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On the Epistemology of the Precautionary Principle

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Abstract In this paper we present two distinctly epistemological puzzles that arise for one who aspires to defend some plausible version of the precautionary principle. The first puzzle involves an application of contextualism in epistemology; and the second puzzle concerns the task of defending a plausible version of the precautionary principle that would not be invalidated by *de minimis*.

1 Introduction

Ever since its 1992 inclusion in the U.N. Rio Conference on Sustainable Development, what has come to be called the *precautionary principle* has increasingly been used as a key decision rule in environmental and health decision making.[1] The key intuition motivating the precautionary principle is that, at least in some circumstances, the rational decision is to act rather than to wait for more information to come in. By reference to the precautionary principle, if a potential

[1] The formulation in the Rio Declaration states: "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

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damage is serious enough, we should go ahead and take action against an activity that credibly threatens such damage. This is so *even if* a connection linking the activity under consideration to the potential damage is by scientific standards not conclusively established (or, indeed, perhaps far from established).

Among the most common objections raised against the principle are that it is ill-defined,[2] absolutist,[3] incoherent,[4] a value judgement,[5] increases risk-taking,[6] and marginalizes science.[7] It falls outside our aim to evaluate these objections.[8] Rather, we want to raise two distinctly epistemological puzzles that arise for one who aspires to defend the precautionary principle. The first puzzle involves an application of contextualism in epistemology; and the second puzzle concerns the task of defending a plausible version of the precautionary principle that would not be invalidated by the *de minimis* principle, according to which far-fetched risks can be effectively ignored.

In §2 we explain why the epistemological condition that features in the precautionary principle has to be formulated in a more nuanced way than commentators have recognized, and in §3 and §4 we present our two epistemological puzzles. The first epistemological puzzle involves a dilemma that arises once we compare invariantist and contextualist approaches to the matter of whether epistemic standards that must be met depend on the severity of the anticipated damage. The second problem concerns the task of defending a plausible version of the precautionary principle that would not be invalidated by *de minimis*. We claim that the application of the precautionary principle in combination with the *de minimis* principle raises issues discussed in the debate over contextualism.

2 The E-Condition

In some respects, it is misleading to speak of "the precautionary principle" as though there is a standard interpretation of the principle.[9] There is not.[10] Even more, several distinct *kinds* of principles are often conflated under the description of the precautionary principle. For our purposes the more interesting interpretation of the principle is as a *decision rule*, as opposed to an argumentative tool or a rational constraint on what qualifies as an appropriate justification for failing to take action, in certain circumstances.[11]

[2] See Bodansky (1992).

[3] See Nollkaemper (1996).

[4] See Peterson (2006).

[5] See Charnley (1999).

[6] See Gray and Brewers (1996).

[7] See Gray and Brewers (1996) and Resnik (2003).

[8] See Sandin et al. (2002) for a defense of the precautionary principle against five of these charges.

[9] Thanks to an anonymous referee for pressing this point.

[10] See Aven (2011) and Munthe (2011). See also Manson (2002), Bodansky (1992) and Peterson (2006).

[11] For discussions of different ways of interpreting the precautionary principle, see Aven (2011) and Munthe (2011). See also Harris and Holm (1999), Sandin (1999) and the San Francisco Precaution Ordinance, (2002). An example of the precautionary principle presented, albeit unhelpfully vaguely, as a decision rule is found in article 191 of the Treaty on the Functioning of the European Union (EU); this treaty describes the principle as "enabling rapid response in the face of a possible danger to human, animal or plant health, or to protect the environment. In particular, where scientific data do not permit a complete

When the precautionary principle is interpreted as a decision rule, it states conditions under which action is rationally mandated. Though there is not a standard substantive interpretation of the precautionary principle as a decision rule,[12] there is, however, a *logical core* that supports a version of the precautionary principle that could most plausibly be viewed as a rational decision rule.[13] As a decision rule, the precautionary principle can be understood as composed of three central elements: a damage condition (D), an epistemological condition (E), and a suggested remedy (R), such that: If D and E are satisfied, then R is prescribed, or activated.[14] On this line of thinking: if there is sufficient epistemic confidence that an activity under consideration will bring about a damage of a certain degree of severity, then this is sufficient grounds for regulating (in some way) the activity. As pointed out by e.g. Sandin (1999), Manson (2002) and Munthe (2011), different versions of the precautionary principle can be viewed as functions of the comparative strengths of the D, E and R conditions, as specified in whatever substantive version of the principle one defends. The following formulation, adopted by the British government in a White Paper on environmental management, serves as a good illustration:

> The precautionary principle applies particularly where there are *good grounds* for judging either that action taken promptly at *comparatively low cost* may avoid more costly damage later, or that irreversible effects may follow if action is delayed.[15]

Similar relationships between the potential damage caused by an action and the epistemic features of the situation at hand have been proposed by e.g. Gärdenfors and Sahlin (1982) and Levi (1990) for other decision rules. However, these authors do not advocate, or discuss, the precautionary principle.

Having said that, we believe that the straightforward interpretation of the precautionary principle's logical core outlined above is oversimplified, in a way that is misleading. The epistemically significant aspects of the precautionary principle cannot be captured simply by specifying a certain degree of epistemic strength that

Footnote 11 continued
evaluation of the risk, recourse to this principle may, for example, be used to stop distribution or order withdrawal from the market of products likely to be hazardous." See also, for instance, the 2002 UK-ILGRA statement of the precautionary principle, the Wingspread Statement on the Precautionary Principle and the (1998) Vancouver Statement on the Globalization and the Industrialization of Agriculture.

[12] See, for instance, Morris (2000) and Peterson (2006).

[13] For instance, the Science and Environmental Health Network, in response to the critique that the principle is ill defined, remarks (as Montague (2008) puts it, that) "in all formulations of the precautionary principle, we find three elements", where these elements are the damage, epistemological and remedy elements that correspond with Manson (2002) and Peterson (2006).

[14] For a table representing different versions of the principle, as functions of the different ways of interpreting the damage, epistemological and remedy concepts, see Manson (2002: 267). For a further presentation of different versions of the precautionary principle, see Morris (*Op. Cit.*) "Defining the Precautionary Principle" in Morris, ed. Rethinking Risk and the Precautionary Principle (Woburn, Mass: Butterworth-Heinemann 2000).

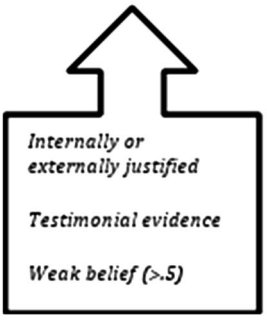
[15] White Paper: "This Common Inheritance: Britain's Environmental Strategy", HM Govt, 1990, our emph.

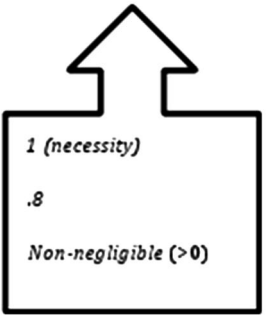
is supposed to mark the relevant epistemic state. To appreciate the point, consider that the object toward which we take an epistemic attitude in precautionary contexts will always be a *proposition* that makes direct reference to the relevant damage condition. Importantly, though, the object of our epistemic attitude will not be a proposition that expresses merely *that* some specified damage will occur, or is likely to occur. After all, one's epistemic position with respect to some likelihood that some damage will be brought about provides grounds for taking action against some activity *A only if* the evidence that one has supports a certain connection between *A* and the relevant damage. One plausible way of interpreting this connection is as a causal connection.

Some causal propositions do not contain operators. For instance, "Methyltrexate causes a lowering of the immune system."[16] Here, the connection between cause and effect is left unqualified. Often, though, the causal propositions we use in practical deliberations are not "all or nothing" in this sense, particularly in cases where the precautionary principle would be germane.[17] For example, the United Kingdom Interdepartmental Liaison Group on Risk Assessment (UK-ILGRA) claims that, by reference to the precautionary principle, prevention remedies are actionable only when there is "good reason" to believe "that harmful effects may occur could be demonstrated by empirical evidence."[18]

The logical core of the precautionary principle must, we suggest, be revised to account for the *two* epistemically significant elements that the enaction of a remedy/restriction on an activity should be sensitive to: (1) the epistemic strength with respect to the entire causal proposition (specifying an action and a damage), and (2) the epistemic strength of the operator at play in the causal proposition itself. Notice how both of these epistemic elements could be independently adjusted:

1. Second-order E-condition {First-order E-condition (Activity $\Box\!\!\rightarrow$ Damage)}





[16] This proposition of course could of course be adjusted so that it is qualified—for example, "There's a .9 likelihood that methyltrexate will lower the immune system of a given human." The point here is that, as stated, that proposition "Methyltrexate causes a lowering of the immune system" is unqualified.

[17] This point has a venerable tradition in Bayesian epistemology.

[18] Our emphasis. See the full 2002 UK-ILGRA document here: http://www.hse.gov.uk/aboutus/meetings/committees/ilgra/pppa.pdf.

Because the contents of the relevant causal propositions themselves are typically epistemologically loaded, specifying the "E-condition" in the precautionary principle is not as simple as citing some degree of strength *N*.[19] After all, for two activities, A and B, and some damage threat (say, the extinction of a salmon species), you can know with perfect certainty that A is .30 likely to bring about the extinction of the species, and have a weakly justified belief that B is .80 likely to bring about the extinction of the same species. Which epistemological situation best justifies a restriction on the activities in question? It seems that the right answer will require reference to some principle that we can appeal to justify weighting *mixtures of epistemic states and probabilistic contents of those states*.

In §4 we will consider a problem that arises for the purposes of weighing the epistemic mixtures introduced above, but first, in §3, we want to introduce a epistemological puzzle that faces *any* defender of the precautionary principle—a puzzle which we take to be theoretically prior to the problem of how to weigh the relevant epistemic mixtures.

3 The First Epistemological Puzzle

In this section we introduce and evaluate a dilemma for proponents of the precautionary principle that arises as a result of an appeal, by analogy, to a straightforward line of reasoning in the literature on contextualism in epistemology.[20] Contextualists about knowledge (e.g. DeRose 1992; 1999, Cohen 2004) hold that the conditions under which one counts as knowing a proposition are sensitive to what is at stake in the relevant context.[21]

Suppose your evidence that the bank is open this Saturday consists in you having read a sign that says so. The contextualist allows that this evidence might be good enough for you to qualify as knowing in a context in which little to nothing rides on the matter of whether the bank is open, while the very same evidence fails to provide you with knowledge that the bank is open in a context in which your friend's life depends on the bank being open so that I can wire money this Saturday.

The key point here can be framed in terms of a *dependence* insight: the standards one must meet to qualify as knowing depend on how much is at

[19] Again, this is because, within the propositional content that is the object of the epistemic state, we have operators in whose scope is the causal connection. While the operator will rarely be a necessity operator, it will in many cases be a probability operator, or some type of non-probabilistic operator that nonetheless captures the agent's confidence about the causal connection. For example, one can have good evidence that activity A is *likely* to bring about damage D. One might also know that A tends to bring about D.

[20] The most common line of contextualistm is *attributor contextualism* (e.g. DeRose 1992; Cohen 2004) according to which the relevant standards are those of the attributor.

[21] As DeRose (1999) puts it, "the truth-conditions of knowledge ascribing and knowledge denying sentences (sentences of the form "S knows that P" and "S doesn't know that P" and related variants of such sentences) vary in certain ways according to the contexts in which they are uttered". What so varies is the epistemic standards that S must meet (or, in the case of a denial of knowledge, fail to meet) in order for such a statement to be true. (DeRose 1999: 187).

stake.[22] Interestingly, the same kinds of practical considerations that motivate contextualists to take a rating of an epistemic state to depend on the contextually relevant practical stakes might lead a defender of the precautionary principle to reason along broadly similar lines: the more *severe* the anticipated damage, the *less certain* we must be that some activity threatens that damage in order to be warranted in acting to regulate the activity. On this way of thinking, the way we fill out the epistemological condition depends on how we fill out the damage condition, as the former is sensitive to the latter.

To clarify the connection between contextualism about knowledge, on the one hand, and contextualism about the epistemic standards operative in the precautionary principle, on the other, it is helpful to consider the respective correlations at play. In the case of *knowledge attributions*, the dependence of standards on the severity of what's at stake is a *positive* correlation: the more significant the practical stakes, the higher the epistemic standard one must meet to qualify as possessing knowledge. However, in cases where application of the precautionary would be germane, the dependence of standards on the severity of what's at stake appears to be a *negative,* or inverse, correlation: the greater the severity of the anticipated damage, the *lower* the epistemic standard that needs to be met for the relevant remedy to be warranted.

On first blush, a contextualist approach to the precautionary principle looks to have a lot going for it. In particular, it seems to generate the right results in high-stakes and low-stakes cases. Restricting some activity with little expected damage would appear draconian if the evidence is scant, while perfectly sensible if the anticipated damage were massively catastrophic. Such an approach would seem, then, to have some clear theoretical advantages over an invariantist approach to the precautionary principle, according to which the requisite epistemic standards that must be satisfied are held fixed across contexts.[23]

There is, however, a special problem that arises for one who defends a contextualist version of the precautionary principle, and it is a problem not faced in the same way by contextualists about knowledge in epistemology. The problem emerges once we consider that, if we want to preserve the insight that how much we must know about some activity's connection to a damage in order to restrict that activity depends on how severely we rate the anticipated damage, then we are in effect saying that the severity of the damage condition circumscribes what the relevant epistemic standards will be (relevant, that is, to justifying the restriction of some activity).

The problem is that, in situations where an application of the precautionary principle is germane, we have *competing* interests at play, and the extent to which the severity of some anticipated damage is judged is (in many cases) going to vary with respect to whose interests are at stake. Take (again) as an example of an anticipated damage, the extinction of a species of salmon in Alaska. In light of the

[22] According to a rival position that aims to preserve a similar insight—that standards for knowing vary across context—what fixes the standards are the practical interests of the *subject*, as opposed to the ascriber of the epistemic state. This position is called *subject-sensitive invariantism*, and has been defended by (among others) Stanley (2005) and Hawthorne (2004).

[23] *Cf.* Classical invariantism vis-a-vis knowledge attributions, according to which, as Black (2005) puts it "the truth conditions of knowledge attributions depend neither on the subject's context nor on the attributor's context."

interests of the environmental regulatory body, this damage is severe (and, accordingly, the epistemic standards that must be met in order to justify restricting the activity would be low). But in light of the interests of a construction company that wishes to build in Alaska, this damage is not severe (and, accordingly, the epistemic standards that must be met in order to justify restricting the activity are not low).[24] A contextualist approach to the precautionary principle, then, seems like it could be plausible as a decision rule only if supplemented with some additional *favouring rule,* a rule which adjudicates *whose* interests determine the severity of the damage in question, a severity that (for the contextualist) is what fixes the relevant epistemic standard that must be satisfied.[25]

Taking a step back, then, we can see how a larger puzzle emerges. The puzzle takes the form of a dilemma. In circumstances in which the precautionary principle is advocated as a decision rule we ask: *should the epistemic standards that must be met depend on the severity of the anticipated damage*? The invariantist says no, and the contextualist says yes. If a defender of the precautionary principle goes the invariantist route, she lacks any principled way to explain why threats of (say) massive irreversible catastrophe warrant special treatment, i.e. why we need to know *less* to justifiably restrict threatening activities. This is the first horn of the dilemma.

If the defender of the precautionary principle answers yes, and goes the contextualist route, she will be forced to supplement her position with some additional favouring rule, which adjudicates *whose* interests (e.g. the regulatory body's or the developer's) are relevant to assessing the extent of the anticipated damage.

Rejecting the invariantist route constitutes a "horn" of the dilemma because the most natural ways to defend such a needed favouring rule run into serious, perhaps intractable, problems. Consider an especially sensitive proposal: if, relative to *anyone*'s interest, the damage in question is taken to be severe, then this is sufficient for lowering the epistemic standards that must be met in order to restrict some activity that threatens that (anticipated) damage. The sensitive position is far too sensitive. For nearly any possible damage, there is likely someone for whom the damage is judged as severe. The sensitive proposal would seem to make the epistemic standards problematically low in all precautionary contexts.[26]

[24] An actual, and much more extreme case occurred in Texas in 2012; a $15 million dollar highway construction project was put on hold for several weeks because the believed-to-be-extinct Braken Bat Cave meshweaver spider was spotted on the construction site. Environmentalists (whose interests were heeded) and construction workers differed profoundly on the significance of the potential damage which would be the spider's extinction. http://news.yahoo.com/blogs/trending-now/endangered-spider-halts-construction-15-million-texas-highway-174932636.html.

[25] The analogue of such a rule, in the epistemology literature—where contextualism about knowledge is what's at issue—is a rule staying whose interests determine whether one knows, in a context. Here, attributor contextualists say that the relevant interests that fix the standards are the interests of the *attributor*; the subject-sensitive invariantist claims it is always the *subject's* interests—the subject to whom the epistemic state is being attributed. Whereas the generation of such a rule in the debate about contextualism about knowledge just amounts to allowing for different theory choices, the generation of such a rule, for one who proposes a contextualist treatment of the precautionary principle, would involve a rule that would appear to be an unfair kind of favouring.

[26] As we'll see in §4, if the standards are too low, a conflict with *de minimis* emerges.

Consider then an egalitarian favouring rule: all interests count equally, in assessing the severity of the damage (which, itself, fixes the epistemic standard at play). To see why the egalitarian favouring rule–though initially promising–won't work, let's take another cue from contextualism in epistemology. For example, suppose John's life depends on his being able to wire money to some loan-sharks (today), and what's at issue is whether he counts as knowing that the only bank around is open (today). Randall, who is discussing the issue with John, is a nihilist, and has no interest in John's fate. The insight motivating (attributor) contextualists is that the stakes are *higher* for John than for Randall, and this is supposed to explain why the truth value of "John knows the bank is open" can differ depending on whose interests are at stake in the context of utterance. Now the rub is that an egalitarian favouring rule would imply that the truth value of "John knows the bank is open" is invariant across context of utterances, fixed by a standard that is something like a *mean* of all (relevant) standards. But if such a mean standard always fixes the truth value of knowledge attributions, the knowledge attributions simply *aren't* context sensitive. For instance, with reference to such a mean, there is no way to account for why *John* (but not Randall) needs a stronger epistemic position to know, when the stakes are raised for *him* (John).

A parallel problem emerges when we apply this strategy in the precautionary context. After all, given the entrenched interests of (for example) developers and environmental regulatory bodies, the mean of all relevant standards for damage will typically be *insensitive* to differences in actual damage.[27] But sensitivity to the severity of actual damage is precisely what contextualist approaches can claim, as a key advantage, over invariantist approaches.

The egalitarian favouring rule, in a *precautionary* context, would therefore *mutatis mutandis* convert the attempted contextualist approach into a kind of invariantism and thus be faced with the same problem facing other invariantist approaches to the precautionary principle: that, plausibly, we need to know *less* to justifiably restrict some threatening activities than others, and the invariantist approach can't explain this.

A third proposal would be to contextualise the favouring rule itself. Let SEVERITY_R represent the severity of a damage, D, as assessed by some regulatory body R, and let SEVERITY_I represent the severity of D as assessed by some industry I. On our third proposal, the relevant epistemic standards depend on the severity of the anticipated damage, and (in our example) in some contexts this will be SEVERITY_R and in other contexts SEVERITY_I. This approach effectively passes the buck. In the absence of a *further* favouring rule, which adjudicates which assessments of the severity of damage matter for fixing the epistemic standards in which contexts, this third contextualist approach to the precautionary principle falls short of a *decision rule*.

[27] Suppose the issue is developing a project that poses some threat to the environment. It is in the developer's interest to downplay severity of damage, *regardless* of the actual damage expected; likewise, it is in the environmental agency's advantage to prevent development even if actual expected damage is low. Plausibly, the mean of these standards will be fixed across cases where the degree of actual expected damage varies.

4 The Second Epistemological Puzzle

In this section we introduce our second epistemological puzzle. Its point of departure is the widely accepted claim, defended by several authors working on the precautionary principle, that any reasonable formulation of the principle has to be combined with the *de minimis* principle, according to which sufficiently improbable risks should be ignored.[28] If a *mere possibility* that an activity may cause some damage would be sufficient for justifying precautionary measures, then this would put far too much restrictions on what we are allowed to do. In his recent book *The Price of Precaution and the Ethics of Risk*, Munthe explains this standard view very clearly:

> PP has to employ some limit on how unlikely a risk-scenario of an activity can be in order for this activity to be within PP's range of applicability. Otherwise, even the most trivial activity would have to be subjected to the requirements of PP, since everything we do might … produce some kind of [sufficiently] undesirable outcome.[29]

It would be absurd to take precautionary measures against, say, doses of radiation that are smaller than one percent of the natural background level, or against increases of PbB levels below 10 μg/dl, or against the 1-in-19 billion lifetime risk of getting cancer from certain food additives.[30] According to the *de minimis* principle these risks are so small that they ought to be ignored, and given that they are, the precautionary principle ought to be applied only to risks "above the threshold".

The *de minimis* principle stems from the Latin phrase *de minimis non curat lex*, which is a legal principle meaning that the court should not concern itself with trifles. For instance, if you steal one cent that would in a strict sense count as theft. However, since the amount is so small the court should apply the *de minimis* clause and refrain from taking up the case. The idea that sufficiently trivial risks are beyond concern was introduced in the 1980s by the US Food and Drug Administration (FDA). The FDA argued that a very large number of different substances can in principle cause cancer, but some cancerogenic substances are so unlikely to cause cancer in the quantities they are actually being used, meaning that those risks are *de minimis* and ought to be ignored. The *de minimis* principle has in recent years become widely accepted by risk professionals.

In the literature on *de minimis*, various probabilistic thresholds have been proposed for when a risk is so small that it should be ignored.[31] However, it is worth keeping in mind that the *de minimis* principle does not require that we are able to establish precisely what the relative frequency of some event it is. The probability limit could be

[28] The claim that a reasonable version of the precautionary principle has to be combined with the *de minimis* principle is defended by e.g. Peterson (2002), Sandin (2004: 21), Clarke (2005), Steele (2006), Ashford (2007), and Zander (2010: 72).

[29] Munthe (2011: 24). Note that Munthe then goes on to formulate a general objcetion to the *de minimis* principle, which we shall not discuss here.

[30] Whipple (1987).

[31] See Whipple (1987) and Peterson (2002).

interpreted as a subjective probability (as assessed by the relevant experts); then all that has to be established is that the probability is below the relevant limit.

That said, contrary to what is often recognized in the literature, it is not sufficient to merely establish a first-order epistemic threshold by stipulating that, say, a lifetime risk below one in a billion is *de minimis*. We also have to establish a second-order epistemic threshold, which tells us how certain it is that a risk really is so small that it falls below the threshold. In order to see this, recall the E-condition stated in §2, according to which the enaction of a remedy or restriction on an activity should be sensitive to (1) the epistemic strength with respect to the entire causal proposition (specifying an action and a damage), and (2) the epistemic strength of the operator at play in the causal proposition itself.

Let us illustrate this point in an example. Imagine that you estimate the probability that a person will get cancer from substance X to be one in a billion. This is in itself not sufficient for concluding that the risk is *de minimis*, because your assessment of the probability may be highly uncertain. This type of uncertainty can be rendered more precise by distinguishing between first- and second-order probability. In our example, the first-order probability is the probability that substance X will cause cancer. The second-order probability refers to the probability that the assessment of the first-order probability is correct.

Note that if the second-order probability (that the first-order probability is correct) is low, then the risk is not *de minimis*. For instance, if the probability is .01 that the probability is one in a billion that substance XYZ will cause cancer, it would be ridiculous to claim that XYZ is *de minimis*. The actual first-order probability could be much higher. This insight is what drives the second epistemological puzzle, because it is far from obvious how the defender of the precautionary principle should combine the two types of probability (or any other measure of the two types of epistemic strength that figure in the E-condition; see §2) into an adequate threshold for *de minimis* risks.

The second epistemological puzzle can be formulated as a dilemma. The dilemma could be stated in a purely qualitative vocabulary (by using terms such as "highly unlikely" and "almost certain") but in what follows we will state it in a probabilistic vocabulary, mainly because this makes it easier to follow the argument. In order to bring out the first horn of the dilemma, consider the suggestion that the correct way of dealing with the two types of uncertainty is to multiply the second-order probability by the first-order probability, thereby reducing the two measures of uncertainty to a *single* measure. It takes little reflection to see that this approach does not work in discussions of the *de minimis* principle, because if we multiply a small number (the first-order probability) by another small number (the second-order probability), then the all-things-considered probability will be even smaller. For instance, $.01 \times 10^{-9} = 10^{-11}$. It then follows that the *less certain* we are that the second-order assessment is correct, the *smaller* will the all-things-considered risk be, everything else being equal. This is clearly the wrong conclusion. Intuitively, it would make more sense to apply the precautionary principle if the first-order probability is highly uncertain, which is the opposite of what the multiplicative rule suggests.

From a mathematical point of view, this problem could of course be dealt with by "turning around" the probability. Instead of calculating the all-things-considered probability that X is dangerous (causes cancer), one could calculate the all-things-considered probability that X is safe (does not cause cancer). It would then follow that the all-things-considered probability that X is safe is lower than the first-order probability that X is safe, which is arguably the correct conclusion. In the example above we get $.01 \times (1 - 10^{-9}) < (1 - 10^{-9})$. The problem with this line of reasoning is that it is *ad hoc*. We get the result we want, but we seem to have no good epistemic reason that explains why this way of carrying out the calculation is correct and the other way incorrect.

Note that our point does not hinge on the fact that we multiply the two types of probabilities. The worry is more general. On the one hand, if the second-order probability is low this should make the all-things-considered probability even lower, since this makes it more unlikely that that the first-order assessment is correct. Hence, the precautionary principle is less likely to be applicable. At the same time, the mere fact that the second-order assessment is less likely to be correct, is actually a reason *for* applying the precautionary principle, and not declaring the risk to be *de minimis*. No matter which minimally plausible rule we use for aggregating first- and second-order probabilities into an all-things-considered probability, we seem to face a tension between two incompatible intuitions.

We are now in a position to bring out the second horn of the dilemma, which arises if we *refrain* from combing the two measures of uncertainty into an all-things-considered measure. So let us suppose that the threshold for what should count as *de minimis* is determined by considering each type of uncertainty separately. Arguably, the *de minimis* threshold has to be sensitive to what is at stake. (See the discussion of contextualism above.) In a high stake case, a risk is *de minimis* only if the first-order probability is sufficiently low that something bad will happen *and* there is little second-order uncertainty about the accuracy of this first-order assessment. However, in a low-stake case, a risk would be *de minimis* even if the first-order probability is somewhat higher that something bad will happen and even if there is somewhat more second-order uncertainty about the accuracy of the first-order assessment.

In order to spell out the problem that arises if we insist on not aggregating the two measures of uncertainty into a unified measure, it is helpful to keep the stakes fixed. So let us suppose that D is one additional death in cancer. Now consider a case in which the second-order probability is just above the threshold and the first-order probability is just below the relevant limit. That is, the second-order probability is sufficiently high that the first-order probability is sufficiently small; hence, the risk is *de minimis*, meaning that advocates of the precautionary principle can safely ignore it. Next consider a parallel case in which the first order probability is *much* smaller, at the same time as the second-order probability is just a *tiny* bit smaller and falls right below the relevant threshold. It follows that the risk in the second case is not *de mimimis*, which seems to be the wrong conclusion. Intuitively, since the first-order probability is much lower, it should not matter that the second-order probability is just a tiny bit lower.

The second horn of the dilemma can, of course, be formulated in a more general way. The problem is that if we refrain from aggregating the two measures into a combined measure, we have to introduce thresholds. But as soon as we introduce two or more thresholds, we can always imagine cases in which small changes to one threshold lead to a "too big" effect on the overall assessment. The only way to avoid this type of threshold effects is to aggregate all uncertainties into a combined measure (and then optimize with respect to that single measure), but if we pursue that strategy we face the first horn of the dilemma.

An additional problem with allowing second-order uncertainty to play a role in the final analysis is that it seems to be arbitrary to stop at that level. Why not allow for third- and fourth-order uncertainty as well? This leads us to a familiar regress problem. We leave it to the reader to adjudicate whether the regress is vicious or benign.

5 Conclusion

A defender of the precautionary principle who aims to present the principle as a normatively reasonable decision rule must be prepared to rigorously defend the principle. We hope to have shown here that several serious challenges to defending a theoretically satisfactory version of the principle turn on the importance of getting the epistemological condition in the precautionary principle right. As our discussion has suggested, this will be a challenge that requires bridging risk analysis and the theory of knowledge.

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