Re: XV10673A
Quantum Bayes' rule affirming consistency in measurement inferences in quantum mechanics
by Mohit Lal Bera and Manabendra Nath Bera

Dear Dr. Jencova,

We would appreciate your review of this manuscript, which has been submitted to Physical Review A.

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ABSTRACT:

Traditional Bayes' rule lays the foundation for causal reasoning and finding} relation between cause (input) and effect (output). \mnb{This causal reasoning is universally applied to all physical processes to establish causal relations.} Here, we show \mnb{that it does not establish correct causal correspondence between quantum causes and effects in general.} In fact, there are instances within the framework of quantum mechanics where the use of traditional Bayes' rule leads to inconsistencies in quantum measurement inferences. We consider two such cases, inspired by Frauchiger-Renner's and Hardy's setups, where traditional Bayes' rule results in paradoxical situations even after assuming quantum mechanics as a non-local theory. As a remedy, we introduce an input-output causal relation \mnb{using the reasoning} based on quantum Bayes' rule. It applies to general quantum processes even when a cause (or effect) is in coherent superposition with other causes (or effects), involves non-local correlations as allowed by quantum mechanics, and in the cases where causes belonging to one system induce effects in some other system as it happens in quantum measurement processes. This enables us to propose a resolution to the contradictions that appear in the context of Frauchiger-Renner's and Hardy's setups. Our results thereby affirm that quantum mechanics, equipped with quantum Bayes' rule, can indeed consistently describe the use of itself.

Report of the First Referee -- XV10673A/Bera

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Report of the Second Referee -- XV10673A/Bera

Report of the Third Referee -- XV10673A/Bera

The authors claim that a couple of well-known paradoxes of inference in quantum mechanics are resolved when the so-called quantum Bayes rule is used instead of the "classical" Bayes rule for (causal) inference. First they recall the standard Bayes rule and give a quick introduction to an inferential map dubbed the quantum Bayes rule in the framework developed by Leifer and Spekkens in reference [7]. Then they compare the quantum and classical settings, essentially claiming that in a purely inferential/logical sense, the "classical" Bayes rule is an inadequate tool for dealing with inference in a quantum scenario. To back up their claim they consider the Frauchiger--Renner paradox and one by Hardy from the perspective of the quantum causal model and propose that both paradoxes are resolved once classical inference is replaced with the appropriate quantum ones.

The main technical contribution of this paper is to cast the aforementioned paradoxes in the causal language of reference [7]. Doing so ends up being rather straightforward; despite the generality of the formalism introduced in section 2, they only ultimately need unitary dynamics and rank-1 projective measurements to treat the paradoxes and for this setting the quantum retrodiction reduces to applying an inverse unitary to the resulting ket. In any case, at a glance, their technical analysis appears to be correct.

However, I believe the authors have drawn incorrect conclusions and as such I cannot recommend publication in its current form. Just reading the abstract, I knew something had to be wrong because the "classical" Bayes rule, understood correctly, is not classical or quantum --- it's a purely logical statement which is true in any universe. Put another way, the quantum Bayes rule does not replace Bayes rule. The quantum Bayes rule is a relation, derived *within* the quantum formalism, between input and output states for a given channel. Meanwhile the regular Bayes rule is a consequence of coherent reasoning and so can be used *with* a physical theory, such as classical or quantum mechanics, but does not itself belong to either. A common example is to use Bayesian updating to refine a prior distribution over possible states in quantum state tomography. There one has a prior probability which I believe comes from talk of quantum theory as a generalization of probability theory. It's actually better to say quantum theory is an *addition* to probability theory because what it actually does is extend the scope of probabilistic constraints in much the same way trying to be consistent with any physical theory might. But quantum theory doesn't deprecate the *concept* of a probability; it's true that in the standard representation we manipulate complex-valued matrices, but standard probabilities are there at the beginning and end in state preparation and measurement and, furthermore, any quantum state *just is* a probability distribution over the outcomes of an informationally complete measurement. All this to say that inference itself is a pre-physical concept and so the purported lesson of the paper must be wrong.

The issue is apparent in their simple example comparing classical and quantum causal reasoning, example 1 in section 3. There they are ultimately comparing incomparable things because to discuss the supposed classical inference, they consider "a classical stochastic process analogous to the evolution". Why would I expect consistency between quantum mechanics and a different physical theory? To try to put them on the same footing, their classical model treats the outcomes of a computational basis measurement as underlying states of reality, when we already know from quantum mechanics that they are not. If we nonetheless allow the Born rule probabilities for state measurements from quantum mechanics to define all of the probabilities used in a classical inference, the issue remains that the actual experiment being done is fundamentally different: in the quantum situation they are considering one coherent isometric evolution followed by a measurement while in the classical part of the example, the fact that they use measurement probabilities for the prior and likelihood implies they are considering an intermediate measurement setup instead. Measurement matters! Thus, I conclude they are knocking down a straw man.

Despite this serious and fundamental error, there may be some value in the technical aspect I mentioned earlier, but the whole discourse would need to be repackaged before it would be possible to adequately assess.

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Manuscript Number: XV10673A

Author: Mohit Lal Bera and Manabendra Nath Bera

Title: Quantum Bayes' rule affirming consistency in measurement inferences in quantum mechanics

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