Centered Chance in the Everett Interpretation

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Abstract

Everettian quantum mechanics tells us that the fundamental dynamics of the universe are deterministic. So what are the 'probabilities' that the Born rule describes? One popular answer has been to treat these probabilities as rational credences. A recent alternative, Isaac Wilhelm's centered Everett Interpretation (CEI), takes the Born probabilities to be centered chances: the objective chances that some centered propositions are true. Thus, the CEI challenges the 'orthodox assumption' that fundamental physical laws concern only uncentered facts. I provide three arguments against the centered Everett Interpretation. First, I argue that the CEI is in apparent tension with a significant motivation for adopting Everettian quantum mechanics: rejecting the attribution of special significance to observers or agents in fundamental physics. I suggest the CEI can avoid this tension, but only at the cost of sacrificing its central claim that there are objective chances in an Everettian multiverse. My second argument concerns the CEI's claim that the centered Born rule is a fundamental physical law. I provide two plausible notions of fundamentality for physical laws, and I argue that the centered Born rule satisfies neither. My final argument is that the CEI's branch-relative laws cannot explain or constrain an agent's rational credences in the way that the CEI claims.

1 Introduction

Despite quantum mechanics' predictive success as a mathematical and experimental framework, it has been notoriously difficult to understand what, if anything, the world is like according to quantum mechanics. According to Everettian quantum mechanics (EQM), also known as the Many Worlds Interpretation (MWI), the fundamental dynamics of the universe are deterministic. The evolution of the universe over time is described deterministically by Schrödinger's equation. However, our best empirical evidence for quantum mechanics comes from 'probabilistic' experiments. The Born rule relates the quantum state at a time to probabilistic experimental results with respect to some observable. For a quantum state $\psi = a|A\rangle + b|B\rangle$ where a and b are normalized amplitudes such that $a^2 + b^2 = 1$, and A and B are each states associated with some observable (say, spin with respect to some axis), the probability of observing outcome A is $|a|^2$. What is really going on, according to EQM, is that a plurality of outcomes occur each time such an experiment is performed, where each outcome occurs in a distinct, causally-isolated 'branch' or 'world'.

So what are the 'probabilities' that the Born rule describes? One popular style of answer, presented by Greaves (2007a, 2007b), Deutsch (1985, 1999), and Wallace (2007, 2012), amongst others, has been to treat these probabilities as rational credences. These strategies, which we may call rationality accounts, take the Born rule to be an important predictive tool for relating the results of quantum mechanical experiments to the dynamics and ontologies of quantum theories.

More recently, Isaac Wilhelm (2022, 2023) developed an alternate account, the centered Everett Interpretation (CEI), which takes the Born rule probabilities to be centered chances: the objective chances that some centered propositions are true. As described by Wilhelm, centered chances are objective in the sense that they are genuine chances rather than measures of epistemic uncertainty.[1] Further, Wilhelm proposes that these centered chances ultimately explain and constrain one's rational credences about experimental results such that the CEI provides explanatory and rational grounds for the principles posited by the rationality accounts.[2]

Despite being an intriguing new approach to understanding probability in the Everett interpretation, I argue in this paper that proponents of Everettian quantum mechanics have reasons to reject the view as Wilhelm presents it. In section 2, I present the three components of Wilhelm's CEI: the worm view, the centered Born rule, and the best system analysis of centered chance. In section 3, I provide three arguments against the view, all of which come from an Everettian perspective.

My first argument against the CEI concerns the fact that the CEI undermines an important motivation for adopting the Everett interpretation in the first place. One of the primary motivations for adopting the Everett interpretation is that it avoids assigning any special significance to consciousness, rational agents, observers, or measurement in our fundamental physical laws. In making the centered Born rule out to be a fundamental physical law, the

[1]Wilhelm's approach seems to build on some of Alastair Wilson's work on objective probability in EQM, such as Wilson (2013).

[2]Wilhelm writes that 'centered chances are those objective, worldly states which constrain rational centered credences. Centered chances explain why some centered credences are rational while other centered credences are not' (p. 1026).

CEI reintroduces the observer into fundamental physical law. While I think that the CEI can escape this conclusion, I suggest it does so at the cost of sacrificing its central claim that there are objective chances in an Everettian multiverse. The second argument concerns the CEI's treatment of the centered Born rule as a fundamental law. I provide two candidate notions of fundamentality with respect to natural laws, and I argue that the CBR satisfies neither. My final argument concerns the practicality of endorsing the centered Born rule as a law given one's uncertainty about their location in a branching universe.

2 The Centered Everett Interpretation

In this section, I provide an overview of Wilhelm's presentation of the centered Everett Interpretation (CEI) by briefly summarizing its three main components: (i) the worm view of persistence, (ii) the centered Born rule, and (iii) the best system analysis of centered chance.

2.1 The Worm View

The 'worm view', also known as the 'Lewisian view' or 'perdurantism', holds that objects are extended temporally as well as spatially. This framework was developed in particular by David Lewis (1976; 1986). On the worm view, objects that persist through time are four-dimensional 'spacetime worms'. Rather than being wholly located at any one time, they have temporal parts (or 'stages') at times, akin to how an ordinary macroscopic object is not wholly located at a single point in space, but rather has a plurality of spatial parts occupying various locations in space. Within this framework, a worm W that exists from time t_1 to time t_n can be understood as the mereological sum of its temporal parts $p_1 + p_2 + ... + p_n$ where each p_i is the temporal part of W located at time t_i.

In the context of EQM, we can describe Everettian branches themselves, along with the persisting objects within them, as spacetime worms. Following Saunders (2010) and Wilson (2012, 2020), the CEI endorses the 'divergence' version of the worm view, which holds that such worms are not created or destroyed by branching events. Rather than being generated by branching, the divergent worm view holds that at certain times—those that occur before events that differentiate those worms' histories—many worms and branches are 'exact physical duplicates of one another' (Wilhelm (2022), p. 1023).[3]

To illustrate this, consider a spacetime worm, Sally the scientist, who performs a quantum

[3] We can also contrast the divergence picture with a view in which worms in different branches overlap—that is, share temporal parts with one another.

experiment corresponding to a branching event at time t_2. Let $Sally_B$ be the spacetime worm that exists along a single branch b. At time t_2, there is a branching event wherein the events on b differ from those on another branch, c. There is another worm, $Sally_C$ who is an exact physical duplicate of $Sally_B$ up until t_2, but who has different properties—a different history than $Sally_B$—from t_2 onward. Up until the branching event at t_2, $Sally_B$ and $Sally_C$ are physical duplicates. They both perform the same experiment, have all of the same memories and time-indexed physical properties, and so on. After t_2, $Sally_B$ and $Sally_C$ will observe different experimental outcomes.

2.2 The Centered Born Rule

The second component of the centered Everett interpretation is the centered Born rule (CBR), which states that Born rule probabilities describe the objective chances that centered propositions like 'I will observe the particle deflect upward when it is measured along its x-axis' or 'I am on one of the upward deflection branches' obtain. Wilhelm presents this formally with the equation $Ch_{E,\psi}(O_a) = |\langle a|\psi\rangle|^2$, where $Ch_{E,\psi}$ is a chance function for an agent E that some centered proposition O_a is true given the quantum state ψ. The CBR thus says that the chance that the centered proposition "I will be in the A-outcome branch" turns out true is equal to the probability that the (standard) Born rule would assign to outcome A given the quantum state prior to measurement. On the Centered Everett Interpretation, Wilhelm contends that 'Born rule probabilities are inherently agent-relative. They tell us what sorts of branches we are likely to be on, by telling us the chances that we ourselves—rather than duplicates of ourselves—will observe certain experimental outcomes' (2022, p. 1023).

It is important to note that the chances of centered propositions can differ from those of related uncentered propositions. Applying the worm view of persistence to the Everett interpretation, if an agent sets up an experiment to measure the x-spin of a particle in a z-spin eigenstate, the uncentered chance that someone—one of the agent's counterparts in some branch or other—will observe an upward x-spin result is 1. This is an uncentered fact; one counterpart will find themselves in a branch in which an upward deflection occurs while the other will find themselves in a branch where a downward deflection occurs.[4] So if we call the agent in the 'x-spin up' branch UpWorm, the chance of the uncentered proposition 'UpWorm is in one of the "x-spin up" branches' is 1. By stipulation, 'UpWorm' just is the

[4]It is more precise to say that one set of counterpart worms will find themselves in the upward deflection branches and another set will find themselves in the downward deflection branches. I use singular language rather than set-talk for illustrative simplicity and convenience, but the appropriate notions can be substituted accordingly.

name given to the agent in a particular branch that includes an 'x-spin up' outcome at that time in its history, so there is no (uncentered) chance that UpWorm could inhabit a branch other than the one that UpWorm does in fact inhabit. On the other hand, the CEI says that the centered proposition 'I am on one of the "x-spin up" branches', will have the chance that the centered Born rule implies. Following Vaidman (1998) and Sebens and Carroll (2018), this is because prior to observing the outcome of the experiment, UpWorm is subject to self-locating uncertainty: UpWorm does not know which branch it inhabits, and thereby which outcome it will observe, so prior to observing the results, UpWorm does not know that it is UpWorm rather than DownWorm.[5]

Since centered chances are agent-relative[6], the truth value of 'I am on one of the "x-spin up" branches' will differ for different individuals. That proposition will be true when uttered by individuals on the 'x-spin up' branches and false for those on the 'x-spin down' branches. Further, on this picture, centered chances will be different for some individuals than for others.

Finally, the CEI takes the CBR to be a fundamental physical law, which challenges the 'orthodox assumption' that fundamental physical laws concern only uncentered facts. Wilhelm writes that

> the fundamental physical laws include the centered Born rule. And the centered Born rule provides an account of centered facts, such as facts about what our branch is like. So the centered Everett interpretation represents a new sort of fundamental physical theory. It takes fundamental physics to be in the business of providing theories of both centered and uncentered facts. It allows for fundamental physical laws which describe centered phenomena (2022, pp. 1030-1031).

While I agree with Wilhelm that the fundamentality of the CBR would challenge this orthodox assumption, I argue in section 3.2 that the CBR does not satisfy plausible conditions for being a fundamental law. Hence, the CEI fails to undermine the assumption that fundamental physical laws concern only uncentered facts.

[5] Again, it is more precise to say that one set of worm agents will be in a set of upward-deflection branches (call this set of worms S_{UW}) and one set will be in a set of downward-deflection branches, and hence that $UpWorm_1$ does not know that it is in the set of agents that are S_{UW} until after observing the result of the experiment.

[6] As I'll discuss in my first argument against the CEI, Wilhelm thinks we can also describe them as 'world-relative', which I take to mean branch-relative (2022, p. 1026).

2.3 The Best System Analysis of Centered Chance

The third component of the CEI is the best system analysis of centered chance, first developed by Lewis (1973). Wilhelm writes that '[a] centered chance is a proposition which (i) assigns a probability to a centered proposition, and (ii) follows from the best deductive systems' (2022, p. 1026). When applied to EQM , the best system account tells us that centered chances help to summarize centered facts about one's location in the branching universe.

Since on the best system account, laws 'are theorems of those deductive systems that best balance theoretical virtues like simplicity, strength, and fit', the CEI regards the centered Born rule (CBR) as a physical law (2022, p. 1026). According to the CEI, the centered facts that the CBR summarizes are the experimental outcome frequencies that occur in a branch, and for this reason Wilhelm states that the CBR will accurately capture the centered facts on some branches but not others.[7] Thus, the CEI holds that some physical laws can be branch-relative, just like centered chances.

So the objective chances the CBR describes are ultimately determined by the frequencies of experimental outcomes within a branch: the 'chance' that I observe outcome A for experiment X in my branch b is simply a summary of the relative frequencies of A outcomes for X in b. If the frequency of A outcomes relative to other outcomes for X in b is 1/2, then the CEI says that the objective chance that I observe A when I perform X is 1/2. In another branch $b*$—one we can call an 'unlucky branch' where A occurs only 1/4 of the time that someone performs X—the relative frequencies of outcomes for X will be different, and thus different objective chances will hold for inhabitants of $b*$. Importantly, the CEI purports that these centered chances ultimately explain and constrain one's rational credences concerning the Born rule probabilities, and hence provide ground for the existing rationalist approaches to Everettian probability.[8]

3 Against the CEI

With an overview of the centered Everett Interpretation in place, I turn to three arguments against the view.

[7] Wilhelm writes that 'on our branch, the centered chances in the centered Born rule correctly capture the frequency facts. For us, the Born rule probabilities get the frequency facts right' (2022, p. 1027).

[8] Wilhelm writes that 'centered chances are those objective, worldly states which constrain rational centered credences. Centered chances explain why some centered credences are rational while other centered credences are not' (2022, p. 1026).

3.1 Undermining Everett or Losing Chance

A *prima facie* objection to the CEI is that it is in tension with one of the primary motivations for adopting the Everett interpretation in the first place: that the Everett interpretation avoids assigning any special significance to consciousness, rational agents, observers, or measurement in our fundamental physical laws.[9] In making the centered Born rule out to be a physical law, the CEI appears to reintroduce special significance to the observer in physical laws. This is because the chance function $Ch_{E,\psi}$ in the centered Born rule is defined in terms of some agent, E. As initially presented, the CBR thus appears to designate a special role for agents in fundamental physics. This reintroduction is likely to be objectionable to Everettians on the grounds that it is contrary to the motivations for adopting the Everett interpretation, along with any other realist solutions to the measurement problem. Adopting a realist interpretation of quantum mechanics comes at a cost. In the case of EQM, one avoids assigning any fundamental importance to 'measurement' or 'observers' by granting that superpositions never collapse, which gives rise to a strange and unintuitive picture of the world as consisting in (perhaps uncountably) many branches, a multiplicity of outcomes when an experiment is performed, and so on.[10] Replacing wave function collapse with multiplicity generates worries about ontological bloat, the coherence of using probabilistic principles, and experimental (dis)confirmation.[11] Why take on these costs if one is happy to allow that observers play a role in fundamental physical laws?

Wilhelm responds to this worry by claiming that the chance function in the CBR can be relativized to branches rather than agents.[12] Since the CEI describes individual agents as four-dimensional subregions of branches, it seems natural that much of the agent talk can be translated into branch terms. After all, recall that by way of the best system analysis of centered chance, it is the properties of the branch—in particular, the relative frequencies of experimental outcomes that obtain within that branch—rather than the properties of a particular agent (such as that agent's credences) that set the centered chances. The upshot is that we can determine what the centered chances are for some branch—and by extension,

[9]Avoiding assigning this sort of special significance is not unique to Everettian quantum mechanics, but is a motivation shared by the realist approaches to quantum mechanics. See for instance, Bell (1990).

[10]For instance, DeWitt (1970) wrote, 'I still recall vividly the shock I experienced on first encountering this multiworld concept. The idea of 10^{100} slightly imperfect copies of oneself all constantly splitting into further copies, which ultimately become unrecognizable, is not easy to reconcile with common sense. Here is schizophrenia with a vengeance' (p.161).

[11]See, for example Greaves (2007b) for discussion of the 'incoherence problem' for Everettian probability and Adlam (2014) and Chapter 8 of Albert (2015) for discussion of confirmation and disconfirmation in EQM.

[12]Wilhelm writes that, 'I stipulated that E is an individual. But E could be an entire world instead. So the chance function invoked in the centered Born rule can be relativized to either individuals or worlds' (2022, p. 1026).

for some agent in that branch—by appealing only to facts about that branch, for example, that the frequency of $\uparrow_z$ outcomes relative to $\downarrow_z$ outcomes is two-to-one in that branch.

While the fact that we can relativize branches to non-agential centers seems to rescue the CEI from the the undermining worry, I think that the shift from agents to branches themselves also appears to dissolve anything like chance. Let me make this more precise. I do not mean to say that making a branch (or something else non-agential) rather than an agent the indexical center for some proposition is what gets rid of the chanciness. After all, questions like 'will this coin's next flip be heads or tails?', 'which branch is this one?', or 'which branch does this chair inhabit?' appear perfectly coherent. But when we remove uncertainty—a feature of agents or observers—it is unclear that chance remains in EQM, and by extension, the CEI, in anything but name. Recall that when we apply the divergent worm view to EQM, there is a determinate fact of the matter about what outcome will occur relative to any center, whether it be an agent, a branch, or a particular chair. The in-branch outcomes, and thereby frequencies of outcomes, are set deterministically by the evolution of the quantum state according to Schrödinger's equation. While an agent will not know which history in the set of exact physical duplicate histories is the one corresponding to 'this branch' or 'this chair', there seems to be nothing chancy going on, beyond my epistemic uncertainty, when it comes to the frequencies themselves. If I could somehow know which worm I am (or equivalently, which branch I am on), I could in principle know not only the relative frequencies along my branch, but also the ordered set of outcomes.

Consider what it would be like if I had this information. Given (i) the deterministic evolution of the multiverse, and (ii) my location within its structure, I know precisely what the outcome will be. Further, I know that holding all of these facts fixed, the outcome could not have been otherwise. So if you were to ask me what the chance is that I am on a branch where the next x-spin measurement yields x-up, I would be inclined to say '1' or '0', depending on what the next outcome, relative to me, is. Would I instead reply '$\frac{1}{2}$', since I also know that the relative frequency of x-up outcomes relative to x-down outcomes on my branch is so? I don't think so. After all, we generally appeal to relative frequencies when, and because, we do not know what the ordered set of outcomes will be—when the actual string of outcomes is epistemically inaccessible, and thus epistemically chancy. It would seem quite strange for me to say, 'I know, as a matter of fact, that the next result will be x-up, but the chance that the next result will be x-up is $\frac{1}{2}$'.

I think that the central issue here—and what makes the Everettian universe appear to have genuine objective chances—is that, according to standard EQM, the outcomes within my branch are not fully determined by the previous state of affairs within my branch. Rather, what determines the subsequent state in my branch (and those that diverge from it) is the quantum state prior to branching. So looking only at the facts in my branch at t_1 prior to the experiment, there is nothing about those in-branch facts that is sufficient to determine which outcome x-up or x-down will occur at t_2 when the measurement is performed. In this sense, the evolution from one branch-relative state to the next is (epistemically) indeterministic. But this does not mean that EQM is indeterministic. It just means that the in-branch facts alone are insufficient to predict future in-branch facts. In EQM, it is the multiplicity (of branches, outcomes, and so on) that explains the apparent indeterminism and epistemic chanciness. But this multiplicity only arises when taking a plurality of branches into account; it is not something found within a particular branch.

One may here object that even if the universe is genuinely probabilistic, things will appear 'fixed' from the God's-eye-view. In other words, even if something like a genuinely stochastic collapse theory like Ghirardi, Rimini, and Weber (1986)'s or orthodox quantum mechanics, is true, then with knowledge of the entire four-dimensional spacetime manifold, I would be able to say, at t_1 prior to performing an experiment, that x-up will occur rather than x-down at t_2. Of course, having God's knowledge would not entail that the process by which the state of the world at t_1 evolved into the state at t_2 was deterministic rather than chancy. God could have rolled (genuinely stochastic) dice.

However, this scenario is disanalogous to EQM. For in the case of genuine stochasticity, despite my prescient knowledge of what outcome occurs at t_2 there is no principle or law to which I could appeal, given the state at t_1, that would tell me that the particular outcome of x-up would follow at t_2. On the other hand, I could make such a prediction in the context of EQM. At t_1, I would be able to predict that the world would evolve deterministically, such that at t_2, x-up would occur in the $|\uparrow_x\rangle$ branches and x-down would occur in the $|\downarrow_x\rangle$ branches. This may seem unsatisfying, since my knowledge (of this uncentered fact) does not tell me why (or that) it is I in particular who will observe x-up rather than x-down, or analogously, why I discover after the measurement that I live in one of the $|\uparrow_x\rangle$ branches rather than in the $|\downarrow_x\rangle$ ones.

But this sort of worry misses the forest for the branches. Moreover, it appears to presuppose that I have some property of primitive 'thisness' or haecceity. Taking EQM, along with the worm view and the CEI's humeanism about laws seriously, asking why I find myself in one of the $|\uparrow_x\rangle$ branches is akin to asking why I was born in the 20^{th} century rather than the 5^{th}.[13] We can talk about someone with many similarities (psychological, physical,

[13] One might wish to answer the 'why I was born in the 20^{th} century rather than the 5^{th}?' by appealing to the frequencies of human births relative to different centuries. After all, many more humans were born in the 20^{th} century than the 5^{th}, so there is a sense in which I, being a human, am more 'more likely' to have been born in the 20^{th} century rather than the 5^{th}. The analogous case for EQM would go something like this.

and otherwise) to me who could have been born in the 5^{th} century (or is in fact born in the 5^{th} century in some nearby possible world). But that is not *me*; that person is merely my counterpart in many relevant contexts. On the divergent worm view, it is sufficient to individuate me from my counterparts (here, my exact physical duplicates) without positing haecceitistic properties. The fact that some property on my branch differs from some on their branch is enough.[14]

In closing my first argument against the CEI, the reader may be struck by the thought that my reasoning over the last few pages amounts to a rejection of objective chance. Perhaps this is the case, but with a qualifier. If I have rejected objective chance, I hope to have at least made clear that it is because I take objective chance and EQM to be uneasy bedfellows; I don't wish to suggest that there is anything implausible about the notion of objective chance on its own. If the reader is unsympathetic, I encourage them to proceed to my next two arguments, which do not hinge on whether there are objective chances in EQM.

3.2 The Fundamentality of Branch-Relative Laws

My second argument against the CEI is that if one endorses EQM, the centered Born rule is not in fact a fundamental physical law. This is not to say that Everettians must reject Wilhelm's claim that there can be such a thing as branch-relative laws—if one has the humean intuition that laws as mere descriptions of regularities, then one can give descriptions of regularities indexed to particular branches much like one can give descriptions of regularities indexed to particular places or times. But I do think that there is a tension between the typical Everett picture and the CEI's assertion that the branch-relative laws are 'fundamental' laws.

Why does it matter whether branch-relative laws are fundamental? Recall that in making branch-relative laws like the centered Born rule, which relate centered chances to the quantum state, the CEI challenges the 'orthodox assumption' that fundamental laws of physics concern only uncentered facts. If branch-relative laws turn out not to be fundamental, then

Why do I find myself observing relative frequencies that align with the Born rule rather than some other branch-dependent law? Because the branches on which the relative frequencies of experimental outcomes align with the Born rule vastly outnumber (or vastly 'outweigh') those in which the relative frequencies are otherwise. But notice that this sort of explanation is given in terms of facts about the 'global' structure of the Everettian universe, rather than the branch-relative facts that yield the CEI's (branch-relative) centered chances and laws.

[14] Rejecting this would either involve a rejection of (i) humeanism, or (ii) the bijection between sets of worms and sets of branches. Rejecting (i) forfeits a primary motivation for adopting the best system analysis of lawhood. Rejecting (ii) in favor of a view in which a single worm may occupy a plurality of branches entails that there is no unique fact of the matter about whether some branch-relative Humean law L — a law like the CBR, for instance — is true for W, since W can inhabit both branches where L holds and branches where L does not.

the orthodox assumption remains unscathed.

In laying out the CEI, Wilhelm does not give an account of what he means by fundamentality with respect to laws. In light of this, here are two plausible candidates for what counts as a fundamental law. A 'fundamental law' is either (i) a law that either concerns ontologically fundamental entities, or (ii) a law that is explanatorily fundamental. In what follows, I will explain each candidate notion, and I will argue that the CBR and other branch-relative laws satisfy neither.

With respect to ontological fundamentality, we could say that a law is fundamental when it describes regularities concerning the ontologically primitive entities, or entities that are ontologically primitive with respect to the framework or theory under consideration.[15] For example, consider the wave function realist view as presented by Albert (1996) and Ney (2021), which takes the fundamental ontology of the world to be a universal wave function in a high-dimensional space.[16] On this view, Schrödinger's equation, which describes the evolution of this wave function, is a fundamental law, in the sense that it is a law that describes the evolution of the fundamental ontology. Now, let us examine whether the CBR and other branch-relative laws of the CEI satisfy this notion of fundamental lawhood.

According to standard EQM, the branches of EQM are not ontologically fundamental. The typical Everettian attitude toward branches is that they are emergent structures used to describe the wave-function's evolution into the sorts of semi-classical states that are familiar to us in day-to-day life. Moreover, there is no non-arbitrary carving of the fundamental ontology into branches: discretizing the fundamental ontology into branches is a matter of choice of grain. Wallace (2012) describes this aptly when he writes

> Decoherence causes the Universe to develop an emergent branching structure. The existence of this branching structure is a robust (albeit emergent) feature of reality; so is the mod-squared amplitude for any *macroscopically described* history. But there is *no* non-arbitrary decomposition of macroscopically-defined histories into 'finest-grained' histories, and *no* non-arbitrary way of counting those histories (p. 102).

If branches are ontologically derivative rather than fundamental, then laws that are mere descriptions of regularities concerning these derivative entities will not count as fundamental in the relevant sense.

[15] I add the second clause primarily to accommodate the possibilities (i) that there is no 'bottom level' to reality, and (ii) that even if there is a rock bottom, our current best scientific theories (like quantum mechanics) may not be descriptions of rock bottom.

[16] See also Ney and Albert (2013).

Further, there is a worry that since branch individuation is contingent upon one's choice of grain, making the CBR and related branch-dependent laws fundamental would entail that fundamental physical laws may be arbitrary (at best) and metaphysically indeterminate (at worst). Glick and Le Bihan (2024) note that treating branches as fundamental rather than ontologically reducible opens the door for fundamental metaphysical indeterminacy with respect to both branch nature and branch number, but note that the Everettian can avoid indeterminacy by taking a deflationary attitude (either reductive or eliminative) toward branches.

What of explanatory fundamentality? We can say that a law is explanatorily fundamental if that law cannot be reduced to or explained in terms of other, more general principles.[17] Again, the CBR relates the relative frequencies of outcomes in a branch—what Wilhelm calls objective chances—to the probabilities given by the Born rule, and the Born rule relates the quantum state to observed experimental outcomes. The first concern to once again highlight is that most Everettians do not take the Born rule to be an explanatorily fundamental law, but rather something that follows from more basic theoretical posits. While there is not yet a consensus on this regard, many philosophers and physicists (Everettian or otherwise) have attempted to derive the Born rule from other principles, suggesting that there is at the very least longstanding discomfort with the idea that the Born rule is a fundamental law.[18]

Of course, longstanding discomfort and derivations of questionable success are insufficient to demonstrate the explanatory non-fundamentality of the Born rule and the CBR. What is more suggestive of the CBR's explanatory non-fundamentality is that the CBR appears to tell us very little on its own; predictively and explanatorily useful descriptions of quantum mechanical experiments must appeal to what is happening outside of a particular branch. In the Everett picture, the quantum state $|\psi\rangle$ in the standard Born rule is a state that cannot be localized to a single branch, since in describing a superposition, $|\psi\rangle$ contains macroscopic states of affairs in a plurality of branches. The CBR relates the quantum state to macroscopic states by way of the standard Born rule. Everettians regard in-branch macroscopic states as emergent features deriving from the holistic quantum state, where the macroscopic outcomes that occur in individual branches are explained in terms of the holistic evolution of the quantum state. The Everettian explanation for why outcome 'x-spin up' happens in branch $b_\uparrow$, after a 'z-spin up' particle is measured along its x-axis is that there is a region of the quantum state corresponding to 'x-spin up' and another region corresponding to 'x-spin down'. As decoherence occurs, these two regions function as causally isolated semi-classical

[17] I am thinking of explanatory fundamentality in terms similar to Nagelian models of theoretic reduction; see Nagel (1962) and Dizadji-Bahmani, Frigg, and Hartmann (2010).

[18] See Wallace (2010), Deutsch (1999), Zurek (2005), and Sebens and Carroll (2018).

worlds—two branches of the Everettian multiverse. But simply looking at the in-branch macroscopic state will not provide this sort of explanation, nor will the in-branch facts provide an explanation of what will happen next in that branch, since Everettian dynamics are set by the entire quantum state's evolution according to Schrödinger's equation. So while an Everettian might grant that we can identify branch-relative regularities like the CBR and perhaps even regard these regularities as laws[19], it is not clear what additional explanatory power these laws provide to those who already endorse the Everett Interpretation, nor why these laws should be regarded as fundamental.

One may here respond that branch-relative laws like the CBR have explanatory power that extends beyond the standard Everett interpretation. Namely, one might think that these sorts of laws explain why we see certain sequences of outcomes rather than others: we see certain sequences because those sequences 'have a high objective chance'.[20] Let's grant that in the CEI, it is true that certain sequences of outcomes have higher objective chances than others. Even so, it is only the case that certain sequences have a higher objective chance within a given branch. This is because these chances, by way of the best system analysis of chance, are summaries of actual relative frequencies within a branch. Chances are branch-dependent. The standard Everett Interpretation will agree that different branches have different relative frequencies of experimental outcomes, and that the specific sequences of these outcomes will also differ across branches. Moreover, they will explain this by appealing to the evolution of the quantum state: outcome α happens in the $|\alpha\rangle$ branches, and β happens in the $|\beta\rangle$ ones, as described by branching and decoherence. As for why one sees some particular string of outcomes $O = \langle o_1, o_2, ..., o_n \rangle$ rather than another sequence $O*$, the CEI offers no further explanation than the standard Everett approach. Allow me to elaborate.

Say that O and $O*$ have the same relative frequencies, but in a different order. The CEI cannot provide a nontrivial explanation for why I observe outcomes like O rather than $O*$. They could of course say that I observe O rather than $O*$ because I inhabit a branch in which the string of outcomes is O, but this is not particularly informative, and this sort of explanation is also available to the standard Everettian without endorsing the CEI. The CEI could also say that I observe O rather than $O*$ because of some facts about the centered chances on my branch: that there is a high objective chance that I observe O. But since the centered chance that I observe a given outcome (or some string of outcomes) is just a summary of the relative frequencies of outcomes on my branch, this is no more informative than saying that I observe O because I am on a branch where the relative frequencies of

[19]If one is a humean about laws, then some branch-relative regularities should count.

[20]I thank an anonymous referee from BJPS for raising this objection.

outcomes are O-like. Moreover, the relative frequencies on a branch where instead $O*$ obtains are also O-like. So the CEI provides no new insight as to why I observe O rather than $O*$.

Now, let's consider the case where O and $O*$ have different relative frequencies with respect to their outcomes. Since the CEI defines objective chances in 'in-branch' terms, it is unclear to me how the CBR can tell me why there is a higher objective chance that I will observe O rather than $O*$. Telling me this would amount to telling me why I have a higher chance of being in some branch b that is characterized by O rather than $b*$ characterized by $O*$. But since (i) objective chances are defined in branch-relative terms, and (ii) whether or not some branch-relative law like the CBR holds is a branch-dependent fact, branch-relative laws cannot tell me why I should find myself (or why I have a high chance of finding myself) in a branch where the frequencies are O rather than $O*$.

One might think that a branch-relative law could tell me the objective chance that the next outcome I observe will be 'x-spin up', given the branch that I inhabit. This is in some sense true, but it presupposes that I know which branch I inhabit, so that I know which law to use. As a matter of fact, I do not know which branch I inhabit. If I knew which branch I inhabited, then I would know the outcome of the experiment before I performed it. And if I were to know all of this, then the branch-relative laws would still fail to be explanatorily fundamental. The fundamental explanation would come from the quantum state and details about my location in it as it evolves. Further, I don't even know what sort of branch I inhabit, in the sense that I don't even know whether the CBR rather than some other branch-relative law holds on my branch. That is to say, I do not know the relative frequencies of experimental outcomes throughout the entire history of my branch. While I have more to say about this, I point the reader to section 3.3 for further discussion of the accessibility and utility of branch-relative laws. Before moving on, I'd like to address a final concern about the fundamentality of branch-relative laws.

Finally, one may object to my choice of the two candidates. Perhaps there is some other, looser way of understanding the term 'fundamental' in the context of laws: something like 'a basic posit within a given physical theory'.[21] For example, Schrödinger's equation is often called a fundamental law with respect to nonrelativistic quantum mechanics, even though philosophers and physicists have strong reason to doubt that nonrelativistic quantum mechanics is a final theory in physics. On this reading, the CBR is a fundamental law in that it is a law that is not reduced within the context of the theory (the centered Everett Interpretation) itself. In other words, it is a basic posit of the CEI that the centered chance that an agent will find themselves in one set of branches rather than another is given by the quantum

[21] Thanks to Isaac Wilhelm and an anonymous referee for bringing this notion to my attention.

state as described by the CBR. I have no objection to the CBR being fundamental in this weaker sense. But if this is all that Wilhelm means with respect to the CBR's fundamentality, then I don't feel the force of the CBR posing a threat to the 'orthodox assumption' that fundamental physics is not in the business of describing centered phenomena. After all, appealing to this weakened notion of fundamentality gives up what philosophers and scientists are likely to find interesting (if not concerning) about centered facts playing a role in fundamental physics. It would, however, be surprising if we needed to appeal to centered phenomena in an explanatorily or ontologically fundamental law or theory.

Allow me to clarify this point. What struck many as mysterious or outright objectionable about early observer- or consciousness-based collapse models of quantum mechanics was not merely that at some level of explanation, observers or consciousness might factor into physics. As mentioned in the previous section, even in standard EQM, it is true that there are observer-dependent facts about which experimental outcomes obtain. But again, these observer-dependent facts are reducible to branch-dependent facts, which are in turn reducible to facts about the quantum state. Rather, what many found objectionable about early collapse theories was that the explanation seemed to bottom out there: according to those theories, observers and/or consciousness appeared as parts of the fundamental explanation or the fundamental ontology of physics. But if this can be avoided, then centered chances being fundamental (in the weak sense) to some level of physical explanation seems no stranger than saying that phenomena like homeostasis or metabolism are fundamental to some level of biological explanation.

In summary, I take it that Everettians have reason to reject the CEI's claim that branch-relative laws like the CBR are fundamental if 'fundamental' means explanatory fundamentality or ontological fundamentality. It is not obvious that there is any reason to reject the claim that such laws are fundamental in a weaker sense. But taking these laws to be fundamental only in the weak sense makes less clear that the CEI undermines the 'orthodox assumption' that fundamental physical laws concern only uncentered propositions.

3.3 The Accessibility and Utility of the CBR

As hinted at in the previous section, my final argument against the CEI concerns the epistemic accessibility and predictive utility of branch-relative laws like the centered Born rule. Even if an Everettian grants that the CBR satisfies the relevant criteria for being a fundamental law, I argue that as it stands, the CBR is not the kind of law whose truth is epistemically accessible to an agent such that it could constrain the agent's rational credences. In essence, it is not the branch-relative laws summarizing the actual objective chances on one's branch that constrain one's credences; rather it is one's observations, combined with principles of rationality and induction, that impose rational constraints on what agents should take the centered chances and branch-relative laws to be.

To begin, let's recall two facts about the CEI:

(1) The centered Born rule states that the centered chance that agent W will observe a particular experimental outcome A for experiment X corresponds to the amplitude associated with that outcome in the quantum state prior to the experiment via the standard Born rule.

(2) By the best system account of centered chance, the centered chance that an agent W in branch b will observe a particular outcome A for experiment X is determined by the relative frequency of A outcomes for experiment X in b.

First, note the apparent tension between (1) and (2) with respect to what the centered chances are for W. On the best system account, the centered chance that W observes A is not given by the CBR directly. Rather, as stated in (2), centered chances are defined in terms of the relative frequencies of A outcomes in W's branch b. The centered Born rule, on the other hand, is regarded as a contingent law which states that centered chances correspond to Born rule probabilities. As mentioned in section 2.3, the CBR will not capture the actual relative frequencies in all branches, and therefore will yield the wrong centered chances for some agents. The CBR will give the wrong chances, and hence be false in what we might call 'unlucky branches'—branches where the relative frequencies of experimental outcomes do not align with the Born rule probabilities.[22]

Wilhelm acknowledges this, stating that the CBR's truth is branch-relative in the CEI, so the CBR does not give the right chances for all branches. Wilhelm writes,

> the centered chances, in the centered Born rule, summarize the frequencies with which experimental outcomes obtain on our branch. For example, on *our* branch, the relative frequency with which we find that 'z-spin up' electrons have x-spin up—after certain kinds of measurements—is 1/2; and the relevant Born rule probability matches that. In other words, on *our* branch, the centered chances in the centered Born rule correctly capture the frequency facts. For us, the Born rule probabilities get the frequency facts right (2022, p. 1027).

[22] It is worth noting that unlucky branches, or as DeWitt (1970) calls them, 'maverick branches' may generate worries for EQM more generally. While I am sympathetic to that concern, I think that their existence specifically undermines the claim that the CEI 'provides helpful constraints on the normative principles that rationality accounts posit' Wilhelm (2022).

The problem for the CEI is that worm-agents do not know which branch they inhabit, and hence do not know whether the centered Born rule is true or false on their branch. It could turn out, for instance, that I am an unlucky worm that has been (apparently) lucky until now. A worm may know that the actual relative frequencies in their branch have from times t_1 to t_2 corresponded to the Born rule. But this fact alone does not entail that the CBR is a law in that branch, since there is no guarantee that the relative frequencies match the Born probabilities from t_2 onward.

Since we know that the CBR cannot be true in all branches, without further argumentation[23], it is circular to assume that 'in particular, that chancy rule—which God would give you—is the centered Born rule' (Wilhelm (2022), p. 1029). To illustrate this, consider the following two cases involving worm agents W_{AU} and W_{AL}:

(I) **Apparently Unlucky:** W_{AU} observes thousands of z-spin up outcomes in a row after setting up experiments to measure the z-spins of particles in x-spin eigenstates. And yet, over the whole history of of W_{AU}'s branch b_{AU}, the relative frequencies of outcomes are such that the (centered) Born rule holds.

(II) **Apparently Lucky:** W_{AL} observes Born-matching outcome distributions from time t_1 to t_2. W_{AL} takes it that the CBR is true in their branch, and predicts that future outcome distributions will follow the trend of matching the Born-probabilities. And yet over the entire history of W_{AL}'s branch, the (centered) Born rule does not hold.

Both cases demonstrate that the frequencies that one observes over some temporal interval t_1 to t_2 have no impact on the frequencies that will be observed from t_2 onward, and thus over the entire history of the branch. The Apparently Unlucky case demonstrates that even if one observes thousands of z-spin up outcomes in a row after setting up experiments to measure the z-spins of particles in x-spin eigenstates, it is still possible for that experimenter to inhabit a branch in which the overall relative frequencies of outcomes are captured by the Born probabilities. As a matter of fact, there is a sense in which it is still 'more likely'[24] that such an observer inhabits a branch in which the total frequencies match the Born rule than

[23] I should note that Wallace (2012) provides an argument for why we are rational to assume that the Born rule probabilities will obtain in our branch, but his account treats the Born rule probabilities as rational credences rather than objective chances. Without supplementing the CEI with something like Wallace's argument, it is unclear how the CEI can provide agents with epistemically accessible laws that serve to make useful experimental predictions.

[24] It is more accurate to say that if Everettian quantum mechanics is right, there is a higher overall 'weight' assigned to Born-conforming branches than unlucky ones. Giving a precise presentation of how this maps on to our intuitions about what is 'likely' is tricky (and closely related to what is at issue), but I point readers to Wallace (2012) , particularly Ch. 5, for defenses of the idea that it is rational, conditional on the truth of the Everett picture, to think that ones lives in a lucky rather than an unlucky branch.

otherwise, so long as the proportion of experiments that will be performed in the future is sufficiently greater than the proportion that have been already performed in one's branch. The total weight of branches wherein the CBR appears to be false for some prolonged interval of time and yet ultimately captures (at least, approximately) the relative frequencies across the entire history of the branch is far greater than the total weight of branches wherein the CBR actually turns out wildly off-base. So it is quite possible that a subject inhabits a branch where the data so far indicate that the CBR is false in their branch, and yet experimental outcome frequencies do in fact converge to Born rule probabilities as more time passes.

In the Apparently Lucky case, W_{AL} seems to have good reason to believe that the (centered) Born rule holds on their branch—it is what best fits the evidence from t_1 to t_2—even though it turns out that the CBR is false there. The main takeaway from both of these cases is that it cannot be the truth (or falsity) of the CBR (or similarly, the actual centered chances on one's branch) that provides rational constraints for the agent.

Let's put the point more generally. For a set of spacetime worms that are exact physical duplicates from t_1 to t_2, the CBR will be true for some worms in the set and false for others. Since all of the worm agents in this set have all of the same information, mental states, and physical properties from t_1 to t_2 (in virtue of being exact physical duplicates from t_1 to t_2), the CEI entails that no amount of information available to a worm-agent W is sufficient to determine whether the CBR gives the right chances for W's branch. This is because the laws are the summaries of branch-relative experimental frequencies along an entire branch, and the future outcomes in one's branch aren't known to an agent, since an agent does not know which branch they inhabit.[25]

While it is often regarded as rational to assume that regularities will persist—particularly, regularities like the relative frequencies of well-controlled experimental outcomes—when it comes to the sorts of experiments that involve Born probabilities, agents *qua* worms do not in fact know which outcome they themselves will observe until they actually observe the results. This is true whether one interprets quantum mechanics as fundamentally probabilistic or instead accepts the Everett interpretation in conjunction with the worm view. Moreover, the truth of EQM entails that there are some branches in which regularities necessarily do not persist: one example being the atypical or 'unlucky' ones. For this reason, it is doubtful that the CEI's presentation of branch-relative laws can help to explain what credence is rational for a subject to have about experimental outcomes in their branch. Wilhelm contends that cases like unlucky branches give us reason to prefer the CEI to rationality-based approaches

[25] Again, at t_2 W may know that some set of worms will observe Born-probabilities from t_2 onward and that another set will be unlucky from t_2 onward, but at t_2 W does not know to which set W belongs.

like Wallace's. The idea is that while rationality approaches appear to entail that subjects on unlucky branches ought to align their credences about experimental outcomes with the Born rule, the CEI does not, since (i) the CEI does not posit any principles of rationality, and (ii) the CEI says that some laws, particularly, ones like the CBR, are branch-relative. But even with (i) and (ii) in mind, it isn't clear that the CEI provides subjects—whether in Born-typical branches or unlucky ones—with helpful constraints. While it is rational to align our credences with the objective chances if we know those chances, branch-relative chances—when defined as the relative frequencies of outcomes along the entire history of a branch—aren't the sort of things that I'm in a position to know.[26] Rather, what constrains rationality is the evidence actually available to an agent, and since the CEI defines branch-relative laws in terms of the frequencies across the entire history of a branch rather than the frequencies that have obtained up until the present, branch-relative laws simply aren't the kinds of things that can factor into what is rational for one to believe.

In summary, it cannot be the objective chances nor the branch-relative laws summarizing them that constrain one's rational credences in an Everettian multiverse. This is because agents are not in a position to know their locations in the multiverse, or analogously, that agents do not know the relative frequencies across the entire history of their branches. In this way, the CEI seems to get our epistemic position backwards. Sine we don't know where we are, it is one's knowledge about quantum mechanics, the evidence available, and standard principles of induction that ought to impose rational constraints on what one takes the laws to be.

4 Conclusions

I have given three arguments against the CEI on broadly Everettian grounds. The first was that adopting the CEI reintroduces agents into fundamental physics, thereby eschewing a common motivation for endorsing a realist interpretation of quantum mechanics like EQM in the first place. While this is a *prima facie* worry for the view, the CEI can avoid this by making non-agents the centers for centered propositions. However, I suggested that doing so may sacrifice the 'chanciness' of the centered chances. My second argument showed that even the CEI can proceed without undermining this initial motivation, the branch-relative laws that the CEI describes are best understood as emergent, rather than fundamental laws. Hence, the Everettian need not reject the orthodox assumption that fundamental physical laws concern only uncentered facts. Finally, I argued that the CEI's branch-relative

[26] If I'm wrong about this, then the apparently lucky agent W_{AL} is irrational to align their credences about experimental outcomes with the Born rule, despite all of their evidence to the contrary.

laws not offer much to the Everettian: they are epistemically inaccessible and incapable of constraining reasoning or making fruitful predictions about the future. Hence, branch-relative laws like the centered Born rule cannot explain and constrain rational credences in the way that the CEI purports.

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