Many worlds or one: reply to Steeger

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Abstract

Steeger (2022) has recently claimed that Bohmians are able to make use of the Deutsch-Wallace derivation of quantum-mechanical chance values. I argue that Steeger's proposal does not succeed, but a close cousin of it—for de Broglie-Bohm epistemic probabilities—does. This clarifies the relationship between Born rule probabilities in Everettian quantum mechanics and de Broglie-Bohm theory, as well as the scope of the Deutsch-Wallace theorem.

1 Introduction

Orthodoxy has it that Everettian quantum mechanics (EQM) has a probability problem (Greaves 2007a,b; Saunders 2022; Wallace 2012). (Oxonian) Everettian orthodoxy also has it that the Deutsch-Wallace (DW) theorem—a symmetry-led derivation of Born rule chance values from a fairly minimal set of constraints on the rational preferences of agents in an Everettian universe—solves that problem, and moreover is a solution which is unavailable to any one-world interpretation of quantum theory (Wallace 2010, 2012). The DW theorem is thus supposed to make Everettian probability "less mysterious" than in one-world quantum theories (Read 2018, p. 140).

However, Steeger (2022) has recently defended a heterodox view according to which the DW derivation of Born rule chance values is not only available to Everettians, but also to other, one-world interpretations of quantum mechanics (QM)—in particular, the de Broglie-Bohm theory. However, *prima facie*, there is something puzzling about this. De Broglie-Bohm theory is supposed to be a deterministic, one-world theory—so in what sense could the DW theorem be a derivation of chance values in such a theory? And if it is not, what is it that Steeger has shown?

In this paper, I critically assess Steeger's argument, and show that it does not succeed. However, the way in which it does not succeed provides insight into the ways in which the DW theorem *could* find application to one-world interpretations of QM such as de Broglie-Bohm theory.[1] First, I outline some background concerning the DW theorem in Everettian quantum mechanics and

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[1] Though cf. Brown and Wallace's (2005) 'Everett in denial' objection.

de Broglie-Bohm theory. I then, in §3, outline Steeger's argument that the DW derivation is also available to the Bohmian, before turning to the analysis of this argument in §4. After showing that the argument is flawed as it stands, I then, in §5, discuss a close analogue of Steeger's proposal which has to do with Myrvold's (2021) recently-articulated notion of epistemic chance, which both avoids these worries, and clarifies the connection between Steeger's approach and those of Dürr et al. (1995) and Valentini (1991a,b). §6 concludes.

2 Background

2.1 EQM and the Deutsch-Wallace theorem

The problem of probability in EQM is well known: what could it mean to talk about probabilities, and how should these agree with the predictions of orthodox QM, in a deterministic Everettian universe where, roughly speaking, everything which can happen does? One of the most sophisticated attempts to address this problem is the Deutsch-Wallace theorem (Deutsch 1999; Wallace 2012). Deutsch and Wallace seek to address this problem by showing that, given a certain set of rationality and richness axioms, one can prove a Savage-style representation theorem to the effect that rational agents who conditionalise on the proposition that EQM is true and that the state of the system is $|\psi\rangle$ will behave, in defining their preference ordering among acts, as if maximising expected utility, for some utility function, using the Born rule. As Wallace (2010, pp. 259-260) stresses, the theorem is essentially a symmetry argument, made rigorous through the decision theoretic framework.

To see how the Deutsch-Wallace approach is supposed to solve the Everettian probability problem, we then need to invoke some philosophical machinery about credences and chances. First, we assume that credences are defined operationally—as whatever it is that is obtained from a Savage-style representation theorem expressing the preferences of rational agents. Next, we need to invoke a further principle about how rational credences, thus defined, relate to chances—Lewis's (1986) famous Principal Principle (PP):

PP: Let S be the statement that the chance of event E at time t is p, and let K be any admissible background knowledge (roughly, which excludes information regarding whether E happened). Then a rational agent's credence $Cr(E|S,K) = p$.

As Lewis notes, the PP appears to capture everything that we know about chance—both how it constrains rational action, and how it can be 'measured' by relative frequencies. One might therefore attempt to define chance as whatever it is that constrains rational credence in accordance with the PP. If one adopts this strategy, and the DW decision-theoretic approach, it follows that the chances in EQM are given by the Born rule.

2.2 De Broglie-Bohm pilot wave theory

The other interpretation of QM which will be relevant to us here is de Broglie-Bohm 'pilot-wave' theory. As in EQM, the wavefunction of de Broglie-Bohm evolves unitarily; unlike EQM, however, de Broglie-Bohm theory modifies the QM formalism to introduce a system of hypothetical particles—Bohmian corpuscles—with configuration $q(t)$, which pick out unique outcomes for quantum experiments. The evolution of the corpuscle configuration q is determined by the guidance equation, which relates $\dot{q}$ to the gradient ∇S of the phase S of ψ, defined by $\psi = Re^{iS/\hbar}$. For example, for a system of N spinless corpuscles with masses m_i and positions $x_i(t)$, the evolution of $q(t) = (\mathbf{x}_1(t), ..., \mathbf{x}_N(t))$ is given by the equation

$$m_i \frac{d^2\mathbf{x}_i}{dt^2} = \nabla_i S.$$

Solving the guidance equation yields a set of configuration space trajectories for the system, each associated with a particular choice of initial conditions. The statistical predictions of orthodox QM are then recovered by appealing to the 'quantum equilibrium' distribution over initial corpuscle configurations $P(q,t) = |\psi(q,t)|^2$.

3 Steeger's argument

Steeger's discussion of the DW theorem centres around one of the key rationality axioms in the DW theorem—state supervenience—which Steeger characterises as the assumption that the chances supervene on the wavefunction ψ. As Steeger notes, Wallace (2012, pp. 147-148) had argued that state supervenience is unavailable to any one-world interpretation of QM, since if there is some physical process which breaks the symmetries of the QM state, then a rational agent's preferences among acts *prima facie* might depend upon facts about this physical process.

Steeger therefore focuses their attention on arguing that state supervenience *is* available to the Bohmian. Their argument for this turns on the following key principle, which Steeger does not formulate precisely, but which can be compactly summarised as follows:

Reliability: If B is admissible background information at t, then B is information that agents can reliably know at t.[2]

Steeger then introduces two further principles, which, together with **reliability**, are supposed to guarantee state supervenience for the Bohmian:

[2]There is a subtlety here regarding Steeger's terminology: their initial statement of **reliability** uses the phrase 'reliably access', but this is replaced by 'reliably know' or 'reliable knowledge' when Steeger returns to the idea throughout the remainder of the article. I am therefore taking it that Steeger has something more like the latter in mind.

Note also that the terminology 'reliably know' carries some redundancy, since knowledge is often taken to be reliable, or counterfactually robust, or something similar. In the interest of staying as close to Steeger's presentation of their argument as possible, though, I am retaining both.

q-ignorance: An agent cannot reliably know a system's configuration q before measurement.

Decoherence exclusivity: Agents gain reliable knowledge about quantum systems exclusively through decoherence along known pointer states, and so ψ is the most that they can reliably know.

Note in particular that the conjunction of **decoherence exclusivity** and **reliability** directly entails state supervenience. **Decoherence exclusivity** also entails **q-ignorance**, but the conjunction of **q-ignorance** and **reliability** only entails state supervenience if we further assume that there is nothing else (other than ψ and q) for a rational agent's preferences to depend upon.

With these principles in hand, Steeger then goes on to consider Everettian justifications for state supervenience, and argues that the best Everettian defence of state supervenience also goes via **decoherence exclusivity**. This is supposed to establish parity between the Bohmian and Everettian justifications of state supervenience. Finally, Steeger uses state supervenience to present an explicit Bohmian analogue of the Deutsch-Wallace theorem.

4 Analysis of Steeger's argument

4.1 Operationalism vs. functionalism

My first point concerns Steeger's (2022) characterisation of the intended status of the PP in the context of the DW theorem, as an "operational definition of chance." To get clear on what is wrong with this, it is helpful to recall the general ideas of operationalism and functionalism about some X:

Operationalism about X: Articulate a procedure which can, in principle, be carried out empirically, for obtaining X.[3] Define X to be whatever is obtained from this procedure.

Functionalism about X: Identify the role which X is supposed to satisfy. Define X to be whatever it is that satisfies that role.[4]

But it should now be clear from §2.1 that the PP is invoked in the DW approach not as an operational procedure, but a functional definition. The operational part of the DW approach comes earlier—in the definition of credences.

Of course, this could be merely a terminological mistake on Steeger's part. But at least in this case, the difference matters. In particular, it matters for Steeger's insistence on **reliability** (we will return to this point again in §4.3).

[3]I am intending this definition to be broad enough to capture e.g. Savage-style operationalism about credences, in which we don't have to actually carry out the procedure empirically. My characterisation of operationalism is therefore weaker than e.g. Bridgman-style operationalism (Bridgman 1927).

[4]Note that I am eliding the distinction between so-called 'role functionalism' and 'realiser functionalism' here, but this distinction won't matter for what follows.

It is (perhaps!—though again see below in §4.3) possible to see how **reliability** might follow if the PP is understood as defining an operational procedure for determining the chances; in that case, one might reasonably demand, as a precondition for being able to carry out this operational procedure, that the background information that features in the PP is the sort of information that is reliably accessible to realistic agents. However, this is altogether less clear if the PP is a functional definition of chance. In that case, the functional role articulated for chance by the PP is at least *prima facie* independent of what background information realistic agents might have access to, since the information that agents can conditionalise on is not limited to the information they might happen to know, or even be capable of knowing.

In any case, going forward we can charitably assume that Steeger was equivocating between operationalism and functionalism in their discussion of the role of the PP in the DW derivation, and that the correct way to understand the PP is as a functional definition of chance.

4.2 Being precise about state supervenience

The next point has to do with Steeger's characterisation of state supervenience. Steeger introduces state supervenience as the principle that "the chances supervene on the wavefunction ψ". (Again, it may seem as if I am splitting hairs over terminological issues here, but the importance of this point will become obvious in the following section.) To get clearer on what is wrong with this characterisation, let's recall how Wallace (2010, 2012) defines state supervenience:

State supervenience: 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 whose prefers U to V given that the initial state is ψ should also prefer U' to V' given that the initial state is ψ'.

Now, it is true that **state supervenience**, alongside the other rationality and richness axioms, and the PP as a functional definition of chance, *entails* that the chances supervene on the wavefunction—and one might charitably read Steeger's formulation of state supervenience in this way. However, the difference between these two formulations will matter later, when we consider how state supervenience is justified in EQM.

4.3 Admissibility, conditionalisation, and knowledge

We have seen that Steeger's argument that the Bohmian can justify state supervenience via decoherence exclusivity relies crucially on the acceptance of **reliability**. Steeger themself offers little in the way of an explicit defence of this principle, stating only that:

> On the operational approach, it is crucial that B only includes information that agents can reliably access. As long as it does, agents can increase their credence in the right theory T by updating. (Steeger 2022, p. 97)

Steeger then goes on to use the PP to present the standard (see e.g. Lewis (1986) and Wallace (2012)) Bayesian reconstruction of relative frequency-to-chance inferences for iid trials, all of which are supposed to 'satisfy' some background information B.

These remarks suggest two distinct ways of reconstructing the kind of justification for **reliability** which Steeger has in mind. On the one hand, one might read Steeger as claiming that **reliability** can be motivated by the general operationalist-cum-functionalist strategy; that agents can then use the PP to make the 'right' frequency-to-chance inferences is in some sense a corollary of this. On the other hand, one might read Steeger as arguing in this passage that without the restriction on B imposed by **reliability**, agents will be unable to make the 'right' frequency-to-chance inferences. I will now consider each of these in turn.

Beginning with the first: how might **reliability** be motivated by the general operationalist-cum-functionalist strategy? *Prima facie*, one might attempt to flesh this out as follows:

> Suppose that we are defining chance via the PP, and we are defining credences operationally. Then in order to operationally determine how agents will order their preferences if they conditionalise on the proposition that P, P must be a proposition that realistic agents are in a position to reliably know. This justifies **reliability**, since the only background beliefs which are relevant for determining whether something satisfies the chance role articulated by the PP are those propositions which agents can reliably know.

The problem with this is that the PP says nothing about belief (much less knowledge, or 'reliable' knowledge!)—it is a statement about conditionalisation. Facts about the credences of agents conditional on some proposition P are importantly distinct from facts about the credences of agents who believe that P. (In fact, all this talk of full belief/disbelief is rather difficult to square with our present framework; fortunately, it suffices for our purposes here to assume that full belief/disbelief can be spelled out in terms of agents having a sufficiently high/low credence that P.) In particular, it is *not* the case that an agent must believe that P in order for there to be a well-defined fact about their credences conditional on the proposition that P.[5]

Turning now to the second: is it the case that agents who conditionalise on (otherwise admissible) background information which fails to satisfy **reliability** will make the wrong frequency-to-chance inferences? To see why one might think this, it is helpful to consider an example. Let T be de Broglie-Bohm theory, let B_q be the proposition that the initial configuration of the system on each run of the experiment is q, B_ψ be the proposition that the initial wavefunction of the system is ψ, and let E_M be the proposition that outcome O is observed in M

[5] This is perhaps most obvious if we consider the fact that it is possible to operationalise conditional credences *directly*, e.g. via betting behaviour operationalisations. See also Wallace's (2012) 'Everettian epistemic theorem' for a detailed account of the operationalisation of conditional credences in case of EQM.

out of N runs of the same experiment. Given **q-ignorance**, B_q fails to satisfy **reliability**. But $T \wedge B_q \wedge B_\psi$ entails either that E_N or E_0 (why? Because we are assuming that the initial corpuscle configuration is the same on each run of the experiment.) So for sufficiently large N, and $0 < M < N$, a rational agent's credence $Cr(T|E_M, B_q, B_\psi)$ will become very close to zero, even if the relative frequency M/N well approximates Born rule statistics.

This, I submit, is the right result. Indeed, it had better be right, given the Bohmian story about how observations of non-extremal relative frequencies come about. Recall that in a Bohmian universe, observations of non-extremal relative frequencies for N runs of the same experiment (where the wavefunction of the system is the same on each run) entail that the initial corpuscle configuration cannot have been the same on each run of the experiment. So the problem here is *not* that the proposition B_q is inadmissible; it is simply the 'wrong' background information. And that the ability of agents to increase their credence in the 'right' theory depends on their choice of background information in this way was already well known from philosophy of science.

Moreover, the solution (such as there is!) to this problem is also well known from philosophy of science: it is just to notice that background information can *also* be subject to empirical (dis)confirmation. In particular, since $T \wedge B_q \wedge B_\psi$ entails either that E_N or E_0, a rational agent's credence $Cr(B_q|T, E_M, B_\psi)$ will also be be very close to zero for sufficiently large N and $0 < M < N$. Meanwhile, if we replace B_q with the proposition B_{QE} that the distribution of initial particle configurations across the N runs of the experiment is well-approximated by the quantum equilibrium distribution, then when E_M is in agreement with Born rule statistics, agents will be able to increase their conditional credence $Cr(T|E_M, B_{QE}, B_\psi)$. As such, this second reconstruction of Steeger's justification of **reliability** does not seem very promising either.

This also points to a more general problem with **reliability** for the Bohmian. In de Broglie-Bohm theory, the corpuscle configuration is generally taken (by Bohmians and non-Bohmians alike) to be absolutely central to the theory. In particular, it is facts about the initial corpuscle configuration which are supposed to explain why one outcome is observed in a given QM experiment rather than any other; it is facts about distribution of initial corpuscle configurations over different runs of the experiment which are supposed to explain the observed relative frequencies; moreover, we are supposed to be able to gain epistemic access to facts about the approximate initial corpuscle configuration of some experimental setup via QM experiments. If I ask why, according to de Broglie-Bohm theory, did I observe a particle detection event here rather than there, the answer is supposed to be: because the initial corpuscle configuration was approximately such-and-such. Conversely, non-Bohmians often focus their efforts on arguing that the corpuscles are not central to the theory in this way—that they are mere 'epiphenomenal pointers' as it were (see e.g. Brown (2010), Brown and Wallace (2005), Deutsch (1996), Wallace (2005), and Zeh (1999)).

But now observe that, for any of this Bohmian story about the explanation of experimental outcomes to go though, it is crucial that facts about the corpuscle configuration can count as admissible background information in the PP. To see this, suppose that an agent wishes to update their credence (density) in the proposition that the initial corpuscle configuration in some experimental setup is q, conditional on the outcome O of the experiment and the initial wavefunction ψ. Application of Bayes' rule yields

$$Cr(q|T,O,\psi) = \frac{Cr(O|T,q,\psi)Cr(q|T,\psi)}{Cr(O|T,\psi)}.$$

Now, iff q counts as admissible background information in the PP, then we can write $Cr(O|T,q,\psi) = Ch(O|T,q,\psi)$, which will then be zero outside some compactly supported region (and 1 inside it). Thus experimental outcomes give us approximate information about initial corpuscle configurations. Conversely, if propositions about the corpuscle configuration do not count as admissible, then we cannot apply this reasoning, since there will only be initial data about the wavefunction to input into the dynamics of de Broglie-Bohm theory. In this case, the Bohmian corpuscles would indeed seem to be reduced to mere epiphenomenal pointers (because propositions about the corpuscle configuration can then do no work in explaining why we observe one experimental outcome rather than any other—which is, to reiterate, precisely what the point of the corpuscle configuration was supposed to be).[6]

Of course, Steeger is absolutely right that not just any proposition will do for admissible background information. The proposition that E occurred (or failed to occur), for example, cannot count as admissible if the PP is to be consistent. But Steeger has as yet given us no compelling reasons to accept that **reliability** is the correct way to flesh out this restriction on admissible background information; moreover, I have argued that from the point of view of de Broglie-Bohm theory, it is crucial that **reliability** is not the correct way to flesh out this restriction.

Not only this, but there are general reasons for thinking that **reliability** cannot be the correct way to flesh this out. For this, it is instructive to recall what Lewis (1986) says about admissible background information. Lewis stipulates that historical propositions are always admissible—in his words "every little detail [of the past]—no matter how hard they might be to discover". This has the intuitively plausible consequence that there are no fundamental chances in a deterministic, one world universe. So insofar as we are defining chance via the PP, and insofar as Lewis's discussion of admissibility seems to capture our idea of what chance is, **reliability** is too stringent a restriction on background information. In a deterministic coin toss, for example, I might be reliably ignorant of the exact microphysics of the coin, or its precise initial conditions when it leaves my hand, but nevertheless, if I were to know those facts, it seems right that my credence that the coin will land heads should be zero or one.

[6] Note that this same point applies for Bohmians who don't think the wavefunction is real to begin with.

4.4 Reliability and EQM?

Thus far, I have argued that (a) Steeger's proposed justification for **reliability** fails, and that (b) there are compelling independent reasons, both from the point of view of the Bohmian and more generally, for not adopting **reliability**. Without **reliability**, Steeger's attempt to co-opt the Deutsch-Wallace theorem for the Bohmian does not succeed. However, Steeger also argues that the Everettian must also make use of **reliability** and **decoherence exclusivity** (or something very much like them) in order to secure **state supervenience**, at least on a charitable Everettian theory of reference. If correct, this leaves the Everettian in much the same position as the Bohmian after all.

Let's begin by unpacking Steeger's argument for this claim. The starting point for Steeger's analysis here is Wallace's (2012) and Saunders' (2010) discussions of semantics for agents in an Everettian universe. On the maximally-deflationary Hydra view, branching Everettian agents are identified with all their successors. This means that facts about the identities of Everettian agents (as picked out by e.g. indexicals) supervene on facts about the QM state. This view, Steeger suggests, might offer a good justification for state supervenience—ψ encompasses all the facts their are, including facts about the diachronic identities of agents—but does not vindicate talk of agents' uncertainty. Steeger then goes on to consider two alternative semantic strategies—the divergence and overlap views—on which agents are confined to only one branch, and which are supposed to introduce self-locating uncertainty. Since the divergence and overlap views introduce facts about the branch-dependent identities of agents, the divergence or overlap Everettian needs to explain why these facts don't pose a problem for **state supervenience**. *Prima facie*, one might think that the divergence or overlap Everettian can still justify **state supervenience** on the basis that, prior to branching, Everettian agents are ignorant of the identity of their branch. But Steeger argues against this idea as follows:

> Does self-ignorance [the claim that agents cannot reliably know the identity of their branch prior to branching] follow from the semantics alone? It might seem so, at first glance. After all, on both the divergence and overlap views, worms are spatially and temporally coincident—and so at least dynamically identical—before branching. But this observation alone does not imply self-ignorance on either view. For divergence, suppose that, say, my chair and the corresponding chair-wise arrangement of atoms are numerically two objects. These objects are spatially and temporally coincident, and they evolve the same way in time. But I see both, and I am clear on which is which. For overlap, suppose one version of me decides to remove my chair's armrests. Another decides otherwise. There is numerically one chair before the time my second self removes the armrests and two afterward. At the moment I make my decision, I am quite clear on which of the two future chairs is mine—even though there is numerically one chair at that moment! So in either case: why should a lack of dynamical difference before branching

limit agents' knowledge? (Steeger 2022, p. 17)

What should we make of this? On the one hand, I am in agreement with Steeger that more needs to be said to explain why a lack of dynamical difference prior to branching limits the ways in which agents can individuate branches prior to branching. On the other hand, I think that Steeger's argument against the semantics-first strategy here trades on a number of important disanalogies between the Everettian case and the chair cases Steeger discusses. Exploring these analogies and disanalogies will clarify the way in which a semantics-first justification of **state supervenience** *is* available to Everettians who adopt either the divergence or overlap views.

Take Steeger's first chair example, in which we suppose that the chair and corresponding chair-wise arrangement of atoms are numerically distinct. In order to probe the analogies between this and the Everettian case more deeply, it is worth pausing to examine *why* one might think that these objects are numerically distinct. The arguments usually advanced in favour of such a view are as follows:

- The chair might have certain properties that its corresponding chair-wise arrangement of atoms lacks (perhaps the chair, but not the chair-wise arrangement of atoms, could be the object of aesthetic appreciation).
- The chair might have different persistence conditions from its corresponding chair-wise arrangement of atoms. For example, maybe the chair would not survive being taken apart and made into a desk, but the collection of atoms which comprise it would.
- Related to the above, the chair might have different modal properties from its corresponding chair-wise arrangement of atoms (e.g. being able to survive being taken apart).

So in each case, the difference between the chair and the corresponding chair-wise arrangement of atoms is to do with a difference in the properties they have. To what extent does this apply to branching agents in an Everettian universe—or equivalently, what properties are there which could invididuate divergent branches prior to branching?

Of course, there is the obvious: divergent branches differ in their properties regarding the outcomes of future QM experiments on that branch. But this, I submit, is where the analogy ends. To reiterate, worms are dynamically identical prior to branching. So, for example, branching objects in an Everettian universe are presumably of the same type prior to branching, and therefore have the same persistence conditions (unless object type depends on the outcomes of future QM experiments, in which case we are back to the first point). Likewise for aesthetic or modal properties. Put somewhat differently, the only properties of diverging branches which differ prior to branching are those which relate, covertly or overtly, to the outcomes of future QM experiments on that branch.[7]

[7] Compare Lewis (1986): "If our world and another are alike point for point, atom for atom,

With this in mind, consider now Steeger's second example, in which one version of themself decides to remove the chair's armrests and another decides otherwise. Here, the relevant difference has to do with the fact that the agents in question have different brain states before the chair branches, and since these brain states encode information about future differences between the two chairs, therefore have access to facts about the identity of their chair. But this has no analogue in the Everettian case. After all, prior to branching, overlapping agents will have the same brain state (they are quantum systems, after all, and by assumption, they haven't branched yet). So, given this, there is no way in which divergent Everettian agents could have differing beliefs about the outcomes of future QM experiments on their branches prior to branching; moreover, an agent who conditionalises on EQM being true will behave as if there is no difference between their brain state and those of their divergent counterparts prior to branching. The analogy fails.

There are two morals to be drawn from all this. First, there is one about the ways in which agents can individuate branches prior to branching:

Individuation: Prior to branching, agents can only individuate branches indexically or by specifying information about the outcomes of future QM experiments on that branch.

Second, there is one about the limitations on decision strategies for Everettian agents:

Branch independence: Prior to branching, divergent or overlapping Everettian agents cannot have branch-dependent decision strategies, since they are dynamically identical to one another.

To reiterate, both **individuation** and **branch independence** can be defended on the basis that branches are dynamically identical prior to branching, once we pay proper attention to the fact that Everettian agents (including their decision strategies!) are themselves quantum systems. Given that Steeger accepts this, they ought to accept **individuation** and **branch independence**. But, I claim, Wallace's original statement of **state supervenience** is entailed by **branch independence** on either the divergence or overlap views, since once we take the branch-dependent identities of agents out of the equation, the only thing left for the preferences of agents in an Everettian universe to depend on is ψ.

As for Steeger's definition of state supervenience, this is entailed by **individuation**. Recall that admissible background information in the PP must exclude propositions concerning whether E occured. So if the only way that agents can individuate branches prior to branching is indexically, or by specifying the outcomes of future QM experiments on that branch, then the only propositions which concern the identity of an agent's branch, and therefore could possibly allow for violations of state supervenience, are either inadmissible or uninformative. If they are purely indexical 'this is my branch' then they are uninformative.

field for field, even spirit for spirit (if such there be) throughout the past and up until noon today, then any proposition that distinguishes the two cannot be entirely about the respects in which there is no difference."

If they concern the outcomes of future QM experiments on that branch, then they are inadmissible. Mixed cases are also inadmissible.

Moreover, there is no analogue of these principles available to the Bohmian. For the first, Bohmian agents are always free to individuate possible histories by specifying the corpuscle configuration at any past time; for the second, there is no dynamical constraint which prevents Bohmian agents' preferences from depending on the future outcomes of QM experiments (since *ex hypothesi* there is only one such agent. Indeed, allowing their preferences to depend on the corpuscle configuration would be entirely rational—after all, it is the corpuscle configuration which determines which future outcomes will happen!

5 Epistemic probabilities, or: what Steeger should have said instead

Thus far, I have critiqued Steeger's argument that the DW derivation of Born rule chance values is also available to the Bohmian. I now want to end, somewhat more positively, with the fact that there is a close cousin of Steeger's argument which *is* available to the Bohmian. After all, Steeger has shown that, given **reliability** and **q-ignorance**, Bohmians also can have **state supervenience**. The relevant question is then: what kind of probabilities are there for which **reliability** is the correct way to flesh out the restriction on background information in the PP?

Such a notion of probability has recently been articulated by Myrvold (2021). Suppose we have a system S, and a dynamical map T_t on its state space. Suppose we are given a class of reasonable credence functions $\mathcal{C}_t$ that an agent might have about the state of S system at t, and, moreover, suppose we are given a threshold ε below which differences in these credence functions are taken not to matter. Let P be any proposition about the state of the system at some future time t'. Then P has *epistemic chance* p at t of obtaining at t' iff every function in $\mathcal{C}_t$, when evolved to t' via T_t, is within ε of p.[8] Epistemic chances, thus defined, are supposed to satisfy the *epistemic chance principal principle* (ECPP):

ECPP: Let S be the statement that the epistemic chance of event E at time t is p, and let K be any accessible background knowledge. Then a rational agent's credence $Cr(E|S, K) = p$.

Like chances, credences conditionalised on epistemic chances are stipulated to be robust under conditionalisation on further background information. Unlike chances, however, this background information is restricted to propositions which are accessible to agents (rather than those which are admissible). So what Steeger has shown is that the epistemic chances, if defined functionally in either EQM or in de Broglie-Bohm theory, are given by the Born rule. This

[8]Note that this is just the method of arbitrary functions, but where the initial input probabilities are interpreted as reasonable initial credence functions.

allows us to clarify, and expand upon, Steeger's claims about the applicability and import of the DW theorem, in two ways.

First, if the arguments of the preceding section are right, then there is still a significant difference between Born rule probabilities in EQM and de Broglie-Bohm theory (or indeed, other one-world interpretations of QM to which the DW theorem might find applicability). In EQM, the DW theorem is a derivation of chance values (that is, the thing which features in the PP), whereas in de Broglie-Bohm theory, the DW theorem could only be a derivation of epistemic chance values (that is, the thing which features in the ECPP). Now, that still might be an important achievement for de Broglie-Bohm theory—for more on which, see below. But at the very least, this clarifies the sense in which the DW theorem might be said to establish EQM, but not de Broglie-Bohm theory, as a genuinely chancy theory.

Secondly, conceiving of Steeger's result as a derivation of Bohmian epistemic chance values brings out more clearly the ways in which this approach might be fruitfully combined with the approaches of Dürr et al. (1995) (DGZ) and Valentini (1991a,b), from whom Steeger (2022, pp. 22-23) sees their work as largely distinct. Very roughly, DGZ seek to explain Born rule statistics by performing a 'typicality' analysis on effective subsystem wavefunctions—showing that, if the initial configuration q is chosen at random with respect to the Born rule measure, then for the overwhelming majority of such q, the effective wavefunctions of isolated subsystems will be in agreement with the quantum equilibrium distribution. Valentini (1991a,b), on the other hand, seeks to show that the quantum equilibrium distribution can be obtained as a relaxation via the dynamics from *any* reasonable (i.e. sufficiently smooth, simply-expressible) initial distribution via a process of coarse graining, in a result he calls the sub-quantum H theorem. Alternatively, as Norsen (2018) points out, we can understand the Valentini sub-quantum H theorem as extending the result of DGZ to show that, for any reasonable typicality measure over initial corpuscle configurations, we should expect to see Born rule statistics at later times.

Now suppose, following Myrvold (2021), that we take the input typicality measures in the DGZ and Valentini derivations to be reasonable initial credence functions. Combined with Steeger's approach, this would yield a Bohmian *derivation* of the ECPP—the DGZ/Valentini-style approaches establish that given any reasonable initial credence function about the corpuscle configuration, these converge under the dynamics to the Born rule, giving the Born rule as an epistemic chance; Steeger's approach then establishes that it is rational for agents to align their credences with such epistemic chances, conditional on de Broglie-Bohm theory being true. This is quite unlike the situation with the DW derivation of Born rule chance values in EQM, in which the PP is assumed, and used as a basis for assigning the chances a particular quantitative value.[9] In this way, understanding Steeger's result as properly concerning epis-

[9]Though cf. Saunders (2010) and Wallace (2012) who suggest that the DW theorem *is* an Everettian derivation of the PP. The best way I know of making sense of these claims is as saying that given the DW theorem, the PP is redundant, since if we are interested in how rational agents should distribute their credences conditional on EQM being true, we can

temic chances might seem to be a substantial philosophical advantage for the Bohmian.

6 Close: many worlds vs. one

In this paper, I have sought to clarify Steeger's argument that the DW theorem is available to the Bohmian, and have shown that, understood as a derivation of chance values—and *contra* Steeger—it is not. This vindicates Wallace's claim that, as far as Born rule chances go, there is a fundamental difference between many worlds and one: in many worlds, but not in one, is a symmetry-led derivation of chance values available.

However, in many ways, I am in broad agreement with Steeger that the interest of the DW theorem is not limited to EQM. But the *way* in which it might be of interest to one-world quantum theories is different. For example, I have argued that Steeger's application of the DW theorem to de Broglie-Bohm theory should properly be understood as a derivation of Born rule epistemic chance values. But conceiving of Steeger's result in this way does not undermine Steeger's attempt to co-opt the DW theorem for the Bohmian—indeed, I have suggested, it brings out more clearly the ways in which the DW theorem might be of interest to the Bohmian in particular. The fact that differences remain is just what is to be expected—many worlds are, after all, quite different than one.

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just go directly via the DW theorem rather than having to first apply the PP to replace the credences with chance values and then look at the theory for what the chance values are. *Deriving* the PP in EQM would require us to have antecedently established that the Everettian chances are given by the Born rule, and aside from the DW theorem, it is not obvious how else this might be achieved.

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