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An Impossibility Theorem for Parameter Independent Hidden Variable Theories

Recently, Roger Colbeck and Renato Renner (C&R) have claimed that “[n]o extension of quantum theory can have improved predictive power” [3,5]. If correct, this is a spectacular no-go theorem for hidden variable theories, which is much more general then the theorems of Bell [1] and Leggett [7].
The claim implies that if a quantum state is supplemented with hidden variables, the values of these variables have no bearing on the probabilities of measurement outcomes. Such a claim is relevant for the question, famously raised in 1935 by Einstein, Podolsky and Rosen [6], whether quantum mechanics is a complete theory. If it is not possible to introduce additional variables that have any connection to measurement outcomes, it seems such variables are redundant and can be discarded. This suggests that the quantum state itself, without additional hidden variables, gives a complete description of a physical system. Indeed, elsewhere C&R have used the above claim to conclude that the quantum state of a system is in one-to-one correspondence with its elements of reality [4].
On closer inspection, however, the generality and validity of the claim can be contested. Firstly, it is based on an assumption called “Freedom of Choice”. As the name suggests, this is an assumption involving the independence of the experimenter’s choice of settings when performing a measurement. But in the way Colbeck and Renner define this assumption, a no-signaling condition is actually presupposed, making the assumption much less innocent than it sounds. When using this definition, any hidden variable theory violating Parameter Independence, such as Bohmian Mechanics, is immediately ruled out. The use of this assumption has been criticized previously5. Secondly, the argument of Colbeck and Renner is hard to follow and some important steps in the mathematical derivation are absent.
We argue that these shortcomings can be repaired. Regarding the second issue, the absent steps can be filled in, although not trivially. The first issue can be circumvented by explicitly assuming Parameter Independence. This makes the result less general, but better founded. In this case we obtain an impossibility theorem for hidden variable theories that satisfy Parameter Independence.
As stated above, such hidden variable theories are impossible in the sense that any supplemental variables have no bearing on outcome probabilities, and are therefore trivial. So, while quantum mechanics itself satisfies Parameter Independence, if a variable is added that changes the outcome probabilities only slightly, Parameter Independence must be violated.
On this poster we explain how the idea of chained Bell inequalities can be used to arrive at conclusions about outcome probabilities, and a rough sketch is given how this leads to the no-

go Theorem.

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