, a decision rule can be defined guiding the decision-maker: if the expected utility for alternative 1 is higher than for alternative 2, alternative 1 should be chosen. In its most general form, a decision rule is a logical statement of the type "if [condition], then [decision]". As formulated by Peterson [29], "A decision rule simply tells decision-makers what to do, given what they believe about a particular problem and what they seek to achieve". Given such a definition, we need to clarify whether the cautionary principle is a decision rule or not.

The definition of the cautionary principle, "If the consequences of an activity could be serious and subject to uncertainties, then cautionary measures should be taken, or the activity should not be carried out", seems at first glance to indicate that it is a decision rule in this sense. However, the definition does not point to a specific decision, and the term 'should' is used, indicating that there is no direct link between the condition and the decision. Also, the condition referred to for using the principle is vague, allowing for different interpretations and judgements.

It is concluded that the cautionary principle as here defined is not a decision rule. Rather, it is to be considered a guiding perspective for risk handling, a perspective which is considered expedient, prudent or advantageous. This type of interpretation is rejected by scholars like Peterson [29], who argues against it in relation to the precautionary principle:

> From an intellectual point of view, this is not good enough. The respectable way to discuss decision-making based on qualitative information is to use qualitative decision theory, which requires that we have one or more precise formulations of the decision rule. Essentially, we need a principle that tells us what to do and what not to do for each possible input of qualitative information. Until such a formulation of the precautionary principle is agreed on, it is normatively empty [29].

The point made also applies to the cautionary principle. But what does the phrase "From an intellectual point of view" really mean? The following discussion will demonstrate that attempts made to use such a decision rule formulation fails to capture the essence of what the principle is aiming to achieve.

Let us return to the concept of the decision rule as expressed by Peterson [29]: "A decision rule simply tells decision-makers what to do, given what they believe about a particular problem and what they seek to achieve". A key point here is the expression "given what they believe". Decision-makers may have beliefs about what can happen in the case of an activity and even express these using some types of likelihood judgements. However, to rely fully on these beliefs is to violate the idea of the cautionary principle. With uncertainties about the consequences C, care needs to be shown in giving weight to beliefs and judgements about C, as these can be more or less strong and even erroneous. An assessor (which could be the decision-maker) may judge an event F to be more likely than G, but the decision-maker should not give much weight to this when the judgement is poorly founded. The actual outcomes may not be consistent with the likelihood judgements made.

Attempts have been made to show that the precautionary principle leads to inconsistencies when used as a decision rule [28]. The problem is, however, that the conditions applied to ensure these results build on comparisons of likelihood judgements. One such condition states that "If one act is more likely to give rise to a fatal outcome than another, then the latter should be preferred to the former, given that both fatal outcomes are equally undesirable" [28]. As commented above, such judgements cannot be justified in the case of large uncertainties.

3. The scope of the cautionary principle – its link to risk

As a guiding perspective for risk handling, there are several aspects that the cautionary principle seeks to highlight. Firstly, it points to the need for actions when the consequences C can be extreme, as in several of the examples discussed in Section 1. Caution is needed when the potential for such Cs exists. Related uncertainty and likelihood judgements affect the degree of caution.

Secondly, the cautionary principle points to actions when the consequences are sensitive to how the activity is realised, as in the car example presented in Section 1. Lack of awareness can, for example, easily lead to severe consequences. The issue is also related to risk compensation, behavioural adaptation and the notion of risk homeostasis [35,39]. The idea is that people may avoid or reduce risky behaviour in some types of situations but then increase it in others. Cautionary thinking in relation to car driving could for example be replaced by more risky behaviour as a biker.

The same type of sensitivity argumentation can be used for the offshore and nuclear examples. These examples also illustrate a third aspect, captured by the saying ‘better safe than sorry’. It is considered wise to be cautious, even when it does not seem necessary, to avoid problems, failures and losses later. If not being cautious, one may later regret it. If you go for a hike in the mountains, it is wise to have extra clothes in case the weather should change. The calculated risk reduction of having living quarters protected by fireproof panels of a certain quality, for walls facing process and drilling areas, may be low but justified by references to the cautionary principle, as discussed in Section 1. A fire scenario threatening the living quarters may occur, and the specific requirements ensure a minimum protection level.

In statistics, there are two types of errors: false-negative and false-positive. In science, it is generally considered more important to avoid false positives than false negatives as discussed, for example, by Peterson [29]. We will avoid concluding that a substance has a positive effect when that is not the case. This is in line with the cautionary principle. Without a strategy for avoiding false positives, the consequences could be serious. We (society) will not introduce a new substance if we are not sufficiently confident that it is safe. The point of departure is that the substance is risky, and the producer must demonstrate that it is safe. In this sense, the burden of proof is reversed. Society does not have to prove that the substance is dangerous.

As the last and fifth aspect, the cautionary principle highlights the case of scientific uncertainties, as introduced in Section 1. In this case, the principle is referred to as the precautionary principle.

It is illustrative to relate the cautionary principle to risk. In its broadest sense, risk can be viewed as the combination of the consequences of an activity and related uncertainties [5,33], denoted (C,U) using the symbols introduced above. Describing or characterising the risk, we are led to (C’,Q,K), where C’ are the specified consequences, Q a measure (in a wide sense) of uncertainty and K the knowledge supporting this measure. This representation of risk covers, as special cases, most other commonly used conceptualisations of risk. Without loss of generality, we can also write risk as (A,C,U), where A represents events (changes, hazards, threats), which can lead to some consequences C. The risk characterisation can then be reformulated as (A’,C’,Q,K).

From this basis, we see that the cautionary principle applies when risk is judged high in the following ways:

(1) There is a potential for C values that are extreme (highly negative).
(2) There is a potential for serious C values if the activity is not cautiously executed – C is very sensitive to how the activity is run.
(3) There is a potential for serious C values if something unlikely, surprising, or unforeseen should happen (for example an event A not anticipated or a new type of event A).
(4) Weak knowledge about the consequences C of a specific type of activity, for example about the effect of the use of a specific drug. There is a potential for serious C values.
(5) There is a potential for serious C values, and these are subject to scientific uncertainties.

Some of these criteria are closely linked and overlapping, as for Example (4) and (5). What is a serious or extreme C is a judgment call, as illustrated by the examples in Section 1. The consequences may relate to different types of values, such as life, health, the environment and economic quantities. Interpreting risk as above, the cautionary principle reflects a type of risk aversion, in the sense of disliking the risk (the negative consequences and the related uncertainties). The technical definition of risk aversion commonly used in economic contexts [33] is not very useful when discussing the scope and rationale of the cautionary principle, as expected values and the decision maker's certainty equivalent are not easily determined or meaningful in the situations here considered.

4. The rationale of the principle

The cautionary principle states that, if risk is high in the sense of (1) – (5), caution is in place: measures should be implemented, or the activity should not be realised. The principle provides guidance, it does not prescribe what to do. No risk management principle should prescribe what to do, as there is always a gap between principle and action. In the face of risk with the potential for serious consequences, there is no general formula or approach that can objectively produce the best decisions. Statistical analysis and traditional risk assessments can provide strong support for specific decisions in cases where ‘objective’ probabilities can be established, but for situations characterised by uncertainties, the analytical approaches have severe limitations. Decision analysis theories reflecting the uncertainties exist, like the subjective expected utility theory, but they all have limitations in providing clear answers on what is the best decision. The subjective expected utility theory is suitable for individual decision makers, but not for the organisational and societal levels [17,26,31]. The theory is difficult to use, with its demanding ways of assigning probabilities and utilities [3].

Consequently, the use of risk management principles is needed, to provide guidance on how to think and make good decisions. In relation to risk, there are two main types of concern: The need for creating values on the one hand and protection on the other. The cautionary principle is of the latter type. It gives weight to the uncertainties. It has a role in notifying people and society in relation to protection against potential hazards and threats with serious consequences. A principle highlighting value creation is the use of traditional cost-benefit type of analysis CBA (expected net present value calculations), as risk and uncertainties are here not given weight beyond expected values. Adopting one of these principles and ignoring the others would clearly lead to poor risk management. We need both categories of principles, as well as principles highlighting other concerns, in particular the need to obtain a balance between development and protection; refer to the discussion in Aven and Renn [12].

The case of smoking and passive smoking is an interesting one, in relation to this discussion. Recently, we have seen a trend for governments to ban public smoking, often following intense discussion [12]. For example, in UK [37], questions are asked about the evidence for such a ban: is the decision a disproportionate response to a relatively minor health concern? The basis is CBA type of reasoning. As discussed in Aven and Renn [12], the analysis demonstrates a lack of understanding of the fundamental principles of risk management and governance. The approach used does give proper weight to the importance of people and their well-being and the health conditions of having a smoke-free environment. A ban may also contribute to a general reduction of smoking in society, having strong implications. Highlighting the cautionary principle would justify such a ban to protect people from involuntarily being exposed to the health-damaging activities of others, and generally reduce the effects of smoking in society.

One of the reviewers of the original version of the present paper requested some reflections on why anti-terror security measures in the chemical industry are hardly used in Europe, although they are in the US. Such measures can be viewed as justified by reference to the cautionary principle. To provide a comment on this, it is essential to acknowledge that cautionary measures always have to be balanced against other concerns, such as efficiency, effectiveness and costs, and the balance is strongly influenced by historical and social factors, for example recent events. As for the nuclear industry, different countries have come to different conclusions, what measures to implement, as they give different weight to different concerns and values.

In society, there is a continuous ‘battle’ between development on the one side and protection on the other. This battle is rooted in differences in values and priorities, but also in scientific and analytical argumentations. For example, public administration is strongly guided by the use of cost-benefit type of analysis. Risk and uncertainty considerations are given little attention beyond expected values. The rationale is that the expectation will approximate well the average value when considering a large portfolio of activities or projects [6,20]. There could be dependencies between the activities, which could lead to deviations between the average value and the expectation, which need to be taken into account in the risk management. However, the potential for extreme outcomes in relation to specific activities can be basically ignored when the number of activities is large. This means, for example, that the risk related to a major accident in a country is given rather little weight in traditional cost-benefit analysis (CBA) when taking a national or global perspective. As a result, traditional cost-benefit analysis would, for example, normally 'justify' nuclear industry in a country.

The cautionary principle has a role to play in relation to this type of consideration and management. A warning is in place – there is a potential for serious consequences and there are uncertainties. The development tools have spoken – now it is time for the protection side to highlight important aspects for the decision-makers to adequately balance the various concerns. The protection side also needs a scientific voice and justification, as

(1) CBAs have strong limitations as a scientific tool – they do not adequately reflect risk and uncertainties
(2) CBAs favour development at the expense of protection.

The arguments for these assertions are well known (see e.g. [6]), the key point being that the analysis is based on expected value. Let us look into an example to illustrate the discussion.

A country has about 100 installations of a special type which all have the potential for a major accident, leading to a high number of fatalities. A risk assessment is conducted and the total probability of such an event in the next 10 years is computed as 0.010. From the assessment, one such major event is expected in this period. A safety measure is considered for implementation. It is, however, not justified by reference to a cost-benefit analysis, as the expected benefit of the measure is calculated to be rather small. The costs are considered too large in comparison with this expected value. The basic rationale is that we should expect one such event in the period and the measure considered would not really change this conclusion.

However, the perspective taken is close to being deterministic and destiny-oriented. One such event does not need to happen. Safety and risk management aim to avoid such accidents, and, if we succeed, the benefits are high – saving many lives. The value of the safety measure is not fully described by the expected number. The measure's value is mainly about confidence and beliefs that the measure can contribute to avoiding an occurrence of the accident.

Probabilities are commonly used for this purpose. Implementing the safety measure can, for example, result in a reduction in the accident probability estimate from 0.010 to 0.009, which shows that it is less likely that a major accident will occur. However, the difference is small and will not really make any difference for the decision-making problem. One major accident is still foreseen.

It is essential to acknowledge that probability and probabilistic analysis are just tools for supporting decision-making. These tools do not capture all aspects of importance for the decision-making, as thoroughly discussed in the literature (e.g. [19]) and also addressed above.

The full effect of a risk-reducing measure is not adequately described by reference to a probability number alone. A broader concept of 'confidence' is better able to reflect the total effect. This concept is based on probability judgements, as well as assessments of the knowledge supporting these judgements. For example, it matters a great deal whether the probability judgements are based on strong knowledge or weak knowledge. Different schemes exist for evaluating the strength of the knowledge, see for example discussions by Aven and Flage [9]. Key aspects to consider are: reasonability of the assumptions made, the amount and relevancy of data/information, the degree of agreement among experts, and the degree to which the phenomena involved are understood and accurate models exist. A strong knowledge corresponds to low uncertainty. It is, however, important to clarify what the uncertainty is about. For example, if the issue is about the correctness of a belief A and we have strong knowledge supporting this belief, the uncertainty about A being true or not would be low.

Due considerations need to be given to potential surprises, although their risk contribution is per definition difficult to measure or describe. As resilience measures are to a large extent motivated by meeting potential surprises and the unforeseen, it is also a challenge to adequately characterize the effect of resilience measures. Surprising scenarios will always occur in complex systems, and traditional risk management approaches using risk assessment struggle to provide suitable analysis perspectives and solutions to meet the risks [13,21,36]. Measuring the benefit of investing in resilience is thus difficult. Such an investment can contribute to avoiding the occurrence of a major accident, although the effect on calculated probability and risk numbers could be relatively small.

To further illustrate the need to see beyond approaches based on analysis and judgements alone, think about an event A, for which a probability of less than 0.000001 is assigned, given the knowledge K, that is, $P(A|K) < 0.000001$. The probability is judged so low that the occurrence of the event is basically ignored, refer to example by Bjerga and Aven [15]. Now, suppose the probability judgement is based on a specific assumption, for example that some potential attackers do not have the capacity to perform a type of attack. Given this assumption, the probability is judged to be negligible. Hence, if the event occurs, it will come as a surprise, given the knowledge available. However, the assumption could be wrong and, clearly, with a different knowledge base, the probability could be judged high, and the occurrence of the event would not be seen as surprising. The cautionary principle highlights the need for further checking of the assessments made: Is the knowledge supporting the judgement strong enough? Could there be a potential for surprises relative to current knowledge? The assessors may consider the situation to be characterised by rather strong knowledge, yet the cautionary principle stimulates both better analysis and robust/resilient measures. The key point made is that the analysis could have limitations in accurately reflecting the real world, and surprises can occur relative to current knowledge. This justifies robustness and resilience-based measures, for example implementation of safety barriers, different layers of protection, 'defence-in-depth', redundancy, diversification, the ALARP (As Low As Reasonably Practicable) principle, etc. Current industry practice is based on this thinking and these types of measures – the cautionary principle is commonly adopted.

A remark is in place concerning the ALARP principle. It is a principle designed to support protection as the basic idea is that a measure that will reduce risk should be implemented [1,22,25]. Only in the case that it can be demonstrated that the costs are grossly disproportionate to the benefits gained, the measure does not need to be realised. Thus, it can be said to be highlighting a cautionary thinking. However, in practice we often see that the gross disproportion criterion is verified by using cost-benefit types of analyses [12]. These analyses are based on expected values and hence are not given much weight to risk and uncertainties. The result is that ALARP becomes a principle more highlighting development than protection. Alternative ways of verifying the disproportionate criterion are therefore suggested; see for example Aven [6]. The essential point is that if the cautionary thinking is to be given weight, measures should also be considered when the computed expected net present value is negative, provided these measure can contribute to a reduction in risks and uncertainties and a strengthening of the robustness and resilience of relevant systems [12].

See Jones-Lee [24], Ayyub [14] and Reniers and Van Erp [31] for thorough reviews of economic aspects of safety. These references also cover discussions of other economic approaches than CBAs, for example the use of disproportion factors. As discussed by Aven and Flage [8] these approaches meet to varying degree the critique raised against the CBAs and their expected value based philosophy. Yet they all face the problem that they are based on probability or another measure of uncertainty, which is conditional on some knowledge and this knowledge could be more or less strong and even wrong. Caution and precaution mean also highlighting the weakness and limitations of this knowledge.

Whether the uncertainties are scientific or not is not really the interesting issue in many cases. Think about cautionary measures implemented in airports all over the world. We do not know when an attack will occur, but, certainly, if no such measures had been implemented, extreme events would have been the result. The cautionary principle is applicable and has played a key role in the way this problem has been dealt with. The cautionary principle has not been specifically referred to – as it is not broadly known – but the above discussion has shown that it is in fact a main perspective adopted for handling the risk. Using the broader concept of the cautionary principle instead of the precautionary principle, we can avoid unnecessary discussion about what type of uncertainties we face, and focus can be placed on action and how to manage the risk. However, for some specific situations, it may be important to clarify whether the uncertainties are in fact scientific, so that the appropriate measures are taken. In relation to the approval of new products, the concept of scientific uncertainties is important, to ensure proper qualification processes. Clarifying when we face scientific uncertainties is also important in relation to other contexts, such as climate change, when more knowledge and science can reduce the scientific uncertainties, and, in this way, clarify the issues, and better distinguish between discussions about uncertainties and discussions about values.

The cautionary principle is introduced to protect values. The concerns are negative or undesirable consequences. A natural question to ask is whether it is possible and meaningful to define and use an opposite type of principle, highlighting wanted, desirable and positive consequences. Looking at the five criteria considered in Section 3, it follows that such a principle can indeed be formulated. The following definition is suggested: If the consequences of an activity could be highly positive and subject to uncertainties, then the activity should be carried out and supporting (stimulating) measures should be taken. The principle could be referred to as a type of 'development principle' or inspired by the 'anti-fragility' concept of Taleb [4,34], an 'anti-cautionary principle'. The five criteria could be rephrased as:

(1) There is a potential for extreme positive C values.
(2) There is a potential for highly positive C values if the activity is cautiously executed – C is very sensitive to how the activity is run.
(3) There is a potential for highly positive C values if a rather likely, specific type of event occurs
(4) Weak knowledge about the consequences C of a specific type of activity, for example about the effect of the use of a specific drug. There is a potential for highly positive C values.
(5) There is a potential for highly positive C values, and these are subject to scientific uncertainties.

An example of the criterion (3) could be that an opportunity arises as a result of a rival company going bankrupt. The criterion 5 can be interpreted as an 'anti-precautionary principle': If the consequences of an activity could be highly positive and subject to scientific uncertainties, then the activity should be carried out and supporting (stimulating) measures should be taken.

The anti-cautionary principle could reflect a high level of risk appetite in the sense of a strong willingness to take on a risky activity in pursuit of values; the riskiness depending of course on the potential for negative losses. Interpreting the risk appetite concept in this way (in line with [33]), it is a broader concept than the anti-cautionary principle, as it relates also to situations with 'objective probabilities' and negligible uncertainties.

In contrast to the cautionary principle, which is established to protect values, the 'anti-cautionary' principle is designed to generate highly positive values. The 'anti-cautionary' principle represents an extreme form for development principle, and as all such risk management principles, it needs to be balanced against other principles, including the cautionary principle. We can for example think of a situation where there is a potential for extreme consequences, both positive and negative, and the uncertainties are considerable. Then both of these principles are applicable and they need to be balanced. One of the reviewers of the original version of the present paper refers to the Ebola attack in Africa. No cure existed and many people died or suffered. A vaccine was developed with good effect, but according to international regulation any new product has to pass a number of tests, usually requiring months of time. The (pre)cautionary principle that applies in medicine of this type will abandon the use until all tests are carried out appropriately, since limited knowledge was available on any side effect of the new medicine. However, discussion arose whether the benefits (the wanted, desirable consequence C) were so promising that the (pre) cautionary principle should not be used. Giving weight to the anti-(pre) cautionary principle as defined above, on the expense of the (pre)cautionary principle, would had led to the conclusion that the vaccine should have been implemented.

5. Conclusions

The above analysis has shown that the cautionary principle has a rationale. Five criteria are developed to make sense of the cautionary principle, and arguments are provided to show that the principle meets a need in risk management. Analyses (such as risk assessments and CBAs) have strong limitations in guiding the decision-making in the case of large uncertainties. The cautionary principle is seen as a guiding perspective for risk management, a perspective which is considered expedient, prudent or advantageous. Precise guidance on when it is to be used cannot be provided, as the criteria for its invocation is subject to value judgements. The cautionary principle is not a decision rule. Risk management principles, like the cautionary principle, provide guidance on how we should think in relation to risk and what should be highlighted to protect something of value. There are different interests in most activities in life, and there is often a need to protect 'weak' parties. History shows us many examples of when protection has failed, with the result that numerous people have suffered and the environment has been damaged. The cautionary principle highlights protectional aspects and is balanced against principles that seek development and growth. Too much emphasis on caution would hamper innovation and new arrangements and solutions. Risk management gives proper weight to the cautionary principle and finds the right balance between development and protection. The cautionary principle includes the precautionary principle, which is invoked in the case of scientific uncertainties. For many types of situations, the cautionary principle is the appropriate concept, but, as discussed above, there are also situations where it is important to highlight that the uncertainties are scientific and the precautionary principle is the one reflected.

One of the reviewers of the present paper commented that, although analyses and economic approaches have limitations, they are the best there is at the moment to support decision-making (a bit like risk analysis techniques). The reviewer also points to the fact that the principle is rather philosophical and indicates that the principle is very hard to use in industrial practice. As a response to these comments, it is acknowledged that the principle does not provide clear-cut guidelines for what decisions to make in real life applications. However, the principle is still considered useful in risk management by providing a perspective on how to think in relation to uncertainties and risk, and as the examples discussed in Section 1 and the criteria referred to in Section 3 show, the use of the principle may lead to specific decision recommendations. In addition, the principle represents a 'correction' to the analytical approaches as these have limitations in reflecting all types of uncertainties and risks as discussed in the paper (Section 4 in particular). In this way it can be argued that the proper invocation of the principle will improve the way the analytical approaches are applied in practice – a more balanced use of risk management means is obtained. An example is presented by Aven and Kristensen [10] showing how judgments of knowledge strength is used to weighing different categories of risk management strategies, including those founded on the cautionary principle.

The discussion in the previous section has also motivated the definition of the 'anti-cautionary' principle. This principle stimulates actions and measures that can produce highly positive values. It is to be viewed as an example of a principle highlighting development in contrast to the cautionary principle which gives weight to protection. Criteria are established for both principles using a general risk set-up highlighting consequences of the activity considered and related uncertainties.

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