# Review of: "Bell's Theorem and Counter factual Definiteness CH"

Tim Maudlin[1]

1 New York University

Potential competing interests: No potential competing interests to declare.

The main burden of this article is to argue that various attempts to get around the fundamental claim of Bell's theorem—namely that any theory capable of predicting violations of Bell's inequality for experiments done at space-like separation must contain some sort of non-locality or "spooky action-at-a-distance"—fail to establish their thesis. In particular, it has been for some time rather popular to claim that Bell somehow surreptitiously assumes a condition called Counterfactual Definiteness (CFD) in the course of his derivation. If so, then any theory that denies CFD would apparently be automatically immune from the theorem. Such a theory could (as far as Bell's result goes) predict violations of his inequality without postulating any sort of non-locality at all.

The article goes into the structure—and obscurities—of these arguments in great detail and isolates various parts of the arguments that are unsupported or implausible. It is important to work through these sorts of claims carefully and in detail. I have no objections at all to the particular observations that Husbands makes. Nonetheless, I do harbor some fear that the intricacy and fine detail gone into here may produce the misleading impression that the failure of these arguments is more subtle than it actually is. In fact, the whole idea that Bell's argument relies on a tacit assumption of CFD is not only incorrect, but it was forcefully and vociferously denied by Bell himself. Husbands does point out that, as a matter of logical structure, the arguments in some of the papers he cites do not even purport to *demonstrate* that Bell presupposes CFD, but rather simply *presume* that he does. But the situation is more dire than that: what can be demonstrated is that Bell *does not* presume CFD and that he was perfectly aware and insisted that he did not.

What is CFD? It is the claim that certain counterfactual (or contrary-to-fact) conditionals have definite truth values. A counterfactual conditional makes a claim about *what would have happened* had some situation been different from how it actually was. That is, it is not a claim about how the actual physical world *is* but rather *how it would have been had something been different*. Now one might immediately be puzzled by the claim that these sorts of counterfactual assertions could have any bearing on Bell's result, since the result is only about *actual* data, the *actual* outcomes of experiments that were *actually* performed. The question is whether a certain sort of physical theory can predict those outcomes. And it is violations of Bell's inequality in the *actual* data that rules out locality. Clearly, there just cannot be data about the outcomes of *merely possible but actually unperformed experiments*. If violating Bell's inequality required one to make assertions about what would have happened if one had performed different experiments, then experimentalists could not produce data that would violate the inequality. But they do.

Pushing a little further, what sorts of physical theories do support CFD, that is, do make definite claims about what would

have happened had things been different? Well, clearly only *deterministic* theories do. Any theory with a fundamentally indeterministic or stochastic dynamics will not support CFD. All it will say about such an unperformed experiment is that it *might* have come out one way and *might* have come out another, and possibly another, and so on, with various probabilities associated with each possible outcome. So essentially, to say that Bell presumes CFD in his derivation is to say that Bell presumes determinism, and that his result only applies to deterministic theories. Therefore, the reasoning goes, all one has to do is deny determinism to get around Bell's result. But the standard Copenhagen approach as well as objective collapse theories like the Ghirardi-Rimini-Weber theory do deny determinism. So by this logic, violations of Bell inequality are completely irrelevant to theories like that. That would make Bell's result so narrow and parochial to be of almost no interest.

But now we can make direct contact with what Bell himself insists. In "Bertlmann's socks and the nature of reality" Bell writes: "It is important to note that to the limited degree that *determinism* plays a role in the EPR argument, it is not assumed but *inferred*. What is held sacred is the principle of 'local causality' or 'no action at a distance'. Of course, mere *correlation* between distant events does not by itself imply action at a distance, but only correlations between signals reaching the two places. These signals, in the idealized example of Bohm, must be sufficient to *determine* whether the particles go up or down. For *any* residual undeterminism could only spoil the perfect correlation".

Let's unpack this comment. It is about the original EPR argument and its conclusion that the quantum description of a system must be incomplete. Clearly, Einstein, Podolosky and Rosen do not *presume* that any complete theory must be deterministic. If they did, then their argument against Copenhagen would be both only one line long and completely question-begging. Rather, EPR argue any *local* theory that can predict *perfect correlations* between the outcomes of distant experiments must be deterministic. The perfect correlations in the EPR example are the correlations between the outcomes of Alice's and Bob's position measurements (when they both make them) and the correlations between their momentum measurement (when they both make them). It is these perfect correlations that allow Bob to accurately predict the outcome of Alice's experiment from seeing only the result of his own. If the correlations were not perfect, Bob could not make such perfect predictions. What EPR argue is that in a *causally local* theory, such perfect correlations can only be predicted if the theory is deterministic. Hence, as Bell says, the determinism (and accompanying CFD) is *inferred* from the EPR correlations and locality rather than presumed.

For if the theory were indeterministic—if Alice's experiment in a particular run could have come out in different ways given all the physical inputs—then the only way Bob's outcome could always be perfectly correlated with hers is if information about how hers came out was somehow non-locally made available to Bob's particle. As Bell says in the case of Bertlmann's always mismatched socks: "It is as if we had come to deny the reality of Bertlmann's socks, or at least of their colours, when not looked at. And as if a child has asked: how come they always choose different colors when they *are* looked at? How does the second sock know what the first has done". Note that the child's puzzlement is not about what the outcome *would have been* had we looked (in a case where we didn't), but about how the*actual* colors are produced in the case where we *do* look.

Bell's remarks above are about the EPR argument and the EPR perfect correlations. So one might ask what bearing they

have on his own argument. But the answer to that is simple too: Bell's argument starts by presuming that the reader has already understood and appreciated the force of the EPR argument. Since he is dealing with the idealized Bohm spin setting, where there are perfect correlations between spin experiments done at the same angle, he is already entitled to the EPR result: any *local* theory predicting those outcomes must be deterministic. Bell can focus on the class of local deterministic theories (and hence local CFD-supporting theories) because EPR have already ruled out the possibility of local *indeterministic* theories. But in the important sense, Bell does not*presume* determinism or CFD because, as he says, EPR did not presume these things: they rather *infer* them from the locality condition and the perfect correlations.

All of this is made clear in the first paragraph of "On the Einstein-Podolsky-Rosen paradox", and from the very title it is manifest that Bell's real presumption is that the reader of his paper has already read the EPR paper and understood its logical structure. Bell was certainly too charitable to the reader here, as his remarks in "Bertlmann's socks" illustrate. Bell thought the readers of his paper would already understand that EPR derive determinism from locality and perfect correlations rather than just presuming determinism. And since determinism and CFD are essentially the same condition, the same goes for CFD. But as Bell's later paper proves, he had a very hard time getting people to see that point. And it seems that those who claim that Bell *presumes* CFD in his proof have not gotten the point to this day.