Induction, Probability, Bayesianism[*]

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[527] In this contribution, we show how Rudolf Carnap's thinking about logical probability (ch.51,52) was initiated by his approach to empiricism and induction (section 1), we give an outline of some main ideas of his account of the philosophy of probability (section 2), and, finally, indicate what important impact thinking in terms of the program had, and how it might be considered to have dissolved into less logical and more pragmatic accounts of different fields such as that of Bayesianism (section 3).

1 Induction

Logical empiricism relies on an inductive methodology. Carnap emphasized that this reliance was traditionally seen as, ultimately, countering empiricism. The reason for this is that the justification of an inductive methodology hinges on a principle that seems to be *synthetic* (i.e. not logical, mathematical or definitory) and *a priori* (i.e. independent of empirical considerations), which meant a dubious epistemic status for logical empiricists. The principle in question is that about the uniformity of nature. Here is why it is problematic: At the time when Carnap started to work on this topic, the so-called *frequentist account* of the inductive methodology and its conception of probability arose and got established. According to frequentism, simply put, the inductive methodology consists in straightforwardly extrapolating the relative frequency of an observed part of a series of events to the (next) unobserved part of that series of events. Now, the only way to justify such an extrapolation seems to assume that nature is uniform, because if nature—the series of events in question—is uniform, then this extrapolation simply transforms a pattern from the observed to the unobserved part; uniformity guarantees that patterns of the observed part are, indeed, also patterns of the unobserved part, and, hence, if

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our diagnosed pattern of the observed part is correct, also the predicted pattern of the unobserved part will be correct. However, since such a principle is not determined by logic and mathematics, it is *synthetic*. And since we want to use it to justify the empirical/inductive methodology, we cannot use the empirical methodology in order to justify the principle, so it has to be *a priori*. But this means that by accepting such a principle, we would have to "sacrifice empiricism" (cf. Carnap 1950/1962, p.180).

Carnap disagreed with a (solely) frequentist conception of the inductive methodology and its notion of *probability*. Rather, he thought that the frequentist conception covers only the empirical component of the inductive methodology and probability [528] (such as statements of the form "the relative frequency of rainy days among spring days is such and such" entering our probabilistic reasoning), but that there is also a non-deductive, i.e. inductive, logical component of this methodology, and by this inductive logical premises relevantly entering our probabilistic reasoning. For this reason, he first argued that in science and philosophy of science two conceptions of probability are in place, the logical and the frequentist conception (cf. his 1945 and section 2 below); and second, very often the logical component of the inductive methodology is what is relevant for science and philosophy of science; third, it is also the logical conception that can be employed in order to argue for a uniformity assumption in order to tackle the problem of induction. His approach counters in particular the claim that the principle on the uniformity of nature that is needed in order to justify the inductive methodology is *synthetic*. Rather, it is a logical (in the wide sense of an inductive logic) principle and, hence, *analytic a priori*, which allows for the salvation of empiricism.

Let us unpack Carnap's approach among the steps outlined above. We will provide more details for the first step and the characterization of logical probability in the next section. Here we focus on the other two steps and his section F of §41 of (1950/1962), where he speaks about the "presuppositions of induction". There he clarifies the uniformity assumption in question: This assumption or the principle of uniformity can be expressed as "The degree of uniformity of the world is high" (p.179). For Carnap it is important to keep the quantitative version in mind, because he thinks that we can logically extract such a degree from the structure of our linguistic frameworks. He also assumes that we should be fine with a probabilistic form of justifying induction only—there is no need of guaranteed success of a method in order to be justified: "It seems that, indeed, many contemporary philosophers, perhaps the majority, in contradistinction to those of the last century, agree that probability of success in the long run would be sufficient for the validity of inductive inference" (p.180). So, according to Carnap, in order to justify the uniformity assumption, what one needs to show is this:

> *Justification of Uniformity:*
> "On the basis of the available evidence it is very probable that the degree of uniformity of the world is high." (p.180)

Now, we see that the justification of the uniformity hypothesis (let us label the uniformity hypothesis by 'h_u') "The degree of uniformity of the world is high." is itself a probabilistic statement: the probability (Pr) of this hypothesis (h_u) is high—so we can express this as a statement about the probability $Pr(h_u)$ being high. Frequentism and the traditional view takes this probabilistic statement to be empirical, but, as we have seen already, "it cannot be confirmed empirically because such a procedure would use the method of induction which in turn presupposes the statement" (p.180). And it is exactly here where Carnap's account of inductive logic is supposed to take over and stress the logical vs. the empirical component of probabilistic inductive reasoning: "Our conception of the nature of inductive inference and inductive probability leads to a different result. It enables us to regard the inductive method as valid without abandoning empiricism. According to our conception, the theory of induction is inductive logic. Any inductive statement [...] on probability, or estimation is, if true, analytic. This holds also for the statements of the probability of uniformity." (p.181)

So, we see that the argument contra empiricism can blocked according to Carnap, because the statement justifying h_u is a probability statement and contrary to the claim that such a statement is synthetic, in Carnap's account of logical probabilities such statements are *analytic*. In order to see why this holds, we need to understand better Carnap's notion of *probability*.

2 Probability

In his (1936, cf. ch.44), Carnap made clear that, as logical empiricists (contra logical positivism), "instead of verification, we may speak of gradually increasing *confirmation* of the law" (p.425). This highlights the role and need of an understanding of the notion of *probability and confirmation*. [529] Something Carnap started to put his focus on in spring 1941, when he "began to reconsider the whole problem of probability. It seemed to [him] that at least in certain contexts probability should be interpreted as a purely logical concept. [... I]nfluence in this direction came on the one hand from Wittgenstein [(ch.22, ch.23)] and Waismann [(ch.25)], on the other hand from Keynes" (cf. his 1963). The first published systematical approach on this topic was his methodological investigation of (1945), where he distinguished two important steps of an explication (ch.50), namely to first make the constraints for using an established expression, *the explicandum*, as clear as possible, and then work out a new and more exact concept, the *explicatum*, that satisfies these constraints in a better way. It is also in this investigation that Carnap suggested that the constraints in use of the notion of probability were so heterogenous, that it is better to distinguish, as a first step of an explication, between the explicandum of *probability*$_1$ in the sense of the *degree of confirmation/logical probability* of some hypothesis given some evidence and the explicandum of *probability*$_2$ in the sense of the (quasi-)empirical *relative frequency* (in the long run) of a series of events (cf. p.517). The former was, e.g., approached by John Maynard Keynes (1921) and Harold Jeffreys (1939/2003). The latter by, e.g., Richard von Mises (1928/1957) and Hans Reichenbach (1935/1949). Carnap set himself into the former tradition and aimed at explicating the notion of *confirmation* (probability$_1$). He outlined his program of *logical probability* in his (1950/1962) and worked out details of the program within a full monograph devoted to this topic, namely his (1950/1962), in which he investigated conditions for different families of confirmation functions (c functions, representing inductive methods) but also further elaborated on the explicative methodology (cf. chpt.I). Initially, Carnap wanted to extend his work of (1950/1962) by a monograph (a second volume) that was to provide more details of a particular family of confirmation functions ($\mathfrak{c}^*$ functions; cf. the aim stated in the preface to the first edition, pp.ix), but he gave up on this static form of publication (cf. the preface to the 2nd edition, p.xiii), since, first of all, he discovered/defined a full "continuum of inductive methods" (1952, the so-called λ-continuum), and, second, the field was too much in flux in order to keep up with the development within another monograph. Important parts of the discussion of his early system of an inductive logic took place in the Schilpp volume on Carnap's philosophy (1963). Philosophically, he re-stated the aim of such an inductive logic at several occasions as that of defining the concept of *probability*$_1$ or *confirmation* in "a purely logical way" (1966, 1957). Technically, he developed further systems of inductive logic with which he sought to overcome severe restrictions of the defined continuum of inductive methods (cf. 1971, cf. 1980). But before we come to a more detailed account of Carnap's plan, let us very briefly outline the main idea of the program of an inductive logic.

The program of an inductive logic sees an important continuity with respect to deductive and inductive reasoning. Traditionally, a formula A is considered a logical consequence of B iff it holds by necessity that whenever B is true, so is A. Carnap spelled out this necessity formally via the notion of a *state description* ("if [F] is any atomic [formula in a language L], a state-description for L must either affirm or deny [F]" (cf. Carnap 1950/1962, pp.71f, D18-1b) and the notion of a *range* of a formula ("the *range* of [a formula F] in L [... is] the class of those [elements of the set of all state descriptions] in L in which [F] holds", where F holds in a state description iff all its atomic components are elements of the state description (cf. Carnap 1950/1962, p.79, D18.4–6). If we think, e.g., about a language of propositional logic with finitely many propositional variables $p_1,\ldots,p_n$ (cases of an infinite language can be dealt with via limiting frequency considerations), then this set forms a state description as well as any variant thereof that negates variables such as, e.g., $\{p_1, \neg p_2, \ldots, p_n\}$. Both state descriptions are, e.g., in the range of the formula p_1, whereas only the first but not the second one is in the range of $p_1 \& p_2$. [530] That p_1 is a logical consequence of $p_1 \& p_2$ is due to the fact that the range of $p_1 \& p_2$ is included in the range of p_1 (so, whenever $p_1 \& p_2$ is true/holds in a state description, also p_1 is true/holds in that state description). So much for the direction from $p_1 \& p_2$ to p_1. But what about the other direction, from p_1 to $p_1 \& p_2$? Can we say, from a logical perspective, more than simply that the range of p_1 is not included in the range of $p_1 \& p_2$, that $p_1 \& p_2$ is no logical consequence of p_1? It is here where inductive logic pops in. The idea is to fine-grain the range-inclusion claim from included/not included to stating a degree of inclusion, namely the degree of the inclusion of the range of some formula B in some other formula A. If we think about our simple propositional language, then we see that only half of the range of p_1 is included in the range of $p_1 \& p_2$; for this reason, we can say that the degree of inclusion of the range of p_1 in that of $p_1 \& p_2$ or the logical probability of $p_1 \& p_2$ in the light of p_1 is 50%.

Now, so much as an outline for getting the main idea of an inductive logic. Clearly, in order to get out more of such a logic, one needs a more fine-grained structure as that provided by propositional logic. This is what Carnap's programme of an inductive logic is mainly about. Here we aim to give a very elementary overview with toy examples only. For historical and technical details of Carnap's account, the reader is referred to (Zabell 2011).

Carnap provided a fine-grained treatment of inductive logic in his (citeyearcit:carnap1962LogFou). Basically, instead of investigating range-inclusion relations between sets of formulas of propositional logic, Carnap discusses such inclusions of a monadic (first-order) predicate language containing formulas such as $Q_1(a), Q_1(b), Q_2(a), \ldots$. By this, we can already fine-grain patterns whose inductive generalization we might be interested in (cf. 1950/1962). Amongst many others, there is, e.g., the universal inference from "an observed sample to a hypothesis of universal form" (cf. §110.F) such as, e.g., the determination of the logical probability $Pr(\forall x Q(x) | Q(a_1) \& \cdots \& Q(a_n)) = r$; there is the analogical inference where "the evidence known to us is the fact that individuals b and c agree in certain properties and, in addition, that b has a further property, thereupon we consider the hypothesis that c too has this property" (cf. §110.D) such as, e.g., the determination of the logical probability $Pr(Q_2(c) | Q_1(b) \& Q_2(b) \& Q_1(c)) = r$. Etc.

Carnap's program of an inductive logic consists in the study of linguistic frameworks and their possibility to license such inferences on the basis of general probabilistic principles. One of the oldest general principles of accounts of logical probability is the *principle of indifference*, which states that equipossible cases have the same probability (such a principle is to be found already in Leibniz; latter on authors like Bernoulli, Buffon, and Laplace worked with the assumption of a uniform probability distribution; cf. van Fraassen 1989, p.298). One of the main problems with this general principle is the so-called *Bertrand's paradox*, which shows that this principle assigns different probabilities to analytically equivalent statements (cf. the examples provided by van Fraassen 1989, p.303). Now, in order to not run into this problem, Carnap restricted the principle of indifference to a very particular application. The general probabilistic principles he worked with in his (1950/1962, §26 and the appendix) were particularly *regularity* (non-contradictory formulas receive positive logical probability and are, by this, not a priorily excluded), *symmetry* (logical probabilities do not change under the permutation of individual constants because the identity of the single individuals do not matter), and *indifference with respect to so-called structure descriptions*. In later writings, he added further/modified principles. And it were particularly this many amendments and modifications within the Carnapian program of logical probability in order to account for the inductive practice of science that led to much criticism of Carnap's account: although (Hintikka and Niiniluoto 1976) succeeded in providing a system (adding a "free parameter" K) that licenses inductive inferences such as the universal inference and also Carnap succeeded to improve his systems with respect to analogical inferences [531] (adding a "free parameter" μ), many critics of Carnap (among others also Putnam 1979, who initiated already in earlier writings as an alternative account *formal learning theory*) consider this need of an ever increasing set of free parameters (first the λ -continuum, then K for universal confirmation, then μ to capture relations between properties for analogical inferences etc.) in order to explain a sometimes—by language restrictions e.g. concerning the number of monadic predicates etc.—even decreasing set of inductive practice as a typical indicator for a degenerative research program in the Lakatosean sense (cf., e.g. Spohn 1981, p.51). Although we think that Carnap has some methodological tools at hand in order to counter this criticism by stressing the framework dependence of what turns out to be *analytic* and *a priori* (and a more general pragmatic tendency to be attributed to him as we briefly indicate in section 3), we cannot go into detail on this and rather want to quickly indicate how inductive logic helps Carnap to account for the problem of induction as outlined at the end of section 1.

Next to his (1957 and some short remarks in his 1963), Carnap never became really explicit again on how to deal with his initially motivating problem of induction. A very illustrative way to technically embed the Carnapian thought that the justification of induction by the claim that the probability of the world being uniform is quite high (i.e. $Pr(h_u)$ is high) into Carnap's account of inductive logic is provided in (Leitgeb and Carus 2020, Supplement C.): As mentioned earlier, Carnap stresses that probabilistic statements are logical/analytical and that, therefore, such a probabilistic claim about the uniformity of the world (h_u) should, if at all, result from constraints of our linguistic framework.

Let us illustrate this by the help of an example. Assume we have a monadic predicate language with $m = 1$ unary undefined predicates (Q) and $N = 3$ individual constants (a, b, c). Since the range-inclusion considerations of inductive logic are about state descriptions (complete set of atomic formulæ or their negations), and we can form 3 atomic formulæ ($Q(a), Q(b), Q(c)$), we get 8 state descriptions (combinatorically spanning from $\{\neg Q(a), \neg Q(b), \neg Q(c)\}$ to $\{Q(a), Q(b), Q(c)\}$). Now, let us apply (some of) Carnap's general probabilistic principles of his (1950/1962) to this case:

- *regularity*: since none of the state description contains a contradiction, all state descriptions (i.e. the corresponding formulæ) receive a positive logical probability (e.g. $Pr(Q(a) \& Q(b) \& Q(c)) > 0$);
- *symmetry*: we need to cluster together those state descriptions that result just from permutations of the individual constants (our "arbitrary labels"); it is easy to see that this principle clusters together state descriptions according to their number of negations: by permutation of a and c,

we can transform, e.g., $\{\neg Q(a), Q(b), Q(c)\}$ to $\{Q(a), Q(b), \neg Q(c)\}$. So, we end up with 4 clusters:

$$\begin{array}{rrrr}
1 & Q(a) & Q(b) & Q(c) \\
\\
2 & \neg Q(a) & Q(b) & Q(c) \\
2 & Q(a) & \neg Q(b) & Q(c) \\
2 & Q(a) & Q(b) & \neg Q(c) \\
\\
3 & \neg Q(a) & \neg Q(b) & Q(c) \\
3 & \neg Q(a) & Q(b) & \neg Q(c) \\
3 & Q(a) & \neg Q(b) & \neg Q(c) \\
\\
4 & \neg Q(a) & \neg Q(b) & \neg Q(c)
\end{array}$$

Carnap calls the disjunction of the state descriptions within one such cluster a *structure description* (cf. 1950/1962, p.116)

- *indifference*: now we apply a restricted linguistic version of the indifference principle to these clusters and state that each structure description receives the same logical probability (cf. 1950/1962, §110.A). So, in our example, each of the four clusters receives a probability of .25.

[532] Now, we can see that the clusters 1 and 4 are more homogeneous or uniform than the clusters 2 and 3. We also see that with respect to the clusters 2 and 3 we have to distribute their .25 probabilities each over 3 state descriptions, whereas with respect to clusters 1 and 4 it is only one state description. In general, "since structure-descriptions that exhibit 'more uniformity' are instantiated by a smaller number of state descriptions[, . . .] 'more uniform' state-descriptions receive a relatively greater initial probability, corresponding to an inductive bias towards the 'uniformity of the world'." (cf. Leitgeb and Carus 2020, Supplement C). So, e.g. given such a linguistic framework, each probability about being in an uniform/ordered world (individual formulations of h_u) is higher than being in a less uniform/unordered world. It is this kind of reasoning that can be applied in order to substantiate Carnap's claim about the probability of the uniformity of the world. And, so at least in theory, this inductive bias is an analytic consequence of our linguistic framework and nothing to be synthetically or metaphysically justified. However, as we briefly indicate in the next section, Carnap's development included increasingly pragmatic components. In this sense, at latest when it comes to the question of the choice of a framework, this empiricist justification of induction is amended with non-analytic components.

3 Bayesianism and a more Pragmatic Attitude

A broad summary of relevant impact of Carnap's account of an inductive logic is provided in (Leitgeb and Carus 2020, sect.8.2 and Supplement C on Inductive

Logic). Here we focus more on his development with respect to Bayesianism.

We have seen in the previous section that when Carnap worked on probabilities, he focussed on two main approaches, the logical account and the frequentist account. Characteristic for the logical account is that probabilistic statements are about probabilities of linguistic objects (formulæ, sentences etc.), whereas in the frequentist account probabilistic statements are about events (physical states of affairs or stochastic processes). If we think not only about linguistic objects and their formal relations but also about (idealised) epistemic attitudes one can have towards them, then we end up with the more contemporary distinction between *Bayesian* and classical statistics and probability theory, where in the *Bayesian* account in general probabilities are seen as expressions of epistemic attitudes. Now, whereas the classical or frequentist approach makes predictions on the underlying truths of an experiment, using only data from that experiment, the Bayesian approaches (allow to also) rely on past knowledge (e.g. of similar experiments etc.), where the inference runs from a *prior probability* distribution expressing the degree of belief in hypotheses before data has been collected to a *posterior probability distribution* over the hypotheses, expressing the degrees of belief after data has been incorporated (cf. Romeijn 2023). If one relies on *priors* as in the Bayesian account, one might wonder where they come from or which constraints we put forward for them (cf. Talbott 2008). *Subjective* Bayesian accounts allow for any *priors* that make up for a coherent probability distribution; so, they are pretty much unconstrained. *Objective* Bayesians, on the other hand, put forward constraints such as the freedom from biases.

We have seen in our discussion in section 2 that Carnap has put forward in his (1950/1962) three general probabilistic principles: *regularity*, *symmetry*, and a linguistic version of *indifference*. All three principles can be interpreted as putting forward objective *Bayesian* constraints for priors in order to avoid biases: regularity avoids "overly strong" probability assignments in the sense that it does not allow one to put coherent and incoherent beliefs on a par; symmetry aims at avoiding biased probabilistic assessments on the basis of irrelevant information such as our labelling of individuals; and indifference aims at avoiding biases by demanding us to treat structurally equivalent cases also probabilistically equivalent. [533] In this sense, Carnap's account of logical probability makes up for a species of objective Bayesianism. Since it is even only linguistic structure that determines the probabilities, his account has been also labelled as '*Bayesian logicist*' (cf. Hawthorne 2018, sect.2.1).

Carnap is to be located in the Bayesian camp, also because he accepts an important Bayesian justification of probabilities (as degrees of belief, namely *Dutch Book* reasoning; cf. Talbott 2008). This becomes particularly clear in his later writings, where he distinguishes between the logicality of axioms and the non-logicality of their justification (cf. Carnap 1971b, p.26). So, although Carnap was an *objectivist* with respect to the determination of the *priors*, he accepted a traditionally *subjectivist* justification for the general (coherence) principles of probabilities. Also, we agree with the interpretation of Leitgeb and Carus (2020, Supplement C) that Carnap's final account on logical probabilities in his (1980) where he introduced geometrical resources for defining quality spaces and so allowing for the definition of distance measures in order to fine-grain probabilistic inferences even further as an indicator that Carnap became more and more liberal with respect to explicating inductive probabilistic measures and by this “moved closer to the Bayesian position of regarding all probability measures (with a subjective interpretation) as adequate—the Bayesian step taken, e.g., by Carnap’s student Richard Jeffrey” (who even introduced a method of updating on unknown/hypothetical evidence pushing the subjective component even further). Particularly this final contribution of Carnap connects also to new developments such as that of *conceptual spaces* (cf. Gärdenfors 2000) in the field. And although “Carnapian inductive logic is a normative project; [... whereas] the ambition of the theory of conceptual spaces, on the other hand, is primarily descriptive” (cf. for details and a comparison Sznajder 2016, pp.69f; note that Gärdenfors 2000, only briefly mentions Carnap in sect.6.3.2), it seems to be yet another indicator that this close connection between normative and descriptive accounts amounts to some further shift towards a subjective or more pragmatic understanding of Carnap. [534]

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