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Jan Sprenger and Stephan Hartmann, *Bayesian Philosophy of Science*

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The status of Bayesianism has considerably evolved since the beginning of the 1990s, when Howson and Urbach published *Scientific Reasoning: The Bayesian Approach* (1989). At the time, Bayesianism was a philosophical theory of scientific reasoning rival to falsificationism. While it claimed to account for important aspects of reasoning in empirical science and to solve difficulties such as Duhem's Problem or Hempel's Raven Paradox, it was hardly used by scientists themselves and it faced its own share of problems and objections—primarily the Old Evidence Problem first raised by Glymour (1980) and the Objection of Subjectivity already formulated in the 1950s by Fisher (1956) or Popper (1959). In contrast, Bayesianism today is undoubtedly the dominant theory of reasoning on empirical matters. On the normative side, its core arguments have been strengthened, and the problems and objections it was facing have been thoroughly discussed and largely overcome. On the descriptive side, much empirical work now establishes Bayesianism as a prominent psychological theory of evidential reasoning. What is more, the Bayesian approach has become a well-established method in philosophy (see, e.g., Jacob Stegenga's "Master Argument" in *Medical Nihilism*, 2018) while Bayesian methods have diffused throughout the empirical sciences. Jan Sprenger and Stephan Hartmann's *Bayesian Philosophy of Science* is a testament to this multi-faceted evolution. It showcases the best of various branches of Bayesian studies in the philosophy of science. Over thirteen demanding chapters, most of which borrow from various articles recently independently published by the authors, it presents the most recent advances in the Bayesian analysis of scientific thinking and offers an up-to-date treatment of the most pressing objections to Bayesianism, while taking stock of recent Bayesian developments in scientific methodology and in the psychology of reasoning.

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Bayesian Philosophy of Science brings together the results of one decade of work by its authors and their collaborators, whether directly on Bayesianism or using the Bayesian toolbox. Its introduction offers a thorough presentation of the principles of Bayesian inference: the static requirement that rational beliefs come in probabilistic degrees, the dynamic principle of relying on Bayesian conditionalization to revise these degrees in light of new evidence, and finally the claim that rational, Bayesian degrees of belief should ground our epistemic and practical decisions. The reader also learns about causal Bayesian networks, which the authors later use as an analytical tool at various points in the book. This sets up the “theme” of a Bayesian philosophy of science, to be followed by “variations” (the authors’ terms) that can be read separately but which are best appreciated as parts of the whole. The end of the first chapter, where the Bayesian theme is played, distributes these variations into three sets: Variations 1 to 5 deal with confirmation; Variations 6 to 10 offer a Bayesian exploration of other concepts in the philosophy of science, such as causal strength; Variations 11 and 12 address major objections to the Bayesian approach in scientific inference. They are followed by a conclusion: “The Theme Revisited”.

Confirmation is the most classical case of a concept that has received a Bayesian analysis: in Sprenger and Hartmann’s words, Bayesian confirmation theory is “the most venerable and well-worked-out branch of Bayesian philosophy of science” (42). The basic tenet of this theory is that judgements of confirmation can be analyzed in terms of rational, Bayesian degrees of belief evolving as new evidence becomes available. Variation 1 defends the explication of confirmation as an increase in rational degrees of belief: evidence *E* confirms hypothesis *H* if, and only if, the degree to which *H* is believed is raised by learning *E*. It is shown that this explication sheds light on the Raven Paradox and Goodman’s New Riddle of Induction. Several measures of confirmation are also presented. While none of this is new, the chapter showcases the qualities and distinctive features of Sprenger and Hartmann’s analysis throughout the book: it is technically flawless and well-grounded; it focuses on adequacy conditions to be imposed on analyzed concepts (here, confirmation) and links these conditions to the analysis by means of representation theorems; it welcomes interpretive pluralism, connects philosophical, normative concerns with relevant empirical findings, and explicitly indicates avenues for future research.

Variation 2 deals with “No-Alternative Arguments”—that is, arguments drawing conclusions from the absence of viable alternatives. The chapter uses the Bayesian framework to model this no-alternative reasoning pattern and identifies plausible assumptions that may warrant its core idea, namely that the absence of a viable alternative to a theory indeed confirms it. All in all, this approach is interesting because it extends the concept of confirmation to encompass cases of so-

called non-empirical confirmation. Variation 3 in turn revisits the long-standing debate over scientific realism, by modeling and assessing No-Miracle Arguments for the empirical adequacy of scientific theories (stating that the predictive success of science would be a miracle if the claims that predictively successful theories make about empirical phenomena were not (at least) approximately correct; see Dawid and Hartmann, 2018). Incidentally, taken together, these two variations make a strong case for the clarifying effect of formalization.

Having first been put to work in its rather basic version, Bayesian confirmation theory is then further refined by the two authors. Variation 4 extends the theory to encompass the case where one learns conditional evidence—that is, evidence “relative to supposing a certain proposition or reference class” (108), for example that one should administer a given drug *if* it is effective (114 et sq.). Variation 5 deals with the Old Evidence Problem, presenting existing solutions and offering new ones.

Starting with Variation 6, Bayesianism is left behind as a theory of reasoning and confirmation as Sprenger and Hartmann turn to analyzing other concepts and arguments along Bayesian lines. Variation 6 provides the “axiomatic foundations for a probabilistic theory of causal strength using causal Bayesian networks” (176). The proposed axioms mirror so-called adequacy conditions, to which they are related by representation theorems. While forcefully arguing in favor of difference rather than ratio approaches to causal strength (along the lines developed in Sprenger, 2018a), the chapter mostly contributes a framework for assessing and comparing contributions on this question coming from various disciplines. Variation 7 does a similar job for explanation and explanatory power. The discussed measures of explanatory power are essentially probabilistic, but they seek to keep track of causal relations and the whole variation has an eye on Inference to the Best Explanation. Thus, the Bayesian toolbox is used to develop and refine an approach to evidential reasoning that is usually considered as rival to, if ever compatible with, Bayesianism. The same holds of Variation 9, where the resources of the Bayesian approach are put in use to serve the Popperian philosophy of science and a probabilistic notion of corroboration is developed, that is meant to complement the classical, Fisherian approach to statistical inference. This highly interesting and thought-provoking chapter not only uses Bayesian weapons in the service of Bayesianism long-standing rival. It also embeds Bayesianism in a more general approach to hypotheses assessment, as Bayes factors appear as a special case of the corroboration measure that the authors support.

Variation 10 is initially presented as belonging to the second set of chapters, where Bayesian tools are applied to topics beyond the concept of confirmation. Yet it fits rather well in the category of a philosophy of Bayesian science, as it offers a philosophical investigation of

Bayesian practices in science. The chapter, which is the most technical of the book, broaches the topic of simplicity by comparing various criteria for model selection, three of which (out of four) are usually characterized as Bayesian. The authors show that the choice of a best criterion is context-dependent and, most importantly, that such allegedly Bayesian criteria are not firmly anchored in the Bayesian theory of reasoning. Instead, the authors implement a form of “instrumental Bayesianism—an approach to statistical inference which is happy to use Bayes’ Theorem as a scientific modeling tool, without however taking the Bayesian elements too literally, as expressions of subjective uncertainty” (281). More broadly, the chapter convincingly shows that philosophy of science has much to gain from scrutinizing the details of the formalisms (here, statistical ones) that are actually used in science.

Variations in the last series deal with objections to Bayesian scientific inference. The first objection, tackled in Variation 11, is a most classical one. Because it makes so much use of apparently subjective degrees of belief, Bayesian reasoning seems at odds with the requirement of objectivity that bears on science. Sprenger and Hartmann focus on the version of Bayesianism that seems most vulnerable to this objection—subjective Bayesianism, as opposed to so-called “objective” Bayesian approaches—and on the domain of statistical inference. They explain why traditional Bayesian answers to the subjectivity objection are lacking. They also proceed to show, based on the philosophical analysis of the concept of scientific objectivity, that Bayesianism does not fare worse than frequentism as regards classically discussed dimensions of scientific objectivity. In fact, it may fare better as regards the socially relevant notions of interactive and convergent objectivity (see, e.g., Sprenger, 2018b). On this analysis, transparency with regard to the subjective elements involved in statistical inference appears as a key feature of Bayesian reasoning. Variation 12 raises a less classical but no less fundamental worry, viz. that the Bayesian approach to scientific reasoning may have no applicability because scientific models rely on many idealizations and approximations and therefore cannot be believed to be true to any strictly positive degree. As an answer to this concern, Sprenger and Hartmann defend a suppositional analysis of Bayesian probabilities, whereby these are relativized to the set of hypothetical models that are envisaged. The probability of a hypothetical model is the degree to which it would be believed “if we supposed that the target system is fully and correctly described by one of the hypotheses” (312) under consideration. This idea is further refined throughout the chapter. Interestingly, it is shown to imply that Bayesianism is best seen as a tool to reason on models, with Bayes’ theorem as principle coordinating different probability functions involved in this exercise.

Each of the twelve Variations making up the book is a valuable contribution to the philosophy of science that is well worth the reader's

time. These chapters are self-contained and can be read independently, so much so that it is not always clear how they cohere together or relate to one another. In fact, the book's organizing principles are not always obvious and their description seem to vary from one part to the next. The introduction suggests the three-part organization I have followed here. The conclusion instead describes Variations 9 to 12 as forming a unit defined by "the wish to answer open questions in statistical inference" (328), yet also notes "a high degree of similarity" between Variations 1, 6, 7 and 9, Variations 4 and 5 and Variations 2 and 3. The difficulty is not overlooked by the authors and the concluding chapter visibly seeks to forge the unity of the book and draw general conclusions. While not plainly succeeding in providing the reader with one or at least a small number of simple take-home messages, *Bayesian Philosophy of Science* gradually raises and broaches important and fascinating questions concerning the status, foundations, and limits of Bayesianism and Bayesian inference. Reading the entirety of this rich and stimulating book, which is both accomplished and forward-looking, is therefore rewarding and highly recommended.

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