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DISCUSSION OF "FORMALIZATION AND APPLICATIONS OF THE PRECAUTIONARY PRINCIPLE"

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This paper discusses the theoretical foundations of Henry and Henry (2002)'s formalization of the precautionary principle. I emphasize their distinctive contribution in defining scientific knowledge objectively, independently of decision-makers' preferences, and their formal characterization of what it means to be "non-precautionary." I situate their work within the broader literature on non-Bayesian decision theory and hint at possible extensions concerning the aggregation of preferences under ambiguity, dynamic consistency, and empirical implementation of bounds on scientific knowledge.

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1. INTRODUCTION

It should come as no surprise that Claude Henry, whose seminal work on irreversibility and option value, Henry (1974a,b, 1981), had a huge impact on environmental economics in particular, was deeply concerned with the formal meaning of the precautionary principle. As nicely put in the paper, *the crucial concept underlying the principle is not "the resolution of uncertainty" but "uncertainty" itself, clearly referred to in the historic formulations as a departure from "sufficient scientific knowledge" or "conclusive scientific evidence"*. The core of the enterprise is thus to propose a formal way to define the precautionary principle based on imperfect, uncertain, yet rigorous and useful science. This endeavor naturally leads the authors to leave the Bayesian world, in order to tackle the notion of uncertainty beyond a probabilistic representation of the world.

Henry and Henry (2002) ranges from the philosophy behind the precautionary principle to legal and political aspects of its definition and implementation, looking into some practical examples, and providing a general and abstract approach to it. All this in less than 20 pages!

I'll focus on the abstract characterization in this discussion. Going back 25 years ago, the literature on non-Bayesian individual decision making was burgeoning. After the breakthrough of Schmeidler (1989) and Gilboa and Schmeidler (1989) published in the late 1980s, the community took some time to digest these new models and publications during the 1990s were relatively scarce. There was a surge in the early 2000s and the current paper is part of this buoyant activity.

This period also coincides with my first encounters with Claude Henry's work on 'uncertain science,' which he presented in a series of influential talks. In a paper published in 2003 —a companion to the current one, Henry and Henry (2003)— Claude and Marc seek to answer, through examples, the important question: "What is exactly meant by uncertain scientific information (...)?" Through the meticulous discussion of a few emblematic cases, they provide informal but convincing answers to that question, identifying *what*

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makes an uncertain piece of scientific information *acceptable* in a decision-making process and taking the reader to the way science practically works. Listening to Claude navigating from asbestos utilization to bovine spongiform encephalopathy, antibiotics used as growth factors, and climate change was a real treat.

2. THE CORE CONTRIBUTION

Henry and Henry (2002) offers a theoretical foundation that can serve as a basis for the use of uncertain science in (public) decision-making. The scientific method does obey rules, and science, even when delivering uncertain predictions, can and should be used to make better decisions. While this trust in science is commendable, it is unfortunately routinely questioned in public discourse. In this context, the paper is more relevant than ever,[1] as it underscores that not all opinions can be treated as valid information to guide action.

The theoretical challenge, as I see it, lies in incorporating a measure of "objective" (yet imperfect, in the sense that it does not take the form of a probability distribution) information into the purely subjective approach inherent in Savage's framework for individual decision-making under uncertainty. The paper achieves this by formally defining "Scientific Knowledge" — understood as *objective* in the sense that it is agreed upon by the scientific community and adheres to recognized scientific methods. Scientific knowledge, even when incomplete or uncertain, constrains the set of admissible descriptions of the world. These constraints are objective in the sense that they arise from shared scientific methods and standards and cannot be reduced to mere opinion or subjective belief. The very general definition embeds the case where this knowledge can be represented by a belief function, Dempster (1967).[2]

Claude and Marc actually define what it means *not to be* precautionary *with respect to a business as usual reference act* (normalized to give a zero utility): a non-precautionary social planner is a Savage EU maximizer whose domain of choice is restricted to the objectively unambiguous acts. Such a social planner would consider only acts that yield "definite", i.e., probabilistic, outcomes to replace the current business-as-usual policy. By restricting the domain of available policies considered, the non-precautionary social planner might not use imperfect but still relevant scientific information.

The definition thus embeds two features: a notion of status quo and a notion of objective (un)ambiguity. An objectively unambiguous act is a decision whose outcomes can be assessed probabilistically: there is a well-defined probability distribution over the events on which the act is measurable. To put it trivially, betting on red in an Ellsberg urn where there are one-third red balls and two-thirds blue or yellow balls in an unknown proportion is a non-precautionary act. (Of course, the business-as-usual act is absent from this trivial example.)

Claude and Marc's approach is first to define in a very general manner what Scientific Knowledge is –without any reference to a decision-making setting. This has the advantage

[1]Already in 2002, Claude and Marc noted that "the US government rejects [the IPCC] contribution as scientifically unfounded"—a discomforting reminder that the present situation is not unprecedented in this respect.

[2]Jaffray (1989) used these belief functions as the key object on which to define a preference relation. Mukerji (1997) also modeled (scientific) imperfect knowledge through the use of a belief function, which was then embedded in a Choquet expected utility criterion.

of clearly distinguishing what models of individual decision making under uncertainty have trouble distinguishing: ambiguity perception on the one hand and ambiguity aversion on the other hand. This clear separation has the advantage of neatly disentangling what belongs to science and what belongs to the social planner's decision-making process. It also explains why, in this context, the precautionary principle thus defined does not necessarily lead to conservative actions.

3. CONNECTIONS TO THE LITERATURE

What Claude and Marc do next is to show the link between their notion of Scientific Knowledge and a more subjective definition of ambiguous acts (as provided by Epstein and Zhang (2001)). This shows how prevalent the subjective approach is in the field, where objective notions are very often considered suspicious (since at least de Finetti) ! The result constitutes a nice link between Jaffray (1989)'s objective approach and Schmeidler (1989)'s fully subjective construct.[3] A recent paper by Denti and Pomatto (2022) provides an interesting alternative: it incorporates the idea of identifiability,[4] in the usual statistical sense, into the smooth ambiguity model of Klibanoff, Marinacci, and Mukerji (2005). The "right" statistical model of the world is unknown, but only models that can eventually be identified (i.e., whose "truth" can be assessed from data) can be considered.

Claude and Marc, by asserting forcefully that science, even when uncertain, does provide bounds on what is conceivable, actually go against the mainstream approach in decision theory. In a world where self-proclaimed experts can easily spread grossly false "scientific" arguments, this provides a clear alternative to the fully subjective approach that dominates much of decision theory. In a more mundane way: science is not an opinion. Of course, Claude and Marc do not ignore (real) scientific controversies and precisely provide the tools to acknowledge them. A limitation of the framework, however, is that it does not model the process by which a given state of knowledge (their family $\mathcal{F}$) emerges. They do refer to experimentation that could be captured by random correspondences (belief functions being one particular case of these), but do not consider an explicit aggregation process of various pieces of knowledge, nor how it is updated. Even without considering these aspects, the source of the uncertainty might be relevant for decision-making. Gajdos and Vergnaud (2013) study how conflicting (precise) information and unanimous imprecise knowledge can lead to different decisions –with an axiom of disagreement aversion built in the analysis.

4. EXTENSIONS AND FUTURE DIRECTIONS

Once uncertainty is represented independently of preferences, a natural next question concerns how such representations interact with social aggregation. By focusing on the representation of uncertain science, the paper does not deal with the construction of the social planner's preferences – it actually does so purposefully, to separate the representation of the state of knowledge from any preference consideration. Yet, under ambiguity,

[3] A few years later, Gajdos, Hayashi, Tallon, and Vergnaud (2008) proposed a different setting, in which the decision maker has preferences directly on couples (acts, information available). They make explicit the link between the revealed (subjective) set of priors of the decision maker and the objective information available.

[4] And only partial identifiability in Denti and Pomatto (2020).

it is well-known that aggregation of individuals' preferences often leads to impossibility results, see, e.g., Gajdos, Hayashi, Tallon, and Vergnaud (2008). Actually, even when they all share the same "beliefs" (same sets of priors –representing objective information– in the maxmin expected utility model, for instance), the aggregation of agents' preferences into a social planner's preference is not possible in general. While in the case of risk (von Neumann-Morgenstern expected utility), Harsanyi's theorem tells us that an expected utility representation exists for the social planner, such unanimity in beliefs is unfortunately not sufficient to aggregate individuals' preferences if one wants to abide by the usual Pareto principle.[5] The current framework could be used to further explore this issue.

As mentioned above, the paper is concerned with the representation of (scientific) uncertainty, not with its resolution. Yet, a main feature of science is to evolve, as new discoveries are made. Modeling this evolution within the general framework proposed by Claude and Marc would probably raise interesting questions, since it is known that dynamic consistency cannot be expected in general when one moves away from the expected utility setup, although ways to restore it do exist, e.g., Riedel, Tallon, and Vergopoulos (2018).

Finally, probably the most important pursuit is now to use this framework to actually provide estimates of bounds on our Scientific knowledge on many issues. While reports like the one produced by the IPCC do now routinely report bounds on various phenomena, it appears that providing the statistical tools to sharpen these estimates is crucial. Marc and co-authors have explored this path (partial identification, incomplete models) from a theoretical perspective.[6] By formalizing scientific uncertainty independently of beliefs and preferences, the paper provides a foundation on which such empirical efforts can coherently build.

[5] However, following Mongin (1995), it is possible to weaken the Pareto axiom and restore some form of aggregation, see, e.g., Danan, Gajdos, Hill, and Tallon (2016).

[6] See, e.g., Galichon and Henry (2011) and Galichon and Henry (2013).

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