

**Uncertainty in risk assessment  
– contents and modes of communication**

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STOCKHOLM 2005

This licentiate thesis consists of the following introductory essay and two articles:

Levin, R., Hansson, S. O., Rudén, C. (2004): “Indicators of uncertainty in chemical risk assessments”, *Regulatory Toxicology and Pharmacology*, 39, pp. 33–43.

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Levin, R.: (2005) “Adequacy conditions for reporting uncertainty in chemical risk assessments”, forthcoming in *Human and Ecological Risk Assessment*.

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## **Abstract**

Levin, R. 2005. Uncertainty in risk assessment – contents and modes of communication. *Theses in Philosophy from the Royal Institute of Technology* 8. 71 + viii pp. Stockholm. ISBN 91-7178-175-7

Assessments of chemical health risks are performed by scientific experts. Their intended use is as bases for decisions. This thesis tries to answer the questions of how uncertainty is, and should be, communicated in such risk assessments. The thesis consists of two articles and an introductory essay.

*Article I* focuses on the linguistic aspect of the communication of uncertainty in risk assessments. The aim of the article is to elucidate how risk assessors actually indicate uncertainty in risk assessment reports. Because of the prevalent uncertainty in risk assessment, deriving from several sources, uncertainty is communicated in verbal, rather than numerical terms. A typology of *uncertainty indicators* – phrases used to express uncertainty – is proposed and applied to the reviewed reports. It is found that the use of such phrases is not transparent, and the article concludes by a number of recommendations for improving the practice.

*Article II* mainly deals with the content of the communication. The overall question treated is what a characterization of uncertainty should include if a decision made on the basis of the risk assessment information is to be as well-founded as possible. A set of conditions is put forward to be fulfilled by a characterization of uncertainty if it is to be adequate from a decision-making point of view.

The greater part of the *introductory essay* is devoted to the concept of uncertainty which, at the conceptual level, does not appear to have been much discussed by philosophers.

**Key words:** uncertainty, scientific uncertainty, characterization of uncertainty, decision-making under uncertainty, risk assessment, risk management

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ISSN 1650-8831  
ISBN 91-7178-175-7



## **Acknowledgements**

I am very grateful to my supervisor, Sven Ove Hansson, for his support, encouragement, and invaluable suggestions on how to improve the work. Also John Cantwell deserves special mention for his advice on solutions to crucial issues. A special thank is due to Anders Persson for his constant willingness to discuss philosophical matters in relation to the work with this thesis. I also wish to thank Marion Ledwig, Niklas Möller, Birgitte Wandall, and Per Wikman Svahn for suggestions and helpful comments on drafts of the manuscript. Of course, I am responsible for all remaining errors.

This work has been financially supported by MISTRA, The Foundation for Strategic Environmental Research, through the research programme NewS – A New Strategy for the Risk Management of Chemicals.

Stockholm, October 2, 2005



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### Article I

“Indicators of uncertainty in chemical risk assessments”, *Regulatory Toxicology and Pharmacology*, 39, pp. 33–43.

### Article II

“Adequacy conditions for reporting uncertainty in chemical risk assessments”, forthcoming in *Human and Ecological Risk Assessment*.



## **1 Introduction**

This thesis deals with the problem of how scientific experts should communicate uncertainty in reports on chemical health risks to be used in decision-making. Chemical risk assessment is an area where uncertainty is more prevalent than in many other applied sciences whose results are used in decision-making.

The points of departure in the thesis are (a) that a decision-maker's possibility of making a well-founded decision improves if, apart from decision-relevant knowledge, also uncertainty that may be relevant to the decision is carefully addressed in the information on which this is to be based, (b) that extensive uncertainty surrounds assessments of health risks posed by chemicals, and (c) that the risk assessment information often suffers from incompleteness and lack of clarity with regard to uncertainty about health risks.

Each of the two articles of which this thesis consists focuses on the third point of departure, that is, the communication of uncertainty in risk assessments. Article I is about its linguistic aspect: How is uncertainty actually indicated in risk assessments? It ends with a number of recommendations on how to improve the existing practice. Article II mainly deals with the content of the communication from a normative point of view: What should be included in a characterization of uncertainty to be of use to its intended audience? To answer this question, I propose a set of adequacy conditions to be fulfilled by a characterization of decision-relevant uncertainty.

### **1.1 Aim and scope of the thesis**

The aim of the thesis, which directly connects to the articles that follow, is to suggest how to improve the practice of characterizing uncertainty in chemical risk assessments. Related to that is the indirect aim to give a possible point of departure for a discussion of the corresponding practices in risk assessment on other areas, including economics, and large-scale policy-making where communication of uncertainty from experts to decision-makers and the public is needed. Since

uncertainty is the subject of characterization, a relevant, preliminary question concerns the nature of this concept: What is it to be uncertain? How is uncertainty related to other epistemic concepts, such as belief, knowledge, and ignorance? To clarify the concept of uncertainty is the major philosophical aim of this introductory essay.

## **1.2 Outline of the thesis**

The thesis consists of two articles following this introductory essay. In section 2 of this essay I give some background for the subsequent discussion. In section 3 an attempt is made at clarifying the relation between uncertainty and ignorance. In section 4 I introduce the definitions of the concept of uncertainty, and its two varieties, proposed in Article II. The major part of the section is devoted to some problems of the uncertainty definitions. In section 5 I make some general remarks on what it means to characterize uncertainty. In this connection I also discuss the possibilities of correlating linguistic expressions of uncertainty with underlying types of uncertainty, and mention a couple associated problems. Finally, in section 6 the contents of the articles are summarized.

## **2 Some introductory remarks on uncertainty**

In this section I want to give some background for the rest of the essay, by briefly referring to, and commenting upon, some views on uncertainty in relevant research areas, starting with philosophy.

Philosophers appear to have been only sparsely interested in the concept of uncertainty. This is also true of epistemologists, although one might expect some interest among them: the subject of epistemology is the nature of knowledge, and its central problem is what to count as justified acceptance of belief. One could argue that since uncertainty clearly has to do with lack of knowledge, or insufficient justification, analyzing the concept of uncertainty would be dealt with in epistemology. Now, against this an epistemologist might reply that, as long as there

are sceptics around, the epistemologically hard question is that of justification of belief to qualify as *knowledge*; the nature of degenerate concepts such as uncertainty, and for that matter, also ignorance, which clearly have to do with *incomplete* justification, are of less interest. For an epistemologist, it may suffice to say that in cases of uncertainty knowledge, or justification, is lacking.

A similar account may be provided by a philosopher of science interested in the problems of induction and confirmation of hypotheses. Uncertainty is undeniably involved in inductive inferences and confirmation, but ascertaining its nature is of minor importance in relation to the questions of how induction can be justified, and hypotheses confirmed.

However, in the more practically oriented field of decision-theory, much explored by philosophers, the concept of uncertainty plays an important role. This also applies to economics and some applied sciences, such as engineering, risk assessment and policy analysis. Since the concept of uncertainty, and its relation to risk, employed in the classical formulation of decision theory have strong affinities with a view earlier laid out by the economist Frank Knight in the 1920's I will take this as a starting point.

According to Knight, the term “risk” is used ambiguously, sometimes to refer to “a quantity susceptible of measurement”, and sometimes to refer to “something distinctly not of this character” (Knight, 1921, pp. 19f).<sup>1</sup> Whereas this *something* is uncertainty, the measurable quantity is objective probability, namely relative frequencies (“statistical probability”) and classical, “*a priori*” probability (Knight, 1921, pp. 214 – 216, 224f ). Apart from *a priori* and statistical probabilities, Knight discusses a third category, namely “estimates” or “probability judgments”, which are to be identified with subjective probabilities (Knight, 1921, pp. 223ff, 233).

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<sup>1</sup> This is not the only ambiguity of “risk”. The word is also used of the very outcome of a decision, especially if it is undesirable. Several other senses can be distinguished; see Hansson (2004) for a discussion.

Although estimates are distinguished from the two other kinds of probability as a separate kind, to fall under the category of risk, probabilities have to be measurable in an objective sense. Estimates are not measurable in any of the senses prescribed by Knight, and therefore belong to the category of uncertainty (Knight, 1921, p. 231).<sup>2</sup>

Knight's distinction between uncertainty and risk is quite well preserved in classical decision theory, as presented by Luce and Raiffa in the 1950's. In the classification of decisions, "uncertainty" is distinguished from "risk" and "certainty". "Certainty" here means that the outcomes of the decision-alternatives are known. A decision is made under risk when the probability of each outcome is known, and under uncertainty if the outcomes of the alternatives are known, but the probabilities of these outcomes are "completely unknown or are not even meaningful" (Luce and Raiffa 1957, p. 13). Between decisions under risk and uncertainty is the intermediate case of *partial ignorance*, when at best subjective probabilities can be obtained (Luce and Raiffa 1957, pp. 299ff). The distinction between uncertainty and partial ignorance (corresponding to *estimates*) was also made by Knight although both states are covered by his notion of uncertainty.

The emphasis on probabilities and outcomes in the decision-theoretic account is due to the aim of elaborating strategies for decision-making applicable in situations where more or less is known about the decision situation. That probabilities of outcomes are known is another way of saying that the relevant aspects of the possible states of affairs that determine the outcomes, given the various actions, are sufficiently known for probabilities to be derived. This I also take as the essence of the following passage from Knight:

"The practical difference between the two categories, risk and uncertainty, is that in the former the distribution of the outcome in a group of instances is known (either through

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<sup>2</sup> One may note that by "estimate" Knight does not mean a *subjective estimate of an objective probability*, although the difference is one of degree rather than kind (p. 225).

calculation *a priori* or from statistics of past experience), while in the case of uncertainty this is not true, the reason being in general that it is impossible to form a group of instances, because the situation dealt with is in a high degree unique.” (Knight, 1921, p. 233)

The distinction between risk and uncertainty according to Knight and classical decision theory is challenged by Bayesian decision theory. Central in this theory is the idea that a unique, numerical subjective probability, or degree of belief, can be assigned to any state of affairs (Savage, 1954). Accordingly, decisions made under less than certainty are reduced to decisions made under risk, if it would at all be meaningful to speak of decisions under risk, a notion being understood in contradistinction to uncertainty.

However, the Bayesian view referred to has in its turn been challenged by philosophers who disagree with the Bayesian doctrine that a unique probability may always be assigned. The underlying idea is that a subjective probability assignment will be more or less reliable depending on the amount and quality of available evidence, or conversely, depending on the degree of uncertainty about the basis of the probabilities. Several ways of numerically representing uncertainty by numerical qualifications of probabilities have been proposed. (The proposals are mentioned in Article II, section 2.3, where also references are given.) When such approaches are employed, distinguishing between decisions under risk and under uncertainty appears again to be meaningful.

Policy analysis, risk assessment, and engineering are other fields where uncertainty has been discussed at length. In the vast literature in these disciplines, there seems to be agreement that uncertainty is associated with lack of knowledge. When defined, uncertainty is often simply identified with lack of knowledge.<sup>3</sup> However,

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<sup>3</sup> Two definitions are given in Article II, section 2.1. It is often not clear how the various types of uncertainty in the classifications proposed relate to lack of knowledge.

there are also more elaborate definitions which are not always entirely transparently interpreted:<sup>4</sup>

“[Uncertainty is] any departure from the unachievable ideal of completely deterministic knowledge of the relevant system” (Walker: W. E. *et al.*, 2003, abstract).

“[U]ncertainty is a condition of not knowing. This thesis formally defines uncertainty as the difference between an anticipated or predicted value (behavior) and a future actual value (behavior).” (Thunnisen, 2005, p. 36)

In discussions on uncertainty in these fields, classifications of uncertainty are often introduced according to the nature of the problems dealt with. Two common main categories in such classifications are *parameter* and *model uncertainty* (NRC, 1994, p. 165), where the sources of parameter uncertainty are various kinds of measurement error, sampling errors, misclassifications and so on; and model uncertainty derives from oversimplification, and relationship errors in models, among other things. In another framework for classifying uncertainty, the two main categories are *epistemic* and *aleatory uncertainty*. The distinction between these two categories have strong resemblance with that between evidential and outcome uncertainty, that are introduced in Article II, and discussed in section 4 of this essay. Epistemic and aleatory uncertainty have been defined in the following ways:

“Epistemic uncertainty is any lack of knowledge or information in any phase or activity of the modeling process”.

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<sup>4</sup> Possibly, what is intended in the first definition is simply that knowledge is lacking. In the second, uncertainty appears to be a quantity. With this definition it seems difficult to account for uncertainty about non-quantitative things. Suppose I am uncertain about the colour of the apples at the market, and predict that there are only green ones, but find that they are all red. (*Green* and *red* then are values or *determinates* of the *determinable* colour.) Then my uncertainty would be the *difference* between *green* and *red*, but this sounds strange, to say the least..

“Aleatory uncertainty is inherent variation associated with a physical system or environment under consideration” (Thunnisen, 2005, p. 36, 39).

If the definitions are taken literally (and one disregards the specified object of uncertainty), then there is a fundamental difference between the above-mentioned distinction and mine, because I take lack of knowledge and non-determinateness (“inherent variation”) to be *sources* of uncertainty rather than the very uncertainty itself, which is said above. Although the relations between them remains to find out, the underlying rationale for making the distinctions is apparently the same. Possibly, the distinctions coincide.

In conclusion, decision theory appears to be the only philosophical field where uncertainty is taken into explicit consideration. However, the concept of uncertainty itself is not in focus, but rather the consequences of uncertainty for obtaining probability distributions, and for the choice of decision strategies. I can only guess about the scant interest of the concept of uncertainty within epistemology and philosophy of science. The approach to uncertainty in risk assessment, policy analysis and engineering is guided by the needs of these applied disciplines. I find most definitions of the concept of uncertainty in those fields rather unsatisfactory, including those identifying uncertainty with lack of knowledge. This does not preclude that they are sufficiently clear for some practical purposes in their domestic environment, although I believe that a conceptual clarification would facilitate the understanding of the inter-relations in the many classifications of sources of uncertainty.

### **3 Uncertainty and ignorance**

Uncertainty is often somewhat loosely distinguished from ignorance. The above-mentioned distinction between decision-making under partial ignorance and uncertainty may be a case in point. Now, if uncertainty is identified with mere lack of knowledge, its distinction from ignorance completely dissolves. Something more is

required in the case of uncertainty. For a person to be uncertain whether  $p$ , she must also (a) be aware, or at least believe that she lacks knowledge that  $p$ , and (b) be aware the possibility that  $p$ , or have a belief about  $p$ .<sup>5</sup> Two intuitively clear-cut kinds of ignorance can be singled out: (i) unrecognized, and (ii) recognized ignorance.<sup>6</sup>

There are two types of situation where unrecognized ignorance is present. Assume that the size of the population of Ulan Bator is at issue. First, a person who has never heard about this city is undoubtedly also ignorant of the size of its population. This person lacks knowledge, a fact that she is unaware of (non-fulfilment of condition (a)), and accordingly she has no belief about any proposition about the population (non-fulfilment of condition (b)). If uncertainty were merely lack of knowledge, this person would be uncertain. Second, erroneous belief implies lack of knowledge, and if the possibility of error is not acknowledged, then the believer is ignorant, as in case she says:

(A) “I believe that Ulan Bator has 2 620 000 inhabitants”,

which is a false statement. If, on the other hand, the possibility of error is acknowledged the subject would be uncertain:

(B) “I believe that Ulan Bator has 2 620 000 inhabitants, but of course, I may be wrong.”

When ignorance is recognized, the ignorant subject is aware that she lacks knowledge. The statement

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<sup>5</sup> Condition (b) is, admittedly, not very precise, but I think that it is sufficiently precise for my present purpose. It should be clear that the object of belief or awareness in condition (a) is distinct from that of condition (b): the agent's epistemic state, and something external to the agent; for the present it is assumed to be a proposition.

<sup>6</sup> In his “Four types of ignorance” (1977), Isaac Levi uses “ignorance” in another sense than I do. In my terminology, his types of ignorance would count as uncertainty.

(C) “I haven't the slightest idea of the population of Ulan Bator”,

would be an expression of recognized ignorance. The speaker is certainly well aware of her lack of knowledge (condition (a) for uncertainty fulfilled), but she has no belief about any proposition about the population of the city, so condition (b) above for speaking of uncertainty is not fulfilled.<sup>7</sup> It seems however that due to the vagueness of the phrase, “to be aware of the possibility that  $p$ , or to have a belief about  $p$ ” (condition (b)), the difference between recognized ignorance and uncertainty will be only one of degree: someone who has said (C) above, could presumably, on second thoughts, come up with at least a range covering the number of inhabitants – that it is between 100 000 and 10 million. In that case, she would have (a) acknowledged her lack of knowledge, and (b) expressed a belief about a proposition about the population, and would thus count as uncertain instead of ignorant. But although many cases of recognized ignorance can be considered cases of uncertainty after some reflection, there are unquestionably statements of recognized ignorance which is authentic, like the following, if uttered by me:

(D) “I haven't the slightest idea of how to prove the Riemann hypothesis”.

What is missing here, is awareness of, or belief about, a proposition about the proof of the hypothesis (non-fulfilment of condition (b)), and this makes (D) an

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<sup>7</sup> In this example as it is stated, the object of ignorance does not have the convenient form “ $x$  is ignorant about whether  $p$ ”. Paraphrasing the example might reveal the convenient form of the ignorance claim: “There is a true proposition,  $p$ , about the population of U.B., and I do not know  $p$ ” is one possibility. In the present context, this paraphrase is satisfactory since I do not intend to define the concept of ignorance, but only want to distinguish it from uncertainty. This formal detail is inessential for the present argument. I discuss it in connection with the definitions of uncertainty in the next section.

expression of ignorance. Accordingly, the notion of recognized ignorance is not empty after all.

To summarize, although lack of knowledge is necessary for uncertainty I hope to have shown that it is not sufficient.

#### **4 A definition of uncertainty and some of its problems**

Here, I will discuss the view on uncertainty proposed in Article II. My main purpose is to point out some problems in the proposal, and to indicate a possible solution. The examples in section 2.1 of Article II may be of help for clarification of certain points.

The reason why I wanted to define the concept of uncertainty was that I had not found any explicit definition in the literature that both was stringent, and in a satisfactory way took everyday intuitions (at least *mine*) into account. I took as a criterion for adequacy of the definition that it preserves such intuitions. (It may thus be viewed as an explication of the concept of uncertainty.) One such intuition is that uncertainty is not mere lack of knowledge, but rather *derives* from lack of knowledge. I ascribe uncertainty to knowing subjects, typically individuals but also to research groups and the scientific community. Hence, statements of the form “*x* is uncertain whether *p*”, or equivalently, “*x* is uncertain about the truth of *p*”, will be considered. I take it that ascriptions of uncertainty to propositions (“*p* is uncertain”) and external things (“the rate of interest one month from now is uncertain”) can be paraphrased as ascriptions of uncertainty to persons (“*x* is uncertain whether *p*”, “*x* is uncertain about the the rate of interest”).

In the conceptual scheme I propose in Article II (section 2.1), a person is, at a particular time *t*, uncertain *simpliciter* about a particular proposition *p*, *if, and only if* she at *t* believes that either *p* or its negation ( $\neg p$ ) may be true.<sup>8</sup> The time indexing is meant to take into account the possibility that uncertainty may reduce, and for that

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<sup>8</sup> To simplify things, the time indexing was omitted in the article.

matter also increase. In paper II of this thesis I use the term “uncertainty” in the following way:

**DU**  $x$  is at time  $t$  uncertain whether  $p$  if and only if  $x$  at  $t$  believes that either  $p$  or  $\neg p$  may be true.

This definition is intended to capture the general concept of uncertainty, or uncertainty *simpliciter*.<sup>9</sup> It is further specified as *outcome uncertainty* and *evidential uncertainty*, according to whether the object of the knowledge lacking is non-determinate or determinate. Outcome uncertainty is uncertainty about propositions whose truth value is non-determinate, as is the case of many propositions about the future. The object of the uncertainty is here the same as the object of the knowledge lacking. The object of outcome uncertainty is non-determinate and is therefore, in principle, unknowable at a particular time  $t$ . When there is evidential uncertainty, there is lack of knowledge of some determinate proposition or propositions,  $e_1, \dots, e_n$ , standing in an evidential relation to the object of uncertainty,  $p$ . Evidential uncertainty can thus be said to arise due to lack of evidence for asserting a proposition. The proposition in question may be either determinate, in which case it is, in principle, knowable at  $t$ , or non-determinate, and hence unknowable. The terms “outcome” and “evidential uncertainty” are defined as follows:

**DO**  $x$  is at  $t$  outcome uncertain whether  $p$   
if and only if  
(a)  $x$  is at  $t$  uncertain whether  $p$ , and  
(b) the truth-value of  $p$  is non-determinate at  $t$ .

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<sup>9</sup> Evidently, this is exactly the same epistemic state as Levi's “modal ignorance”: “When  $h$  and  $\neg h$  are both serious possibilities from  $X$ 's point of view, he shall be said to be *modally ignorant*” (Levi, 1977, p. 129).

- DE**  $x$  is at  $t$  evidentially uncertain whether  $p$   
*if and only if*
- (a)  $x$  is at  $t$  uncertain whether  $p$ ,
  - (b)  $x$  lacks knowledge of  $e_1, \dots, e_n$ , and
  - (b)  $e_1, \dots, e_n$  stand in an evidential relation to  $p$ .

In Article II, the difference between outcome and evidential uncertainty is illustrated by the so-called Popper's paradox of ideal evidence, and a hypothetical example from risk assessment. (Again, see section 2.1 of Article II.)

#### **4.1 Formal and other problems**

In Article II, I say that the uncertainty definitions may need to be further elaborated, but that they should be sufficiently clear for my purposes in the article. I think that the latter point is correct, but that the former is too cautious – elaboration is needed. The problem of the definition of uncertainty *simpliciter* (DU) is formal in character, and the major problems pertaining to the definition of outcome uncertainty (DO), and its distinction from evidential uncertainty (DE) are metaphysical and epistemological, but there may also be other aspects involved.<sup>10</sup>

I will confine myself to formulating the problems and suggest some possible remedies. Among the unresolved issues are the following.

##### **Problem 1: Uncertainty *simpliciter* and its object**

In the definition of uncertainty *simpliciter*, DU, the object of uncertainty is assumed to be a proposition. However, if this is assumed the intuition inherent in a large class of uncertainty claims is lost. And nor does it seem that the intuition of the class that after all is covered is very well preserved when uncertainty claims are interpreted according to the definition. Consider this example:

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<sup>10</sup> Of these problems at least problem 3 also hits the concept of aleatory uncertainty, if this is defined in terms of inherent variation or randomness.

Ex. 1 “I’m uncertain whether *the population of Sweden is 9.0 million.*”

Spelled out in accordance with DU, Ex. 1 would read:

Ex 1’ “I believe that *the population may be 9.0 million* or that *it may not be 9.0 million*”.

There are certainly cases of uncertainty where one considers only one possibility without having any idea at all of what else to believe. However, as in fact is the case, I have read in a newspaper that the last census found the Swedish population to be 9.0 million, but I later heard of a possible miscalculation to the effect that 100 000 people may have been forgotten or added. I thus believe that the population may be 9.0 but as well 9.1 or 8.9 million. My uncertainty consists in my consideration of a number of mutually exclusive possibilities.<sup>11</sup>

Next, consider Ex. 2, which is, I believe, at least as representative as Ex. 1 among expressions of uncertainty:

Ex. 2 “I’m uncertain about *the size of the population of Sweden.*”

The object of uncertainty in this statement is not a proposition. Rather, it resembles the value of a definite description, or better: the object of uncertainty is what value,  $x$ , that satisfies the predicate “is the size of the population of Sweden”.<sup>12</sup> Interpreted along this line of thought, Ex. 2 could be rephrased in this way:

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<sup>11</sup> Although the idea is not preserved in DU, I actually made use of it in Article II when I outlined the principles of characterizing uncertainty. It is very well captured by a definition proposed by George Shackle: “To be uncertain is to entertain many rival hypotheses. The hypotheses are rivals of each other in the sense that they all refer to the same event” (Shackle, 1972, p. 19).

<sup>12</sup> Apparently, the following implications between the examples Ex. 1 – Ex. 2 hold:

1  $\rightarrow$  1’, 1  $\rightarrow$  2, 1’  $\rightarrow$  2,  $\neg$ (2  $\rightarrow$  1), and  $\neg$ (2  $\rightarrow$  1’).

Ex. 2' "There is a set  $V$  of possible values  $x$ , such that for each element  $x$  in  $V$ , I'm uncertain about whether  $P(x)$ , where  $P =$  'is the size of the population of Sweden'."

Here,  $V = \{8.9 \text{ million}, 9.0 \text{ million}, 9.1 \text{ million}\}$ . Certainly, also the converse of Ex. 2 may be the case: someone may be uncertain about what Scandinavian country has the population 8.9, 9.0 or 9.1 million inhabitants. In that case there would be uncertainty about what value  $x$  satisfies the predicate "has a population of 8.9, 9.0 or 9.1 million inhabitants". And then,  $V = \{\text{Sweden}, \text{Norway}\}$ .

### **Problem 2: Outcome uncertainty and non-determinate truth-values**

This is a metaphysical problem, which is also associated with the assumption that objects of uncertainty are propositional. According to ordinary, bivalent logic, propositions are, once and for, all either true or false. But definition DO, of outcome uncertainty, is stated in terms of non-determinate truth values of propositions. Consequently, the concept of outcome uncertainty requires the law of the excluded middle to be abandoned, or else, outcome uncertainty will be an empty concept. But assuming a three-valued logic in order to account for outcome uncertainty is quite high a price to pay, at least before other alternatives have been considered. There seems to be two possible approaches to solving this problem: either one tries to characterize non-determinateness of objects of uncertainty, still being propositions, by some other notion than truth. Or, one tries to account for the non-determinateness by construing the object of uncertainty in other than propositional terms. However, it is also clear that, on many occasions, what explicitly is the object of uncertainty is a proposition.

### **Problem 3: Outcome uncertainty and determinism**

The metaphysical problem of the truth of determinism leads further to some epistemological problems of how to distinguish between outcome uncertainty and evidential uncertainty.

**(a) Metaphysical problem.** If there were a plausible alternative to propositions as objects of uncertainty, say, for instance events or states of affairs, then the problem of the eternally determinate truth of propositions could be evaded.<sup>13</sup> However, if determinism is true, then all events and states of affairs would also be determinate, and only evidential uncertainty would be left. Of course, this is a problem only if one sees a point of capturing the intuition that the larger part of the future is uncertain in a more unavoidable way than the past and present. That this intuition is worth preserving is a prerequisite also for the rest of the argument. Since we do not know whether determinism is true or not, it is untenable to separate outcome uncertainty from evidential uncertainty in terms of determinateness and non-determinateness. A potential objection to this conclusion is that what matters is *epistemic* non-determinateness. But to say that an event, state of affairs, proposition or whatever, is epistemically non-determinate is nothing but a roundabout way of saying that we do not know, and this is already implied by the condition that the subject be uncertain. So, a condition of epistemic non-determinateness would add nothing to DO.

**(b) Epistemological problem.** It seems that characterizing the object of outcome uncertainty as non-determinate could equally well be done by saying that it belongs to, or is about the future. So, one may argue, if non-determinateness is inappropriate for the purpose of definition, because of the possibility of determinism being true, then why not simply say that outcome uncertainty is uncertainty about the future? After all, the future can be distinguished from the

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<sup>13</sup> Yet, since the truths of mathematics are propositional, and to be sure, can be objects of uncertainty, one cannot exclude propositions as objects of uncertainty. An *ad hoc* solution would be to formulate separate definitions for on the one hand, events and states of affairs, and on the other, propositions. Alternatively, one could attempt to make the definition sufficiently general so as to allow entities from several ontological categories to be objects of uncertainty.

past, and there is indeed “a dramatic difference in epistemological accessibility between the past and the future regions of time” (Horwich, 1987, p. 7). The immediate counterquestion would nevertheless be: what's so special about being future that makes it a possible defining feature? Perhaps, it would be that it is unknowable, whereas the past can be known. Unless “knowable” and “unknowable” are given very special meanings, then this answer would be unsatisfactory: The time and place of the first cell-division is a past event that certainly is not knowable, and the time and place of the next solar eclipse in Stockholm is an example of a knowable future event.

#### **4.1.1 Concluding remarks and indications of solutions**

**Uncertainty simpliciter.** Appeal to linguistic intuitions has shown the definition of uncertainty simpliciter (DU) to be an inadequate analysis of many uncertainty statements. The definition should not be construed with a proposition as the object of uncertainty, but instead with an object of the form *the x satisfying the predicate P*. Moreover, it has to preserve the idea that being uncertain means to entertain several, mutually exclusive epistemic possibilities.

**Outcome uncertainty.** Problem 2 is a serious problem against DO as it stands. However, considerations of problem 3b make me think that, if a definition of uncertainty is to take non-determinateness in some sense into account, this notion has to be taken in a weaker sense than that of objective, or “true” non-determinateness, assumed in DO.<sup>14</sup> (Then problem 2 may not be of significance, even if it arises when uncertainty *simpliciter* is defined along the lines of the preceding remarks.) In my opinion it is clear that for certain practical purposes, for instance decision-making, a distinction between evidential and outcome uncertainty is significant, even if the object of outcome uncertainty is not *known* to be non-

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<sup>14</sup> In fact, I tacitly assume some such weaker sense in the coin-flipping example used in Article II to illustrate the distinction between evidential and outcome uncertainty.

determinate. The numbers generated by a pseudo-random number generator are certainly not random or non-determinate, but the very point is that they, for all practical purposes, can be so considered. In this case the object of uncertainty is even known to be determinate; if one knew the algorithm one could predict the next random number. Considerations of practical unpredictability have led some to adopt a “personalist view of randomness”:

“You see a quantity as random if you do not know of any pattern or model that can account for its variation. [...] A quantity may legitimately be random to one person, but deterministic to another who knows its underlying generating process.” (Morgan and Henrion, 1990, p. 63)

It seems difficult to accommodate this idea with that of outcome uncertainty as distinguished from evidential uncertainty. Moreover, I think one misses an important point in speaking of outcome uncertainty if the personalist view is accepted, namely that the practical importance of distinguishing outcome from evidential uncertainty is to say something about the possibilities of reducing the uncertainty. Evidential uncertainty may be reduced by information gathering at the time being; outcome uncertainty may be reduced by waiting and seeing.<sup>15</sup> I do however think that what is said in the first part of the quotation has to be brought

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<sup>15</sup> Arguably, if  $O$  is the object of my uncertainty and  $O$  *seems* non-determinate to me, then I have *evidential* uncertainty about whether  $O$  is non-determinate or not. (Hence, this can be seen as an uncertainty of second order in relation to my uncertainty of  $O$ .) To reduce the evidential uncertainty whether I have outcome or evidential uncertainty about  $O$  I ask all experts in the field. If it happens that there is universal agreement that  $O$  appears non-determinate, then speaking of outcome uncertainty about  $O$  would say something interesting: if you want to know about  $O$ , wait and see. Otherwise, if someone I trust tells me that  $O$  is in fact determinate, then I may at once start to gather information to reduce my uncertainty about  $O$ .

to terms with the concept of outcome uncertainty. To do this in an epistemologically satisfactory way would certainly be difficult as well.

## **5 Representing, characterizing, and communicating uncertainty**

I will in this section make some remarks on what I say in Article II about representing uncertainty and its relation to characterizing uncertainty, and on characterization of uncertainty in general. Moreover, I will try to clarify the relation between the subjects treated in Article I and Article II, respectively, and finally, discuss a couple of questions in relation to the problem of expressing uncertainty.

### **5.1 Representing and characterizing uncertainty**

In Article II I tacitly assume that a *representation* and a *characterization* of uncertainty are two different things. Probably, it is difficult to make a clear-cut distinction between the two kinds of account. However, I take a characterization to be a fuller account of the situation than a representation, especially when a numerical representation of the uncertainty is at issue, which may well be included in a characterization. The example of such a representation that is closest at hand is, I assume, a subjective probability distribution over epistemic possibilities. Unless such a distribution is qualified in some way, as an interval, or by some measure of the reliability of the probabilities, I would count it as a rather meagre representation of uncertainty.<sup>16</sup>

A *characterization* of uncertainty about, say (for simplicity)  $p$ , should, in my view, include some more detailed, presumably verbal, evaluation of the evidence underlying the assessment of the subject's epistemic possibilities with regard to  $p$ .

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<sup>16</sup> See section 2.3 of Article II for references on measures for representing uncertainty about probabilities. In my opinion, subjective probability, in the first place, represents *belief*, or *degree of confidence*, and only remotely uncertainty, provided of course that the probability is not 0 or 1.

From a conceptual point of view, evaluating evidence as a way of characterizing uncertainty seems unsatisfactory, because what would be of interest when uncertainty is at issue is what is *not* known, that is, the evidential facts,  $e_1, \dots, e_n$ , in the definition of evidential uncertainty.<sup>17</sup> This problem seems difficult to overcome, though. That unknown matters are not easily described, and discussions of uncertainty therefore generally focus on what in fact is known, seems to run through all the discussion of uncertainty in the literature. However, it is possible to say what, if known, would change one's belief of the various possibilities, or change the number of possibilities.

Now, a characterization of uncertainty (as well as a representation of uncertainty) can be more or less complete in relation to its purpose. Thus, if  $A$  and  $B$  are subjects, and  $A$  is to provide  $B$  with a characterization of  $A$ 's uncertainty about some issue, then  $A$  can give a more or less exhaustive account of her uncertainty irrespective of  $B$ 's needs, or adapt it to those needs. In this thesis I am concerned with decision-relevant uncertainty, that is scientific uncertainty characterized by experts,  $A$ , to be of use for decision-makers  $B$ . In connection with risk assessment the decision-relevant uncertainty is a proper subset of all uncertainty about the potential risks at issue. In a *complete* characterization of  $A$ 's uncertainty,  $A$  would need to account for all uncertainty in the evidential basis, and besides, relate it to the endpoints of the assessment. This would mean to consider all possible sources of uncertainty on the evidential level (or *levels*), such as potential measurement errors, model relationship errors and so on. An attempt at such a characterization may be perfectly appropriate for the needs of a fellow risk assessor,  $B^*$ . But to  $B$ , the decision-maker, all these uncertainties are arguably not of interest.

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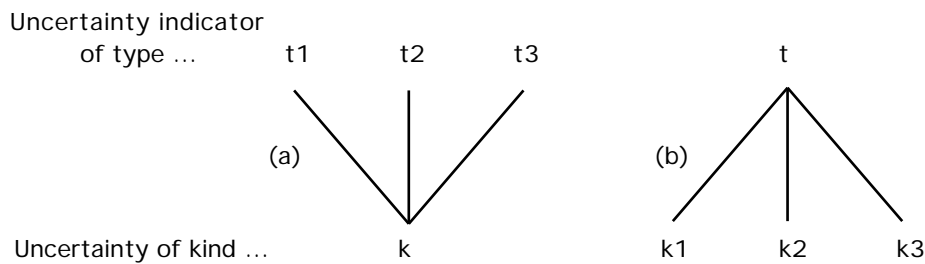
<sup>17</sup> This is certainly not the only problem. For practical purposes the very idea of evaluating evidence, and the notion of *weight of evidence*, are more urgent. Admittedly, they are not given due attention in the Essay (section 4.1.5).

## 5.2 Communication of uncertainty

Thus far, only the content of the communication of uncertainty has been discussed. When uncertainty is communicated verbally rather than in numerical terms, the choice of words becomes critical for the proper understanding and use of the information. It is clear that phrases like “probably,  $p$ ” and “ $x$  is unlikely to be  $y$ ” indicate uncertainty since they express degrees of belief in the open interval  $]0, 1[$ . We called phrases like these “epistemic uncertainty indicators”. A general question to be answered when a classification of linguistic expressions of uncertainty is at issue, is whether one could expect to find some correspondence between types of phrase used and types of underlying uncertainty. (At least this question occurred to me during the preparation of the Article I.) If the typology of uncertainty indicators were based on some classification of uncertainties, so that each type of uncertainty indicator represented a type of uncertainty, then there would of course trivially be a correspondence. However, this was not the approach when the typology of uncertainty indicators in Article I was constructed. And for this typology it seems implausible that any correspondence between the types of phrase and types of underlying uncertainty could be found, neither one-to-one, nor many-to-one, nor one-to-many. To show this lack of correspondence one should first classify the underlying uncertainties according to some reasonable, sufficiently fine-grained typology, and then show (a) that one and the same kind of uncertainty is expressed by different types of uncertainty indicators, and moreover, (b) that one and the same type of uncertainty indicator is used to refer to uncertainties of different kinds, as is illustrated in Diagram 1.<sup>18</sup> (A weaker lack of correspondence would be demonstrated if only one of (a) or (b) could be shown.)

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<sup>18</sup> The definitions of uncertainty proposed in Essay II, appear to have insufficient resolution to be of use as a typology of uncertainty in this context, at least for an attempt to establish a correspondence. Both a phrase like “it is likely that  $x$  is  $y$ ” (an epistemic uncertainty indicator) and “that  $p$  indicates that  $q$ ” (an inferential uncertainty indicator) indicate evidential uncertainty.



**Diagram 1.**

But the typology of uncertainty indicators proposed in Article I is not appropriate for “representing” various kinds of uncertainty. The linguistic units that are classified are too small for that, and they do not involve any specifications of kinds of uncertainty, as such kinds are mostly conceived in uncertainty classifications. (That is, kinds such as parameter uncertainty due to systematic measurement errors, relationship errors in models, and so on.) So, not even if larger linguistic units were considered, a correspondence should be expected. In that case, not one, but several uncertainty indicators, according to the typology, would unavoidably need to be taken into account, and that would complicate matters further.

Despite this negative conclusion, there seems to be interesting philosophical problems associated with the use of uncertainty indicators. The fact that a single phrase may be used to summarize several uncertainties is a problem for the communication of uncertainty. (I here use “uncertainties” in a loose sense, meaning simply, *things about which there is uncertainty*.) In the context of risk assessment, the statement, “it is uncertain whether the rats in this study were exposed exactly to dose  $D$  of the substance  $X$ ”, may be made of the situation where all factors were controlled, except the exact dose, which may have been  $D$  or some dose close to  $D$ . However, the same statement also covers the situation where neither the amount of substance in the food was known, nor whether the rats ate all their food, nor whether the substance  $X$  was contaminated by substance  $Y$ , nor other factors of importance. Of course, the whole point of carefully accounting for and evaluating the evidential basis of judgements is to avoid such unspecificity and vagueness in

reports of uncertainty. But the problem of how to understand evidential reasoning when verbal terms are used remains, and this appears to be one of the most salient problems in risk assessments. Although there are suggestions for how to numerically codify phrases expressing probability, or belief, several other linguistic means, which are not easily codified, are used, and probably will continue to be used. (Codifications of probability phrases are discussed in Article II, section 4.1.4.)

## **6 Preview of the articles**

### **6.1 Article I**

In Article I, phrases actually used to communicate risk information where uncertainty is present are analyzed. The aim of the article is to find a way of classifying these phrases in a coherent and hopefully fruitful way. We call the phrases “uncertainty indicators”.

One cannot say that it is an analysis of the surface level of uncertainty characterizations. Such an analysis presupposes that there is a “substantial”, or explicit, characterization of uncertainty whose surface is at issue. In the analysis of expressions of uncertainty presented in Article I, no such substantial characterization of uncertainty is distinguished. Thus, if that analysis is said to be at a surface level, it is the surface of risk assessment information in general, since the analyzed text passages are not primarily accounts for the uncertainty at hand, but are examples taken from the regular reviews of scientific studies, accounts for effects and their significance for human health. One reason why we did not restrict ourselves to the concluding sections of the texts was that we did not want to take the risk of missing expressions that were not used in the conclusions, which in many cases are not very detailed.

The uncertainty indicators are classified into four main categories: contentual, epistemic, conditionalizing, and inferential uncertainty indicators. A contentual uncertainty indicator is an inexact specification of the propositional content of a statement. Epistemic uncertainty indicators are phrases that indicate less than full

confidence in, or commitment to, the propositional content. A conditionalizing uncertainty indicator specifies conditions for making a claim, without indicating whether the conditions are fulfilled or not, and finally, an inferential uncertainty indicator indicates that there is uncertainty about the inferential step in an inference.

The classification of the phrases takes both semantic and pragmatic aspects of the communication into consideration. One parameter which is taken account in the classification is *writer commitment* to the propositional content of a statement. This is probably the clearest example of the pragmatic aspect. To exemplify, a person expresses a lower degree of commitment to the proposition *x is y* if she writes “*x has been considered by some to be y*”, instead of “*I am of the opinion that x is y*”. In the former case, it does not become clear to the reader whose belief is actually referred – its origin may be some well-reputed researchers, or some shady charlatans. In the latter case, there is no doubt about who is the originator of the statement, and her credibility in *x-and-y* questions may be checked. The notion of writer commitment is important in a communicative perspective. Although an expression of low degree of writer commitment need not necessarily to be intended to express uncertainty, it may create uncertainty in the audience of the information.

It is concluded that the use of uncertainty indicators in the texts we studied is not transparent and that the development of standardized uncertainty indicators should significantly improve communication both within the scientific community and between scientists and policy-makers.

## **6.2 Article II**

In Article II, the focus is not primarily on how uncertainty should be expressed, but on what uncertainty should be included in reports from risk assessors to risk managers if well-informed decisions are to be made. I present a set of necessary conditions to be fulfilled by a characterisation of uncertainty if it is to be adequate for regulatory decision-making. At a general level, the conditions require specification of (1) the character and degree of uncertainty about the assessment endpoints, (2) the

possibility of reducing the uncertainty, and (3) the degree of agreement among experts; and (4) that whatever information covered by the previous conditions is presented in a clear and comprehensible way. The point of departure is that characterizing scientific uncertainty conceptually means specifying all important possibilities that are consistent with the state of scientific knowledge. This idea is not well captured in the definition of uncertainty *simpliciter* (DU), but the principle was followed when the conditions were worked out.

The distinction between outcome and evidential uncertainty plays a subordinate role in the adequacy conditions. The concept of evidential uncertainty is the central one, and that does not seem to be problematic to the same extent as the concept of outcome uncertainty. However, in my view it is clear that the notion of outcome uncertainty, spelled out according to the concluding remarks in section 5.1.1 above, has a significant part to play in risk assessment and risk management of chemicals.

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