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Everettian quantum mechanics and physical probability: Against the principle of "State Supervenience"

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ABSTRACT

Everettian quantum mechanics faces the challenge of how to make sense of probability and probabilistic reasoning in a setting where there is typically no unique outcome of measurements. Wallace has built on a proof by Deutsch to argue that a notion of probability can be recovered in the many worlds setting. In particular, Wallace argues that a rational agent has to assign probabilities in accordance with the Born rule. This argument relies on a rationality constraint that Wallace calls *state supervenience*. I argue that state supervenience is not defensible as a rationality constraint for Everettian agents unless we already invoke probabilistic notions.

1. Introduction

Everettian quantum mechanics has many virtues, and in particular it offers a strikingly simple solution to the measurement problem. The general outline of how the theory does so is by now familiar. Instead of trying to find some means by which the formalism can be supplemented in order to guarantee that there is only one determinate outcome of measurements, the theory claims that there is, typically, no such thing as *the* result of a measurement (or of an interaction in general). Rather, all outcomes that are allowed by the formalism really occur, but they do so on separate, relatively isolated, branches of the universe.[1]

However, the theory faces a peculiar challenge when it comes to making sense of the notion of probability and probabilistic notions of confirmation. In particular, it is hard to make sense of a probability assignment other than 1 or 0 within the theory. Of course, this on its own is not a problem. It is going to be true of any deterministic theory that it is non-trivial to make sense of any other value of objective chance apart from 0 and 1.[2] Normally, this does not cause problems for confirmation. We can take the objective chances to be 0 or 1 and still be forced to rely on probabilistic evidence, or on relative frequencies, due to limitations in our epistemic situation. In the Everett interpretation we will often face a peculiar circumstance where the theory predicts with probability 1 that a certain outcome, or sequence of outcomes, will occur (in some branch or other) and also predicts with probability 1 that it will not occur (in some branch or other). At first glance, it looks like all that we can say about a sequence of outcomes that is allowed (but not necessitated) by the theory is that it definitely occurs in some branches and definitely does not occur in some branches. If this is really all that we can say about the probability of a sequence of outcomes, then it is hard to see how we could distinguish, among the sequences of outcomes that are allowed by the theory, which would count as confirmation for it and which would count as evidence against it. If we cannot make sense of these claims, much of what we take to count as evidence in favour of other versions of quantum theory will fail to count as evidence for Everettian quantum theory.[3]

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[1] Throughout this paper I will assume that we are talking about decoherence versions of Everettian quantum mechanics. Moreover, although I take all versions of Everettian theories to agree that all outcomes really occur, they do not all hold that they actually occur. In particular, Wilson (2013) has argued for a version of Everettianism where other branches should be given a modal interpretation as other possibilities rather than actualities.

[2] I do not want to rule out that there are ways of retrieving non-trivial probabilities from deterministic theories. In particular best-system theories might be a way of doing this (see for example Hoefer, 2007).

[3] I am much indebted to Greaves, Myrvold, Saunders, and Wallace for laying out and delineating these issues.

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1.1. The coherence problem, the quantitative problem, and the evidential problem

Greaves distinguishes three different problems related to the notion of probability in Everettian (or, many worlds) quantum theory.[4] The *coherence problem* is the problem of making sense of ascribing any probability at all to outcomes of measurements.[5] The *quantitative problem* is the problem of recovering probabilities in accordance with the Born rule. As Greaves and Myrvold note, the problem of making sense of probabilities within the many worlds theory is particularly pressing. Quantum mechanics is ordinarily understood as a theory that makes probabilistic predictions, and we take those predictions to be confirmed and disconfirmed in accordance with whether the outcomes (or statistical distribution of outcomes) that we see are ones that the theory tells us are relatively *likely* to occur.[6] Greaves and Myrvold (2010) dub this problem the *evidential problem* and I will follow their terminology.

The overall picture of the problem is made slightly more complicated by the fact that a solution to the evidential problem does not have to involve a solution to the conceptual problem as it is stated above. The challenge of the evidential problem is to make sense of confirmation in such a way that the kind of statistical evidence that we take to count in favour of quantum mechanics continues to do so. Of course, we normally take those practices to involve a notion of non-trivial probabilities assigned to outcomes of experiments, but it is possible that there is some other, close enough, notion that could do the job. This means that we should rephrase the coherence problem somewhat. The truly pressing challenge is to have an Everettian way of making sense of something similar enough to the notion of non-trivial probabilities with respect to our practices of confirmation—including allowing probabilities (or something close enough) to be given by the Born rule. This is the project that I take the decision theoretic approach to take on.

2. Decision theory to the rescue?

The hope is that decision theory will be able to deliver something close enough to probabilities to provide a solution to both the new problem of coherence and the evidential problem. In order to have a solution to the evidential problem, we have to allow that probabilities (or something close enough) are given by the Born rule. There are two different prominent versions of how to tackle this problem. Very roughly, the strategy followed by Greaves and Myrvold is to show that a rational agent in a general, not specifically Everettian, branching situation acts as if she is maximising expected utility with respect to some probability function or other, and moreover that, given some further constraints, she acts as if she believes that there is some optimal such function about which she can learn (provided that she is not dogmatic).[7] Greaves and Myrvold (2010, p. 287)—while not arguing that this is the uniquely rationally required probability measure—claim that merely taking it as a primitive of the theory that the probability measure is given by the Born rule at least leaves the many worlds interpretation in no worse a position than other versions of quantum mechanics and "*no worse off* than any other theory vis-à-vis the philosophy of probability".

> … [C]onsider Everettian quantum mechanics as a theory that retains the Hilbert- space framework, the same associations of operators with experimental set-ups and state vectors or density operators with preparation procedures, but replaces the Born rule with the rule: the squares of amplitudes are to be interpreted, not as chances of outcomes, but as branch weights. Greaves and Myrvold (2010, p. 284)

Wallace (2012, p. 151) accepts this position as an available back-up option but argues that Everettians can do better. His argument that Everettians can do better is the target of this paper.

In order to show that Everettians can do better, Wallace elaborates on a theorem by Deutsch (1999). The strategy is to start *without making any assumptions about probability in an Everettian setting* and to end by showing that a rational agent who both fully accepts Everettian quantum mechanics as true and who knows the state of her branch (from now on simply an *Everettian agent* for short) will take the Born rule to give the probability measure of future branches. This has not yet addressed the evidential problem, but Wallace (2012, Chapter 6) argues that we can do so by relaxing the assumption that our agent is an Everettian one. The strategy is to first address the quantitative problem and to then use this in addressing the evidential problem. Crucially, for this strategy it is illegitimate to simply *postulate* that the chances are given by branch weights. This is what the solution to the quantitative problem aims to establish (and later use in addressing the evidential problem). The claim that Everettians can avoid just postulating that chances are given by branch weights in accordance with the Born rule is the way in which Everettians are claimed to do *better* than other quantum theories with respect to probability.

To argue against the claim that Everettians can do better, I will look in detail at a part of Wallace's derivation of the result that—without assuming anything probabilistic at the outset—we can derive that it is rationally *required* to take probabilities to be given in accordance with the Born rule. In particular, I will argue that the rationale for the initially plausible sounding principle of state supervenience is either unconvincing or not, as required, independent of probabilistic notions.[8]

3. State supervenience

Wallace (2010, p. 238) describes the principle of state supervenience as a *rationality* constraint for Everettian agents.[9] Informally he glosses the principle as below.

> An agent's preferences between acts depend only on what physical state they actually leave his branch in: that is, if $U\psi = U'\psi'$ and $V\psi = V'\psi'$, then an agent who prefers U to V given that the initial state is ψ should also prefer U' to V' given that the initial state is ψ'—$U \succ^{\psi} V$ iff $U' \succ^{\psi'} V'$.

Here, ψ and ψ' give us the quantum states, and actions are represented by unitary operators (U, U', V, and V') on the states. $U \succ^{\psi} V$ is read as: at ψ the agent prefers act U to act V.

Wallace's (2010, p. 246) formal statement stays close to the informal one.

[4] See for example Greaves (2004).

[5] That is to say, it is the question of how it can make sense to talk of any probability ascriptions to just the outcome of experiments rather than merely assigning 0 or 1 as the probability of the outcome occurring *on some branch or other*.

[6] That is, relative to the alternative hypotheses.

[7] Greaves & Myrvold (2010) discuss in depth the considerations that should lead us to expect the rationality constraints to hold equally in a branching case as in an ordinary non-branching case.

[8] For challenges to other aspects of the argument see Dizadji-Bahmani (2015) for a challenge to branching indifference and a defence of branch counting, Baker (2007) for worries about the use of decoherence, and Adlam (2014) for challenges to the application of decision theory.

[9] The same formulation appears in Wallace (2012, p. 170). The formal version there contains a (very minor) typo, so I am quoting the earlier version here.