In defence of non-ontic accounts of quantum states

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The paper discusses objections against non-hidden variable versions of the epistemic conception of quantum states—the view that quantum states do not describe the properties of quantum systems but reflect, in some way to be specified, the epistemic conditions of agents assigning them. In the first half of the paper, the main motivation for the epistemic conception of quantum states is sketched, and a version of it is outlined, which combines ideas from an earlier study of it [Friederich 2011] with elements of Richard Healey's recent pragmatist interpretation of quantum theory [Healey forthcoming a]. In the second half, various objections against epistemic accounts of quantum states are discussed in detail, which are based on criticisms found in the literature. Possible answers by the version outlined here are compared with answers from the quantum Bayesian point of view, which is at present the most discussed version of the epistemic conception of quantum states.

Keywords: quantum states, quantum probabilities, anthropocentric notions, micro/macro divide, explanation and prediction

1 Introduction

The measurement problem and the problem of quantum "non-locality", that is, the claimed tension between quantum theory and relativity theory, are widely regarded as the most outstanding difficulties in the foundations of quantum mechanics. Possible ways to react to these problems (or "paradoxes") range from changing the dynamics (as in GRW theory) to adding determinate particle and field configurations (as in pilot wave approaches) to adopting a non-standard picture of our world according to which our universe (or our minds) constantly splits into an immense number of branches (as in variants of the Everett interpretation). These are attempts to *solve* the paradoxes, either by altering the formalism of the theory or by radically altering our picture of the world so that at least one of the assumptions necessary to derive the paradoxes no longer holds.

The present paper investigates accounts of quantum theory which approach the paradoxes from an entirely different perspective. Their main ambition is to *dissolve* the paradoxes by proposing a perspective on the linguistic roles of the constituents of the quantum theoretical formalism according to which at least one of the assumptions necessary to derive the paradoxes counts not as wrong (in which case one might speak of a *solution* rather than a dissolution) but as conceptually ill-formed. The motivation underlying these approaches is "therapeutic" inasmuch as they aim at "curing" us from what they see as unfounded worries about foundational issues based on conceptual misunderstandings. More specifically, the accounts to be discussed are grounded in the hope that a *non-ontic* reading of quantum states—a reading which construes quantum states as having a non-descriptive linguistic role, which differs from that of representing reality—may hold the key to conceive of the theory in such a way that the paradoxes do not arise in the first place.

The defining characteristic of non-ontic readings of quantum states is that they do reject the notion of a *true* quantum state of a quantum system—a quantum state it *is in*.[1] Non-ontic readings of quantum states mostly embrace some version of the *epistemic* conception of states—the view that quantum states somehow reflect the state-assigning agents' epistemic relations to the systems states are assigned to[2]—and the present paper focuses on these. A defining criterion of what counts as a version of the epistemic conception of states is to allow that agents which are differently situated with respect to one and the same quantum system and have different epistemic relations to it may (and perhaps even should) legitimately assign different quantum states to it. As formulated by Rudolf Peierls, one of its key proponents, the quantum states assigned to the same system by different agents "may differ as the nature and amount of knowledge may differ."[3]

Accounts that are based on the epistemic conception of states must be non-ontic in that they cannot acknowledge any such thing as an agent-independent "true" quantum state of a quantum system—a state it "is in"—, for if such a state exists, assigning precisely that state is the one and only correct way of assigning a quantum state and assigning any other state would be wrong. Any account that accepts the notion of a "quantum state a quantum system is in", without construing it as a sometimes harmless yet potentially misleading *façon de parler*, does not qualify as an epistemic account of quantum states in the sense of the present paper.

Just like any other take on the foundations of quantum theory, the epistemic conception of states has been heavily criticised on a number of different grounds. The main aim of the present paper is to consider the most important objections brought forward against it together with possible rejoinders. Most of the objections considered were originally raised as criticisms of *quantum Bayesianism*, a remarkably radical epistemic account of quantum states the core idea of which is to

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[1] According to the terminological conventions employed in this paper, an account of quantum states qualifies as "non-ontic" if and only if it denies that for every quantum system there exists exactly one (true) quantum state it is in. Accounts which accept this assumption are referred to as "ontic". Thus, accounts need not attribute any metaphysically ambitious kinds of reality to quantum states (as some versions of pilot wave theory may not) in order to count as ontic in the sense used here.

[2] There are versions of the epistemic conception of states which add additional (ontic) variable configurations to the standard formalism of quantum theory. Important contributions to this type of approach include the construction of an explicit toy model based on the epistemic conception of quantum states by Spekkens (see [Spekkens 2007]), which reproduces many signature qualitative features of quantum theory. More recently, a theorem due to Pusey, Barrett and Rudolph (see [Pusey et al. 2011]) has stimulated a lot of interest and research activity, which establishes that an important class of hidden-variable models based on the epistemic conception yields predictions which are compatible with those of standard quantum theory. Hidden-variable models combined with epistemic accounts of quantum states do not conform to the therapeutic ambitions outlined before and are therefore not further discussed in what follows, but their investigation represents no doubt an intriguing and flourishing field of research.

[3] See [Peierls 1991] p. 19.

interpret quantum probabilities as subjective degrees of belief in accordance with the subjective Bayesian account of probability. One of the goals of the present paper is to explore quantum Bayesianism's resources for answering these objections.

In addition to quantum Bayesianism, the paper expounds and develops another version of the epistemic conception of quantum states, introduced in the following sections as the "Rule Perspective" (for reasons to be given), which is based on a combination of ideas developed in an earlier study of the epistemic conception of states (see [Friederich 2011]) with elements drawn from Richard Healey's recent pragmatist interpretation of quantum theory (see [Healey forthcoming a]).[4] The main result of the discussion of objections in later sections of this paper is that the "Rule Perspective" (omitting the scare quotes from now on) fares much better in answering them than quantum Bayesianism. This does not mean, of course, that the Rule Perspective is superior to all other rival interpretive takes on quantum theory or that it even constitutes the uniquely correct account of quantum foundations. Far from making such ambitious claims, my more modest aim in this paper is to argue that the idea of dissolving the paradoxes without introducing any hidden variables, additional dynamics and without accepting Everettian branching can be formulated and defended in a coherent way. Arguably, this suffices to make accounts that are based on it into serious contenders among interpretations of quantum theory.

The structure of the remaining sections of this paper is as follows: Section 2 sketches in which way the epistemic conception of quantum states dissolves the notorious paradoxes of measurement and non-locality by undermining their formulations. Section 3 reviews quantum Bayesianism and introduces the reader to the Rule Perspective. Sections 4, 5, and 6 are the core sections of the paper. They consider objections against the epistemic conception of quantum states (found in the literature or inspired by it) and develop and discuss possible answers from the points of view of quantum Bayesianism and the Rule Perspective. The paper closes in Section 7 with some remarks on the shared ambition of the Rule Perspective and the Everett Interpretation to understand quantum theory without supplementing its standard formalism in any way.

2 Dissolving the paradoxes

The present section gives an outline of how the epistemic conception of quantum states dissolves the measurement problem and the problem of quantum "non-locality", that is, the claimed tension between quantum theory and relativity theory. I consider the measurement problem first.

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[4] For studies elaborating on the epistemic conception of states and views in a similar spirit see [Fuchs and Peres 2000], [Mermin 2003], [Caves et al. 2002a], [Caves et al. 2002b], [Fuchs 2002], [Pitowsky 2003], [Appleby 2005], [Bub 2007], [Caves et al. 2007], [Fuchs and Schack 2009], [Bub and Pitowsky 2010], [Barnum 2010], [Fuchs and Schack 2011], [Friederich 2011].

Healey's pragmatist interpretation is closely related to epistemic accounts of quantum states in many respects, but Healey himself does not regard his own view as a version of the epistemic conception (see [Healey forthcoming a] p. 16). The similarity in spirit becomes clear, for instance, in Healey's take on measurement collapse "as a way of updating [an agent's] authoritative source of advice", in complete agreement with how the epistemic conception of quantum states views collapse, as discussed in Section 2.1.

2.1 The measurement problem

There exist various different formulations of the measurement problem in the literature, which are sometimes even conceived as different measurement problems.[5] Here I focus on an exposition due to [Maudlin 1995] (who alone gives three different formulations), to illustrate how the epistemic conception of quantum states dissolves it. In Maudlin's formulation, the problem arises from the incompatibility of the following three assumptions:

> 1.A The wave-function of a system is complete, i. e. the wave-function specifies (directly or indirectly) all of the physical properties of a system.
> 1.B The wave-function always evolves in accord with a linear dynamical equation (e. g. the Schrödinger equation).
> 1.C Measurements of, e. g., the spin of an electron always (or at least usually) have determinate outcomes, i. e., at the end of the measurement the measuring device is either in a state which indicates spin up (and not down) or spin down (and not up). (See [Maudlin 1995] p. 7.)

To see that these assumptions are incompatible (though not strictly logically inconsistent, see [Maudlin 1995] p. 10), one has to consider a situation in which the system being measured is not in an eigenstate of the measured observable. In that case, according to 1.B, the state of the combined system consisting of the measured system together with the measuring apparatus evolves into a superposition of eigenstates of the measured and the "pointer" observable, whose different possible values correspond to macroscopically different configurations of the "pointer" (or display) of the apparatus. This state doesn't single out or prefer by itself any of the possible values of the measured observable of the measured system nor of the pointer observable pertaining to the apparatus. Nevertheless, according to 1.A, it provides a complete description of the combined system, including both the measured system and the apparatus. On the basis of this assumption we have to conclude that none of the possible values of the measured and the pointer observables is actually realised (or all at once, as Everettians conclude). Assumption 1.C, however, requires that at the end of the measurement process the value of the pointer observable is determinate. Consequently, the three assumptions, taken together, are incompatible and at least one of them has to be dropped. A necessary condition for an interpretation of quantum theory to count as a candidate *solution* to the measurement problem is that it declares either 1.A or 1.B or 1.C to be wrong (or that it finds a loophole in the reasoning leading to their claimed incompatibility, as seems very difficult). Solutions to the measurement problem contrast with *dissolutions*. Dissolutions reject at least one of the assumptions 1.A, 1.B or 1.C as well—but for being senseless rather than for being wrong or, to put it more diplomatically, for being based on mistaken conceptual presuppositions rather than for being mistaken.

Accounts that are based on the epistemic conception of states dissolve the measurement problem in precisely that sense. They do not acknowledge the notion of a quantum state a quantum system "is in" and reject the view that it is part of the linguistic role of quantum states to specify "physical properties of a system" (Maudlin's assumption 1.A) in the first place. Whereas solutions to the

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[5] See [Wallace 2008] for a detailed "modern" take on the measurement problem and an overview of proposed solutions.

measurement problem which reject assumption 1.A as *wrong* hold that quantum states are *incomplete* specifications of the physical properties of quantum systems (pilot wave approaches are examples of such views, inasmuch as according to them the quantum state specifies *some* features of physical reality, but not all), the epistemic conception of states denies that quantum states are appropriately construed as specifications of physical properties in the first place. Assumption 1.C (outcome determinateness) is left untouched, and the ramifications for assumption 1.B are essentially the same as for 1.A since the notion of "*the* wave-function" of a system is rejected as referring to a special case of that of a quantum state a quantum system *is in*. Agents who are competent in applying quantum theory do of course *assign* quantum states to quantum systems and they *make them* undergo unitary time-evolution according to the Schrödinger equation, but acknowledging this is very different from endorsing an interpretation of unitary time-evolution as corresponding to the evolution of physical properties of the system itself.

In applications of quantum theory the measurement problem does not arise as a practical difficulty, as it is circumvented by what is widely seen as an act of brute force: invocation of the notorious von Neumann measurement collapse of the wave-function. From the perspective of ontic accounts of quantum states collapse is disconcerting in that it remains completely dubious and unclear under which conditions it occurs. From the perspective of the epistemic conception of states, in contrast, measurement collapse merely reflects a sudden and discontinuous change in the epistemic situation of the state-assigning agent, not a discontinuity in the time-evolution of the system itself, so the question of under which conditions it occurs becomes meaningless. A question that does make sense from the point of view of the epistemic conception of quantum states is under which conditions an agent assigning a quantum state should apply the collapse postulate. This question will be discussed in more detail in connection with the Rule Perspective in Section 3.2. Objections against the employment of "anthropocentric notions" (such as "measurement", "information", "apparatus"), as it occurs in the epistemic conception of quantum states and its take on collapse, are discussed in Section 5.

The epistemic conception of states undermines the measurement problem in the form just discussed and offers an elegant justification of the otherwise mysterious collapse, but it does not guarantee by itself that the problem will not arise at a different stage in a different form. One objection critics are likely to raise, for instance, is that rejecting conceptual presuppositions of the measurement problem hardly suffices to account for why measurements have determinate outcomes in the first place. No-go theorems on assigning determinate values to observables (the Kochen-Specker theorem and its relatives in particular) make it unattractive to assume that observables do have determinate values at all times, so the question arises as to why observables which we measure never fail to exhibit determinate values at the end of a measurement process. Even though the epistemic conception of states dissolves the measurement problem in the sense of a sharp antinomy of conflicting assumptions, it does not by itself account for why measurements processes always result in determinate values of the observables measured. Different epistemic accounts of quantum states respond differently to this latter challenge, however, and I postpone the discussion of possible answers by the epistemic accounts of quantum states considered here to a later stage (see Section 5.2).

2.2 The problem of "non-locality"

The problem of whether quantum theory is compatible with the principles of relativity theory arises perhaps most blatantly in the challenge of reconciling the time-evolution of quantum states including collapse in whatever suitable form with the requirement of Lorentz invariance as inferred from relativity theory. To see this problem in an example, consider a two-particle system in an EPR-Bohm setup where two spin-1/2 systems A and B are prepared in such a way that those knowing about the preparation procedure assign an entangled state, for instance, the state $\frac{1}{2}(|+\rangle_A|-\rangle_B - |-\rangle_A|+\rangle_B)$ for their combined spin degrees of freedom. Assume further that the two systems A and B have been brought far apart and an agent Alice, located at the first system A, measures its spin in a certain direction. Having registered the result and having applied the projection postulate, she assigns two no longer entangled states to A and B, which depend on the choice of observable measured and on the measured result. Another agent, Bob, located at the second system B, may also perform a spin measurement (in the same or in a different direction of spin) and proceed to assign a pair of no longer entangled states to the two systems in an analogous way. Now the intriguing challenge concerning the compatibility of quantum theory and relativity theory is to specify at which time which system is in which state and to do so in a Lorentz invariant manner. The difficulty is most blatant for cases where the measurements carried out by Alice and Bob occur in spacelike separated regions, perhaps even in such a way that each of them precedes the other in its own rest frame (see [Zbinden et al. 2001]). In that case there is clearly no non-arbitrary answer to the question as to which measurement occurs first and triggers the abrupt change of state of the other. There exist attempts of overcoming this problem without completely abandoning either collapse or the notion of a state a quantum system is in by making the time-evolution of quantum states dependent on foliations of space-time into sets of parallel hyperplanes, but there does not seem to be general agreement as to whether this programme succeeds, and the approach remains controversial.[6]

The epistemic conception of quantum states undermines the conceptual presuppositions of the reasoning leading to this problem by rejecting the notion of a quantum state a quantum system is in and by interpreting the assignment of different states to the two systems by the different agents as at once legitimate and very natural: Alice knows about the preparation procedure for the combined two-particle system, and when she registers the result pertaining to her own system this affects her epistemic condition with respect to the second. The state she assigns to it reflects her epistemic relation to it, and there is no need to assume that her measurement of her own system physically influences the second. The same considerations apply for Bob. Predictions for the results of measurements derived on the basis of entangled states may still be baffling and unexpected, but the dynamics of quantum states do not give rise to any incompatibility between the principles of relativity theory and those of quantum theory as construed by the epistemic conception of states. The paradox of quantum non-locality (inasmuch as

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[6] See [Fleming 1989] for a hyperplane-dependent formulation of state reduction and [Myrvold 2002] for a more recent defence of that approach. For criticism see [Maudlin 2011], which, based on the presupposition that the ontic conception of states is correct, comes to a very negative verdict on whether relativity theory and quantum theory in its present form can be consistently combined at all.

it resides in the challenge of reconciling the time-evolution of quantum states with the principles of relativity theory) is *dissolved* by rejecting its conceptual presupposition, namely, the ontic conception of states and the interpretation of quantum theoretical time-evolution as a physical process.

In analogy to the case of the measurement problem, the dissolution of the problem of "non-locality" just outlined is no demonstration that there are no further problems linked to reconciling quantum theory with relativity theory. Several authors claim that there are some serious further problems, for instance by arguing that quantum theory violates a principle of *local causality*[7] and that this violation can only be accounted for by assuming superluminal causation. However, a shared presupposition of all theories to which such principles of local causality apply is to conceive of quantum probabilities as non-relative, agent-independent objective quantities. The epistemic conception of quantum states rejects this presupposition, which is closely related to the view that for any quantum system there exists one true quantum state it is in (for more details on the relation between the two views see Section 3), so according to this view quantum theory neither exhibits nor violates local causality in the specified sense. Another argumentative strategy found in the literature to establish that there exists a severe tension between quantum theory and relativity theory is to argue that quantum theoretical "non-local" correlations ground certain counterfactual claims which, it is claimed, can only obtain in the presence of superluminal causation.[8] Such arguments do not necessarily presuppose any specific view of quantum states, and, inasmuch as they don't, other moves are required to address them than adopting a non-ontic (or epistemic) account of quantum states. The most promising strategies seem to be either to question that quantum theory really licences the counterfactual claims at issue or to deny that they are really claims about causal connections.[9] Fortunately, it is largely irrelevant for the purposes of the present paper whether or not such counterfactuals deserve to be called "causal" as long as no incompatibility between quantum theory and the principles of relativity theory arises in a more straightforward sense (as most blatantly for the dynamics of collapse in the scenario investigated by [Zbinden et al. 2001] mentioned above). The epistemic conception of states may not completely dispel the felt tension between some aspects of quantum theory and relativity theory, but it arguably removes any clear-cut inconsistency between the two.

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[7] See [Bell 1990] for an account of why quantum theory violates local causality and [Seevinck and Uffink 2011] for a recent extension and sharpening of Bell's claims and results. See [Healey forthcoming c] for a detailed defence of the claim that "non-local" correlations obtained from quantum theory are not in any conflict with relativity theory. The rather sketchy remarks on this issue found in the main text of the present paper are strongly based on Healey's considerations. This holds, in particular, for the observation that the proposed principles of local causality apply to quantum theory only if certain interpretive assumptions are made which conflict both with Healey's pragmatist interpretation and the epistemic accounts of quantum states discussed here.

[8] See, for instance, [Butterfield 1992] and Chapter 5 of [Maudlin 2011] for such arguments.

[9] See [Healey forthcoming c], Section 7, for a detailed defence of the view that the connections between events which are stated in counterfactuals involving "non-local" correlations are not causal.

3 Two epistemic accounts of quantum states

Various different epistemic accounts of quantum states have been proposed, and it is not my aim to provide a systematic overview of them here. Rather, I shall focus on only two (very different) epistemic accounts of quantum states and discuss their respective problems and advantages in more detail. The first account is quantum Bayesianism, a position developed by C. M. Caves, C. A. Fuchs and R. Schack, supported in some of its central tenets by H. N. Barnum, M. D. Appleby (and perhaps other authors).[10] Its core idea is to interpret quantum probabilities as subjective degrees of belief in accordance with the subjective Bayesian take on probability. An exposition of the central claims and results of quantum Bayesianism is given in Section 3.1. The second account to be discussed, the *Rule Perspective*, combines ideas developed in [Friederich 2011] with ideas drawn from Richard Healey's recently proposed pragmatist interpretation of quantum theory (see [Healey forthcoming a]). Section 3.2.1 introduces it as an account of the rules governing the assignment of quantum states as *constitutive rules* in the sense of [Searle 1969]. Section 3.2.2 extends it to an account of quantum probabilities and the Born Rule.

3.1 Quantum Bayesianism

The central idea of quantum Bayesianism is that quantum probabilities, as encoded in quantum states via the Born Rule, are *subjective* probabilities in the subjective Bayesian sense. As such, they are construed as reflecting the state assigning agents' subjective degrees of belief as to what the results of their future "interventions into nature"[11] might be. Degrees of belief may legitimately differ from agent to agent without any of them behaving irrationally or making any kind of mistake. So, from the quantum Bayesian point of view different agents may indeed legitimately assign different quantum states to the same system, no notion of a quantum state as a state some quantum system "is in" is employed, and the position qualifies as a potentially consistent epistemic account of quantum states. According to Fuchs, "quantum states do not exist"[12] in that they are not part of the furniture of the world, they do not correspond to any physical facts or properties of physical system but, instead, represent the assigning agents' degrees of belief as to what the consequences of their actions on the systems the states are assigned to might be.

Quantum Bayesianism, as originally conceived, is not merely a novel philosophical perspective on quantum theory but also an ambitious programme of re-formulating the theory from the start in terms of probabilistic and information-theoretic notions rather than abstract mathematical ones such as Hilbert spaces and complex probability amplitudes. Such an information-theoretic re-formulation, it is hoped, might help us understand which elements of quantum theory represent physical features of the world and which others merely flow from what counts as rational reasoning of the agents applying the theory. The strategy Fuchs an-

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[10] See [Caves et al. 2002a], [Caves et al. 2002b], [Fuchs 2002], [Appleby 2005], [Caves et al. 2007],[Fuchs and Schack 2009], [Fuchs and Schack 2011], [Barnum 2010] for contributions and (essentially) approving comments to the quantum Bayesian programme and [Timpson 2008] for a highly useful review and critique.

[11] See [Fuchs 2002] p. 7.

[12] Thus the title of section II of [Fuchs 2010].

nounces for his programme is this: "Weed out all the terms that have to do with gambling commitments, information, knowledge, and belief, and what is left behind will play the role of Einstein's [space-time] manifold", namely, as he explains, "a mathematical object, the study of which one can hope will tell us something about nature itself, not merely about the observer in nature."[13] In what follows I shall not be concerned with the prospects and problems of this re-formulation programme for quantum theory, even though it certainly merits the attention it gets, but rather focus on the assumptions about the status of quantum observables, states and probabilities on which it is based.

One of the greatest achievements of quantum Bayesianism is its response to the challenge of not being able to make sense of talk about "unknown quantum states" (which has a prominent role, for instance, in quantum state tomography), even though, from the quantum Bayesian point of view, the notion of an "unknown quantum state" makes no sense. The result on which quantum Bayesians ground their response is the so-called *quantum de Finetti theorem*, which makes it understandable why different agents who register the same measured data generally come to agreement in their assignment of quantum states in the long run, even if the states they start out with are very different. The main presupposition used is that the agents (subjectively) judge the states of the sequence of measured systems to be exchangeable, roughly meaning that for all agents both the order of measured events and the number of measurements witnessed are irrelevant. As demonstrated by Caves, Fuchs, and Schack, this suffices to guarantee that "the updated probability $P(\rho|D_K)$ becomes highly peaked on a particular state ρ_{D_K} dictated by the measurement results, regardless of the prior probability $P(\rho)$, as long as $P(\rho)$ is nonzero in a neighbourhood of ρ_{D_K}"[14] This result can be used to account for the fact that the states assigned by different agents will converge after a sufficiently large number of measurements witnessed without postulating that there is any such thing as the agent-independent unknown *true* quantum state the states assigned by the different agents converge to. As this shows, taking seriously quantum theoretical practice inasmuch as it involves talk about "unknown quantum states" does not mean that one has to embrace an ontic account of quantum states, in which such talk is interpreted literally.

In order to be consistent as fully-fledged subjective Bayesian interpretation of quantum probabilities, quantum Bayesianism goes very far in interpreting elements of the quantum mechanical formalism as subjective. The view is particularly radical in its rejection of the innocently looking assumption that there can be an objective matter as to which observable some numerical value obtained in an experiment is a value of. To put it differently, quantum Bayesianism rejects the idea that the question of which observable is measured in which experimental setup ever has a determinate answer. In Fuchs' own wording the main motivation for this astonishing claim is the following:

> Take, as an example, a device that supposedly performs a standard von Neumann measurement $\{\Pi_d\}$, the measurement of which is accompanied by the standard collapse postulate. Then when a click d is found, the posterior quantum state will be $\rho_d = \Pi_d$ regardless of the initial state ρ. If this state-change rule is an objective feature of the

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[13] See [Fuchs 2002] p. 6.

[14] See [Caves et al. 2002b] p. 4541.

> device or its interaction with the system—i. e., it has nothing to do with the observer's subjective judgement—then the final state must be an objective feature of the quantum system. ([Fuchs 2002] p. 39)

According to this line of thought, if we suppose that the question of which observable some value obtained in an experiment is a value of has a determinate answer, applying the projection postulate to the state assigned to the system prior to measurement results in a uniquely determined post-measurement state, depending only on the observable measured and the measured result, not on the state assigned previously. But this means that assigning any other state than the one obtained from application of the projection postulate would be wrong. At least with respect to those cases where the post-measurement state has no dependence at all on the pre-measurement state (as in projective measurement of a non-degenerate observable), it seems difficult to avoid the conclusion that this must be the true quantum state of the system—the one it is in—, yet this conclusion is incompatible with a non-ontic reading of quantum states, according to which quantum states are in general not states quantum systems are in. Even in those cases where the post-measurement state has a residual dependence on the pre-measurement state, application of the projection postulate imposes strong constraints on the post-measurement state if one assumes that which observable has been measured and which value has been obtained are objective matters. Since such constraints severely restrict admissible state assignments, quantum Bayesians, for the sake of consistency of their subjective Bayesian take on probability, feel forced to deny that there can be an objective answer to the question of which observable some measured value is a value of.[15]

This conclusion, however, is extremely difficult to swallow. If there could be no fact of the matter as to which observable some measured value is a value of according to *all* versions of the epistemic conception of quantum states, one could well regard this result as a reductio of the epistemic conception of states itself. The main problems with this conclusion are, first, that in quantum theoretical practice there is virtually always agreement on which observable some value measured in some setup is a value of, and it seems difficult to imagine how quantum theory could be as empirically successful as it is if this were not the case. Second, if there were no fact of the matter as to which observable some measured value is a value of, there could never be any knowledge of the values of observables, at least not knowledge obtained in experiment. It seems clear, however, that physicists often do have knowledge of the values of at least some observables, and this makes the idea that there is no determinate answer to the question of which observable is measured in which setup even more problematic.[16] The account presented in the following subsection of this paper can be seen as an attempt to improve on quantum

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[15] An alternative move with the same consequences would be to accept that the question of which observable some measured value is a value of has a determinate answer while denying that which *mathematical object* (which linear operator, say) represents that observable is an objective matter, even after a Hilbert space representation of the canonical commutation relations has already been chosen and other observables have already been associated with linear operators. Since this option is for all dialectical purposes equivalent to the one discussed in the text I shall not consider it any more in what follows as a possible option for the quantum Bayesian.

[16] See [Friederich 2011], Section 3, for a more detailed version of this argument against the quantum Bayesian claim that there can be no fact of the matter as to which observable some value obtained in experiment is a value of.

Bayesianism in precisely these respects.

3.2 The Rule Perspective

3.2.1 Quantum state assignment

As I have argued, quantum Bayesianism's denial of the assumption that there can be any fact of the matter as to which observable some numerical value obtained in an experiment is a value of leads to serious problems. It seems therefore worth investigating whether one really needs to deny this assumption for consistency in epistemic accounts of quantum states. In what follows I shall give a brief argument that this is not the case. In particular, as I shall argue, abandoning the notion of a quantum state that a quantum system is in does *not* necessarily entail abandoning the notion of a quantum state assignment being performed correctly.

Assuming that there is an objective fact as to which observable some measured value is a value of, it seems plausible that agents having registered such a value must update the states they assign in a fixed and determinate way by applying the projection postulate, taking into account the measured result. However, even with respect to cases where this narrows down possible post-measurement states to assign to a uniquely determined (pure) quantum state, saying this is *not* the same as concluding that this state is the *true* post-measurement quantum state the system "is in" after measurement, which characterises the system in an agent-independent way. Other agents need not have had any chance to register the measured event due to how they are physically situated (outside the future light cone of the measurement process, say). In this case, if we take seriously the idea that quantum states should reflect the epistemic situations of the agents assigning them, assigning the same state as those who have registered the measured result would not only not be mandatory for those who haven't registered it, it would even be wrong, for it would not conform to what they know of the values of observables of the system. Furthermore, even if one interprets that state as somehow objectively privileged or distinguished, this does not mean that other (let alone *all*) quantum systems must have equally privileged quantum states (to be identified with their "true" ones), independently of whether there happen to be any agents having knowledge of the values of their observables. The assumption that even when there are no agents having knowledge narrowing down possible post-measurement states to a uniquely determined quantum state, there exists some state which *would have to be assigned* by anyone intending to assign correctly need not be made and does not go well with the epistemic conception of states. To conclude, admitting that there *can be* (and in general *is*) an objective matter as to which observable some measured value is a value of does not mean that one has to abandon the epistemic conception of quantum states.[17]

If one wants to combine an epistemic account of quantum states with the idea that the observable measured is an objective feature of the measuring device, sense has to be made of the idea of a state assignment being performed correctly without thereby acknowledging the notion of a quantum state a quantum system "is in". The account proposed in [Friederich 2011] does so by appealing to the rules accord-

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[17] See Section 4 of [Friederich 2011] for a defence of this line of thought against the anticipated charge that it accords too much weight to the state assignments of agents who are simply not well-informed about the measured system.

ing to which the assignment of quantum states is performed in the application of quantum theory, arguing that to assign in accordance with them is what it means to assign correctly. An example of a rule governing state assignment is unitary time-evolution as prescribed by the Schrödinger equation, which in this approach is regarded not as a fact about quantum states—that their time-evolution follows the Schrödinger equation—but as the rule an agent must apply to the state she assigns for all times t with respect to which no incoming data concerning the values of observables are registered. Other examples of such rules include the von Neumann projection postulate (and its generalisations such as Lüders' Rule and further generalisations in terms of POVMs) and the principle of entropy maximisation, which determines the state that must be assigned by an agent, depending on what she knows of the values of its observables, if she has not assigned any state before. From the perspective of this account the rules of state assignment are *constitutive* rules[18], that is, they are not strategies for obtaining (decent approximations to) the true quantum states quantum systems are in, but rather *define* the very notion of a quantum state assignment being performed correctly. Mastering these rules is a necessary requirement for being a competent user of quantum theory itself and applying them correctly is part of correctly applying the theory itself. Consequently, any *justification* for these rules—sometimes asked for with respect to the rules of state change in criticisms of epistemic accounts of quantum states[19]—comes in the form of empirical support and confirmation of the theory as a whole. Thus, the rules are constitutive of what it means to correctly assign a quantum state to a quantum system as well as partially fixing to the empirical significance of (the elements of) the formalism of the theory a a whole.[20] Due to the eminent role this account evidently attributes to the rules governing state assignment, I propose to refer to it, as already announced, as the "Rule Perspective". The next section discusses what quantum probabilities should be claimed to be probabilities *of* in the Rule Perspective.

3.2.2 Probabilities of what?

A plausible answer to the question of what quantum probabilities are probabilities *of* that goes very well with the account of the rules of state assignment just outlined has recently been given by Richard Healey in the context of his pragmatist interpretation of quantum theory [Healey forthcoming a]. A central notion in that interpretation is that of a *non-quantum magnitude claim* ("NQMC", for short), which refers to statements of the form "The value of observable A of system s lies in the set of values Δ". Healey calls such statements "non-quantum", arguing that "NQMCs were frequently and correctly made before the development of quantum theory and continue to be made after its widespread acceptance, which is why I call them non-quantum."[21] NQMCs essentially seem to be what for adherents of

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[18] The terminology is due to Searle. See [Searle 1969], pp. 33 f., for Searle's original, much more detailed account of the notion of a constitutive rule, contrasting it with that of a *regulative* rule, which both play an eminent role in Searle's philosophy of language.

[19] See, for instance, [Duwell 2011] for objections to Pitowsky's "objective Bayesian" approach of justifying the rules of state change by appeal to rational agents' betting behaviour in the context of quantum gambles.

[20] See [Friederich 2011], Section 6, for more details on this point.

[21] See [Healey forthcoming a] p. 22.

the Copenhagen interpretation were descriptions in terms of "classical concepts"[22], but Healey objects against calling such statements "classical" that doing so runs the risk of inviting the misleading impression that a NQMC "carries with it the full content of classical physics."[23] An endorsement of a NQMC is not to be construed as entailing any commitment to the view that the dynamics of the system at issue are described by classical laws of motion. In Healey's view, taken over in what follows in the Rule Perspective, NQMCs are crucial in the application of quantum theory in that they (not quantum states) have the linguistic function of describing the phenomena and regularities quantum theory is used to predict and explain.

NQMCs are naturally regarded as the bearers of quantum probabilities in the sense that probabilities are ascribed to them when derived from quantum states via the Born Rule

$$\mathrm{prob}_{\rho}(\mathrm{A} \in \Delta) = \mathrm{Tr}(\rho \Pi^{\mathrm{A}}_{\Delta}), \tag{1}$$

where ρ denotes the density operator assigned to the system and Π^{A}_{Δ} the projection on the span of eigenvectors of A with eigenvalues lying in Δ. To a first approximation, at least, we can read this equality as attributing a probability to a statement of the form "The value of A lies in Δ", that is, to a NQMC.

The Rule Perspective can adopt this straightforward reading of NQMCs as what quantum probabilities as probabilities of, but it has to acknowledge the no-go theorems due to Gleason, Bell, Kochen, Specker and others, which impose severe constraints on ascribing determinate values to the observables of a quantum system. One (or perhaps even "the") standard response to this difficulty is to interpret the Born Rule as attributing probabilities to NQMCs only inasmuch as they report on measurement outcomes. According to this view, the quantity $\mathrm{Tr}(\rho \Pi^{\mathrm{A}}_{\Delta})$ is interpreted as the probability of obtaining a value of A lying in Δ, assuming that A were to be measured. This (heavily instrumentalist) take on the Born Rule has the unappealing feature that it construes the empirical relevance of quantum theory as restricted to measurement contexts. In addition, it seems not to do justice to quantum theoretical practice, where claims about the values of observables are often considered (and Born Rule probabilities computed for them either explicitly or implicitly) without determining experimentally what these values really are.[24] In view of this observation the challenge of clarifying the appropriate range of applicability of the Born Rule becomes even more pressing.

Healey's pragmatist interpretation of quantum theory responds to this challenge in a way that arguably does justice to quantum theoretical practice. Appealing to environment-induced decoherence, it holds that an agent is entitled to apply the Born Rule to just those NQMCs which refer to observables for which taking into account the system's interaction with its environment renders the density operator assigned to the system (at least approximately) diagonal. In the words of Healey:

> Born-rule probabilities are well-defined only over claims licensed by quantum theory. According to the quantum theory, interaction of a

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[22] See, for instance, [Heisenberg 1958] p. 30.

[23] See [Healey forthcoming a] p. 8.

[24] See [Healey forthcoming a] pp. 9-16 for a discussion of recent experiments on environment-induced decoherence involving fullerene molecules that greatly elaborates and emphasises this point. See [Schlosshauer 2005] for a helpful introduction to decoherence and a clarification of its relevance for the presently most discussed interpretation of quantum theory.

> system with its environment typically induces decoherence in such a way as (approximately) to select a preferred basis of states in the system's Hilbert space. Quantum theory will fully license claims about the real value only of a dynamical variable represented by an operator that is diagonal in a preferred basis: it will grant a slightly less complete license to claims about approximately diagonal observables. All these dynamical variables can consistently be assigned simultaneous real values distributed in accordance with the Born probabilities. So there is no need to formulate the Born rule so that its probabilities concern only measurement outcomes. ([Healey forthcoming a] p. 15)

Healey spells out what he means by saying that some NQMC is "licensed" by quantum theory in terms of an inferentialist account of linguistic meaning that regards the content of NQMC as determined by what "material inferences"[25] an agent applying quantum theory is entitled to draw from it. In the context of the present investigation I would like to avoid the specific details of this inferentialist account and propose a slightly simplified picture according to which we may think of a NQMC of the form "The value of A lies in Δ" as "licensed" by quantum theory just in case an agent who applies quantum theory to the system in question is entitled to assume as the basis of all her further reasoning that the value of A either determinately lies within Δ or outside Δ.[26] In accordance with Healey's claim in the passage quoted above the Rule Perspective can now say that quantum theory "licenses" NQMC which refer to an observable A for an agent just in case the (reduced) density operator ρ that agent assigns to the system is at least approximately diagonalised in a preferred way by the spectral decomposition of A.[27] The Rule Perspective concurs with Healey's pragmatist interpretation in that it construes Born Rule probabilities as "well-defined only over claims licensed by quantum theory" in a given situation in precisely that sense.

Environment-induced decoherence is relevant here in that taking into account the system's coupling to its environment and performing the trace over the environmental degrees of freedom typically makes ρ (at least approximately) diagonal in an environment-selected basis. In settings functioning as measurement setups, used to determine the values of observables of some quantum system(s), the role of the environment is typically played by the system treated as the measurement apparatus, and the Hilbert space basis selected by decoherence typically coincides with an eigenbasis of the observable commonly referred to as "measured". This accounts for the fact that quantum theory, when employed with competence, licenses

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[25] See [Healey forthcoming a] p. 13. Section 3 of that paper spells out Healey's account of what it means for a NQMC to be licensed by quantum theory in far more detail.

[26] To what degree this simplified way of spelling out what it means for a NQMC to be "licensed" by quantum theory still captures the essence of Healey's more subtle inferentialist account is something I find difficult to assess. It is not impossible that the Rule Perspective, as presented here, may need some refinement in this respect, but the present formulation seems fine enough to allow for a defence of the Rule Perspective against the various objections discussed in later sections of this paper.

[27] It seems natural to assume that for degenerate observables an (approximately) block-diagonal form of the density matrix assigned should suffice for licensing application of the Born Rule. More detailed empirical investigations as to what is conceived of as a legitimate application of the Born Rule in quantum theoretical practice would be useful to say more on this matter.

application of the Born Rule in measurement contexts and thus yields probabilities for the possible values of the observable(s) the apparatus is supposed to measure.

As already remarked, Healey argues for his take on the Born Rule on the basis of an inferentialist theory of conceptual content. Inasmuch as it is simply an accurate statement of what counts as correct employment of the Born Rule in practice, however, it is independent of any particular philosophical take on linguistic meaning and content. Since the main motivation for the Rule Perspective is to dissolve the paradoxes by paying attention to quantum theoretical practice (where the paradoxes do not seem to arise as practical difficulties), it is natural to combine it with Healey's account of the Born Rule as applying to those NQMCs for which environment-induced decoherence makes the density matrix assigned (at least approximately) diagonal. These NQMCs may differ from agent to agent, so not only quantum probabilities themselves can be different for different agents but also their bearers.

4 Challenging the interpretation of probabilities

4.1 The means/end objection

Quantum Bayesianism construes quantum probabilities as subjective in the subjective Bayesian sense of individual agents' degrees of belief. Characterising the status of quantum probabilities in the Rule Perspective in terms of the subjective/objective divide is much less straightforward. On the one hand, they may be regarded as "subjective" in that view as well, as it is claimed that different agents ("subjects") having different epistemic conditions may legitimately ascribe different probabilities to one and the same NQMC. On the other, they are have an "objective" status in the Rule Perspective in that for sufficiently specified epistemic conditions of agents with respect to the values of observables the probabilities to be ascribed to the NQMCs are completely fixed by the rules governing state assignment together with the Born Rule. Depending on what aspects of the (philosophically very rich) notions "subjective" and "objective" one has in mind, quantum probabilities can be seen as either subjective or objective in the Rule Perspective or both.

Interpretations of quantum probabilities as subjective have been criticised on a number of grounds. Since quantum Bayesianism conceives of quantum probabilities as fully subjective and the Rule Perspective does so as well in at least one important respect (as just sketched), I consider in what follows two especially pointed (closely related) criticisms of such accounts, which were originally formulated by Chris Timpson as objections to the quantum Bayesian take on quantum probabilities as subjective degrees of belief. My conclusion will be that despite the important points of agreement between the two positions, the objections apply only to quantum Bayesianism.

The objection I consider first is one that Timpson refers to as the *means/ends objection*. Its underlying idea is that any account which denies quantum probabilities the status of objective features of the world inevitably must make it mysterious how the theory helps us achieve even the modest goal of "the pragmatic business of coping with the world"—let alone the more ambitious goal of "finding out how the world is."[28] According to Timpson, interpreting quantum probabilities not as

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[28] See [Timpson 2008] p. 606.

objective single case probabilities makes it unclear why updating our assignments of probabilities in the light of new data should be useful and enhance our predictive success: "[I]f gathering data does not help us track the extent to which circumstances favour some event over another one (this is the denial of objective single case probability), then why does gathering data and updating our subjective probabilities help us do better in coping with the world?"[29] What makes Timpson's worries most pressing for quantum Bayesianism is that, for the quantum Bayesian, *in which way* an agent should update her probability assignments in the light of new data is a matter of mere subjective preference alone. The reason for this is that according to her position there is no fact of the matter as to which observable has been measured and what kind of update the data prescribe. On this view, the predictive and pragmatic success of quantum theory—why it helps us "coping with the world"—is mysterious: If there is no objective answer as to *how* some assignment of probabilities should be updated in the light of new evidence, it becomes a miracle that updating probabilities as we do is of use. Thus we see that the main force of the means/ends objection to quantum Bayesianism, as we see, derives from that position's denial of the assumption that we can ever know what observable some measured value is a value of.

Timpson outlines a possible quantum Bayesian reply to this challenge "of broadly Darwinian stripe". According to this reply, "[w]e just do look at data and we just do update our probabilities in light of it; and it is just a brute fact that those who do so do better in the world; and those who do not, do not."[30] This response, however, as he argues, is ultimately unsatisfying in that it does not address the original worry, namely, "why do those who observe and update do better[.]"[31] Given that according to quantum Bayesianism no way of updating in the light of incoming data counts as correct (in contrast to all others), this challenge is really serious.

However, this difficulty applies specifically to quantum Bayesianism, it is not generic in epistemic accounts of quantum states. The Rule Perspective, for instance, avoids it. To see this, recall that according to the Rule Perspective quantum theory helps us determine and predict which *non-quantum* claims (NQMCs) are true. So, on this view the theory is not only a tool that helps us with the "business of coping with the world" but also with the more ambitious one of "finding out how the world is", as Timpson calls it. In contrast with quantum Bayesianism, the Rule Perspective concedes that we often do have knowledge of the values of observables, and it regards the practice of making probability ascriptions and updating them in the light of new evidence as directed at the aim of improving that knowledge in various (direct and indirect) ways. Furthermore, it insists that in any sufficiently specified epistemic situation, there exists an objective fact of the matter as to how, according to the theory, the updating of probabilities must be made in the light of new evidence. There remains no "explanatory gap"[32], as Timpson objects to quantum Bayesianism, between the methods of enquiry—assigning quantum states and deriving probabilities from them—and the goals it seeks to achieve—broadly (and somewhat crudely) speaking, to determine true NQMCs. Furthermore, since knowledge about "how the world is" enhances our abilities in "the pragmatic busi-

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[29] Ibid. p. 606.

[30] Ibid. p. 606.

[31] Ibid. p. 606.

[32] Ibid. p. 606.

ness of coping with the world", it is small wonder that quantum theory helps us with the latter if it helps us with the first.

4.2 The quantum Bayesian Moore's paradox

The second of Timpson's criticisms against the interpretation of quantum probabilities as subjective focuses on assignments of probability 1. According to Timpson, if one conceives of quantum probabilities as subjective degrees of belief (as definable, for instance, in terms of the agents' betting behaviour), this commits one to the systematic endorsement of pragmatically problematic sentences of the form of a "quantum Bayesian Moore's paradox". Sentences of this type are cousins of the better known "Moore's paradox" sentences, invented by G. E. Moore, which are characterised by having the form

> p, but I don't believe that p.

There is a long-standing philosophical debate on the status and proper interpretation of these sentences, in particular as to whether they involve a pragmatic or even a semantic contradiction, but there seems to be agreement on their paradoxical nature, as Timpson claims, inasmuch as they "violate the rules for the speech act of sincere assertion."[33] Timpson argues that by interpreting quantum probabilities as subjective degrees of belief and by denying that there is such a thing as *the* quantum state a quantum system is in, quantum Bayesianism is committed to the systematic endorsement of sentences having a similar structure and a similar kind of paradoxical flavour. The problem he diagnoses arises in connection with the assignment of quantum states ascribing probability 1 to one possible value of an observable. Typical examples of practical importance include the assignments of *pure* quantum states, which ascribe only probabilities 0 or 1 to the possible values of observables they are eigenstates of. The problem arises from considering an agent who consciously accepts the quantum Bayesian take on quantum probabilities as subjective degrees of belief and assigns a pure quantum state to a system, for instance the state $|\uparrow_z\rangle$ for the spin degree of freedom of a spin-1/2 system. Such an agent, according to Timpson, "must be happy to assert sentences like: 'I assign a pure state (e. g. $|\uparrow_z\rangle$) to this system, but there is no fact about what the state of this system is.'"[34] In other words, any quantum Bayesian agent is committed to the systematic endorsement of sentences of the form:

> "**QBMP:** 'I am certain that p (that the outcome will be spin-up in the z-direction) but it is not certain that p.'" ([Timpson 2008] p. 604. The acronym "QBMP" stands for "quantum Bayesian Moore's paradox".)[35]

For a quantum Bayesian, an ascription of probability 1 to the value of an observable signals complete certainty as to what the outcome of measurement of that observ-

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[33] See [Timpson 2008] p. 602.

[34] Ibid. p. 604.

[35] The analogy to Moore's original sentence "p, but I don't believe that p" can be made more transparent if the part of the QBMP which reports on the agent's epistemic conditions is put second, just as in Moore's original sentence. (I would like to thank Jeremy Butterfield for pointing this out to me.) A formulation that fulfils this requirement is: "It is uncertain whether p, but I am not uncertain whether p (that is, I am absolutely certain that p)."

able will be, but her subjective Bayesian take on probabilities (including probability 1) implies that she cannot claim that there is any *objective* certainty as to what the measurement outcome since she cannot countenance any “fact determining what the real state is.”[36] Sentences of the form of the QBMP seem pragmatically problematic since expressing absolute certainty seems irrational if one does not believe it to be grounded in facts. Timpson notes that similar-structured paradoxical features of ascriptions of probability 1 are generic in accounts that are based on the subjective Bayesian take on probability and arise not only in the context of quantum Bayesianism. However, whereas subjective Bayesians in other contexts are in principle free to simply refrain from making assignments of probability 1, quantum Bayesians must make them unless they abandon the assignment of pure states. As Timpson notes, “the occurrence of these paradoxical sentences isn’t just an occasional oddity which can be ignored” but one which “arises whenever one finds a quantum Bayesian who is happy to assign pure states and is also explicit about what their understanding of the quantum state is.”[37]

As Timpson points out, quantum Bayesians may react to this problem by adopting a perspective on pure states that is similar to that of ethical non-cognitivism with respect to moral discourse. In analogy to how non-cognitivists may aspire to explain why endorsing moral claims is legitimate in the absence of moral facts, quantum Bayesians might “elaborate on how there can be a role for personal certainty within our intellectual economy which is insulated against the absence of any impersonal certainty.”[38] Whatever the prospects of this defence, the main problem remains that it is unclear how being certain can be rational if at the same time one denies that there are any facts on which one’s certainty might be grounded.

To decide whether the Rule Perspective is committed to the systematic endorsement of QBMP sentences just as much as quantum Bayesianism, we have to recall that the crux of Timpson’s derivation of the QBMP in quantum Bayesianism is his paraphrase of “I ascribe probability 1 to ‘*p*’” with “I am certain that *p*”. This identification makes sense in the quantum Bayesian context inasmuch as this position construes quantum states as “states of knowledge rather than states of nature”[39] and interprets quantum probabilities as subjective degrees of belief. On a plausible reading of this claim, adopted by Timpson, quantum probabilities represent the assigning agents’ degrees of beliefs, not any properties of physical objects. On this reading, the probabilities derived from the quantum state assigned by an agent should always match this agent’s degrees of belief about possible outcomes, for this condition must be met by the state to merit the title of her actual “state of belief”. Timpson paraphrase of “I ascribe probability 1 to ‘*p*”’ with “I am certain that *p*” relies on a reading of the quantum Bayesians’ claim that quantum states are “states of belief” along precisely these lines.

The Rule Perspective evades the quantum Bayesian Moore’s paradox by denying that quantum states are to be conceived as “states of belief” in the first place. On this view, in accordance with Healey’s pragmatist interpretation of quantum theory, the role of quantum states is, first, to licence application of the Born Rule to some non-quantum claims and, second, to actually compute the Born Rule probabilities for these claims. Probabilities derived from the Born Rule need not correspond to

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[36] Ibid. p. 605.

[37] Ibid. p. 605.

[38] Ibid. p. 606.

[39] See [Caves et al. 2002b] p. 4537.

our actual degrees of belief (inasmuch as these are defined at all), even though we employ them when forming our beliefs as to what values the observables we are concerned with are likely to have. As an epistemic account of quantum states the Rule Perspective holds that what state an agent *should* assign depends on her epistemic situation, but this isn't the same as construing the state (or the probabilities derived from it) as *coinciding* with the agent's actual degrees of beliefs. Quantum state assignments, on this view, are correct if performed in accordance with the rules of state assignment, independently of whether the probabilities derived from the states really correspond to the agents' degrees of belief.

The application of quantum theory in practice supports this view: The question of whether or not the probabilities assigned to the possible values of observables of some system precisely coincide with the degrees of belief of the agents carrying out the experiment plays no role when judging whether their state assignments are adequate. Saying this of course does not mean to deny that the states they assign have ramifications for their beliefs about outcomes of their experiments.

To sum up, while the Rule Perspective construes quantum probabilities as subjective (or at least non-objective) in one sense by allowing that probability assignments may legitimately differ from agent to agent, it does not interpret quantum probabilities as directly corresponding to the agents' degrees of beliefs. The quantum Bayesian translation of "I ascribe probability 1 to '*p*' " with "I am certain that *p*" is unacceptable for the Rule Perspective, and this blocks the derivation of the quantum Bayesian Moore's paradox.

5 Challenging anthropocentric notions

5.1 Bell's criticism

Quantum Bayesianism and the Rule Perspective are formulated in terms of notions such as "agent", "epistemic situation" and "state assignment", which are neither themselves fundamental physical notions nor in any evident way reducible to such notions. In the present section I discuss an objection against the employment of such "*anthropocentric* notions" (as I will call them in what follows), which claims that these notions are far too vague and too imprecise to be used in foundational accounts.[40]

Let us first have a more precise look at the role of anthropocentric notions in epistemic accounts of quantum states. The notion of an *agent*, to begin with, is employed in the statement of the epistemic conception of quantum states itself, claiming that quantum states reflect the assigning agents' epistemic conditions with respect to the system states are assigned to. This idea, evidently, cannot be expressed without relying on some notion of a subject having an epistemic condition and assigning a quantum state. The notions "epistemic condition" and "state assignment" themselves are no less anthropocentric than "agent" (or "subject"), and they appear equally irreducibly and ineliminably in the statement of the epistemic conception of states itself. In addition, some relative of the notion of measurement is employed in both quantum Bayesianism and the Rule Perspective: In the case

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[40] See [Bell 1990] p. 209 for a list of anthropocentric notions frequently encountered in formulations of quantum mechanics which, according to Bell, are ill-suited for the purposes of foundational debates.

of quantum Bayesianism the relevant notion is that of an "experimental intervention[...] into nature"[41], in the case of the Rule Perspective it is that of an event resulting in "new knowledge" of the values of observables, to be taken into account when updating one's state assignment in accordance with Lüders' Rule. Different epistemic accounts of quantum states use different anthropocentric notions, but in view of the crucial role which anthropocentric notions play in the statement of the epistemic conception of states itself and in the more detailed considerations of the two versions discussed here it seems highly plausible that epistemic accounts of quantum states cannot dispense with them altogether.

Interpretations of quantum theory that rely on anthropocentric notions are heavily criticised by some of the most distinguished interpreters of the theory. J. S. Bell, for instance, claims that such notions are not sufficiently sharp and fundamental to be used in foundational accounts of the theory. Among the words which, according to him, "however legitimate and necessary in application, have no place in a *formulation* with any pretension to physical precision"[42] one finds, for instance, "observable, information, measurement", which, evidently, are close relatives of the anthropocentric notions encountered in the epistemic accounts of quantum states discussed here. Bell's main complaint concerns the role of these notions in accounts which postulate the occurrence of measurement collapse whenever a quantum system is measured. Famously, Bell comments sarcastically on this idea:

> What exactly qualifies some physical systems to play the role of 'measurer'? Was the wavefunction of the world waiting to jump for thousands of millions of years until a single-celled living creature appeared? Or did it have to wait a little longer, for some better qualified system ... with a PhD? If the theory is to apply to anything but highly idealised laboratory operations, are we not obliged to admit that more or less 'measurement-like' processes are going on more or less all the time, more or less everywhere? Do we not have jumping then all the time? ([Bell 1990] p. 209.)

Bell's criticism of the textbook picture of measurement collapse as occurring whenever the system is measured seems very reasonable and intuitive. However, it does not directly apply to the versions of the epistemic conception of quantum states considered here. These deny that there is such a thing as *the* wavefunction of a quantum system with respect to which the question of when it "jumps" can be meaningfully asked. In particular, according to these accounts there exists no such thing as a "wavefunction of the universe", which at one point "jumps" for the first time in its history. Primitive anthropocentric notions are indeed used in the accounts considered here, but their role is not that of specifying under which conditions which physical process takes place but to characterise, on a conceptual level, the elements of the formalism of quantum theory as employed by competent physicists.

The difference between these two different kinds of appeal to anthropocentric notions is clarified by Fuchs in his quantum Bayesian characterisation of quantum theory as a "users' manual that *any* agent can pick up and use to help make wiser decisions in this world of inherent uncertainty."[43] In this picture of quantum theory,

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[41] See [Fuchs 2002] p. 7 and various other places.

[42] See [Bell 1990] p. 209. The emphasis is Bell's.

[43] See [Fuchs 2010] p. 8.

the theory is construed as an empirical extension of subjective Bayesian probability theory, where probability theory, in turn, is construed as an "extension of logic".[44] Fuchs convincingly argues that on this conception quantum Bayesianism cannot be asked to deliver a reductive analysis of notions such as "agent" any more than philosophers of logic can be asked to deliver a reductive account of notions such as "logical subject" (that is, the notion of an agent employing of the methods of logic):

> [I]s ... quantum mechanics ... obligated to derive the notion of agent for whose aid the theory was built in the first place? The answer comes from turning the tables: Thinking of probability theory in the personalist Bayesian way, as an extension of formal logic, would one ever imagine that the notion of an agent, the user of the theory, could be derived out of its conceptual apparatus? Clearly not. How could you possibly get flesh and bones out of a calculus for making wise decisions? The logician and the logic he uses are two different substances—they live in conceptual categories worlds apart. One is in the stuff of the physical world, and one is somewhere nearer to Plato's heaven of ideal forms. Look as one might in a probability textbook for the ingredients to reconstruct the reader himself, one will never find them. So too, the Quantum Bayesian says of quantum theory. ([Fuchs 2010] p. 8 f.)

Fuchs' point is that if quantum theory is conceived of as normative, namely, as a "manual" to "make wiser decisions", one can hardly expect that the notion of an agent applying the methods of that manual might be spelled out in terms of the manual's own notions. Thus, Bell's criticism of the employment of anthropocentric notions in interpretations of quantum theory does not seem to apply to the epistemic accounts of quantum states considered here due to *how* they rely on such notions. Fuchs' comparison between quantum theory and logic might be criticised on grounds that quantum theory, unlike logic, is a physical theory and that agents using quantum theory and the world they live in are themselves (aggregates of) objects studied in physics, whereas agents availing themselves of the methods of logic and the world they live in are not (aggregates of) objects studied in logic (whatever exactly one takes these to be). The crucial point of Fuchs' argument, however, is that in quantum Bayesianism anthropocentric notions are employed at the *meta-level* of characterising the status of quantum theoretical concepts—claiming that quantum states are used non-descriptively, for instance—not at the *object-level* of describing physical processes themselves—such as physical collapse and under which conditions it occurs. The textbook accounts criticised by Bell, in contrast, make object-level use of anthropocentric notions in that they conceive of measurement collapse as a physical process that takes place whenever the system is measured.

To sum up, Bell's verdict against anthropocentric notions in foundational accounts seems reasonable only with respect to accounts which invoke these notions at the object-level of physical processes. There is no reason to extend it to accounts which use anthropocentric notions to clarify the status and linguistic role of the elements of the quantum theoretical formalism. Inasmuch as this is what quantum Bayesianism and the Rule Perspective do, they are not concerned by Bell's criticism. The following subsection investigates whether the restriction of appeal

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[44] See [Fuchs 2010] fn. 14 on p. 8.

to anthropocentric notions to the meta-level of conceptual clarification can coherently be upheld in view of challenges related to the determinateness of values of observables.

5.2 Anthropocentric notions and value determinateness

In debates about the foundations of quantum theory it is often claimed that appeal to "measurement" should not be understood as entailing the existence of a value of the quantity taken to be "measured" prior to the measurement act. The idea that in the context of quantum theory "measurement" should be construed as denoting an act of *creation* of something thereby brought into existence rather than an act of establishing the existence of something already there has a long tradition. Pascual Jordan, for instance, implicitly endorses such a notion of measurement when he writes that it is "we ourselves [who] bring about the matters of fact"[45] which we usually think of as being determined in experiments. Similar ideas can be found in the writings of adherents of the epistemic conception of quantum states, for instance in those of the quantum Bayesians Fuchs and Schack, who claim that the "measured values" of observables are not merely "'read off'" in measurement but rather "enact[ed] or creat[ed] ... by the [measurement] process itself."[46]

Quantum Bayesianism's main motivation for denying the existence of determinate values prior to measurement is the conflict between assuming such values and the famous no-go theorems on determinate value assignments originating from Gleason, Bell, Kochen and Specker. As explained in Section 3.1, quantum Bayesianism denies that we can ever know which observable some numerical value obtained in an experiment is a value of, but it doesn't go as far as claiming that observables do not have any values at all. Given this assumption, quantum Bayesianism is drawn to the conclusion that determinate values are created only in the act of measurement itself. In the words of Fuchs:

> QBism [i. e., quantum Bayesianism fleshed out by Fuchs] says when an agent reaches out and touches a quantum system—when he performs a quantum measurement—that process gives rise to birth in a nearly literal sense. With the action of the agent upon the system, the no-go theorems of Bell and Kochen-Specker assert that something new comes into the world that wasn't there previously: It is the "outcome," the unpredictable consequence for the very agent who took the action. ([Fuchs 2010] p. 8.)

And a few pages later:

> That the world should violate Bell's theorem remains, even for QBism, the deepest statement ever drawn from quantum theory. It says that quantum measurements are moments of creation. ([Fuchs 2010] p. 14)[47]

The problem with the construal of "quantum measurement" as a type of "birth" or "creation" as advocated by the quantum Bayesians is that this move seems to

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[45] See [Jordan 1934] p. 228, my translation.

[46] See [Fuchs and Schack 2011] p. 3.

[47] See the rest of Section V of [Fuchs 2010] for a detailed argument using Bell-Kochen-Specker-type reasoning for the view that measurements bring about the values of observables determined through them.

lead straightforwardly to an application of “measurement” in what according to the terminology used in the previous subsection counts as an *object-level* type of way. In this case, it is not the occurrence of collapse as a physical process which is taken to occur when a measurement is performed, but the “birth” of the value of an observable when it is measured. According to these considerations, it seems that quantum Bayesianism is unable to confine its employment of anthropocentric notions to the meta-level of conceptual clarification alone, in which case Bell’s criticism applies after all.

From a general perspective, the challenge of accounting for determinate post-measurement values without relying on object-level anthropocentric notions can be construed as a re-appearance of the measurement problem in disguise: As explained in Section 2.1, the original measurement problem is dissolved in epistemic (or, more generally, non-ontic) accounts of quantum states by rejecting the notion of the quantum state a quantum system is in, but the question as to why measurement processes, as a matter of fact, do always result in determinate outcomes remains unaddressed. It is tempting to read the passages of the quantum Bayesians on “quantum measurement” as a type of “birth” or “creation” as a response to this challenge that invokes primitive anthropocentric notions at the object-level. In that case, however, it would still be concerned by Bell’s criticism and its dissolution of the measurement problem could not be considered successful.

To defend themselves against this charge, quantum Bayesians may point out that to conceive of measurement as an act of “birth” of the value of an observable is not the same as using “measurement” to *define* under which conditions determinate values are assumed. Indeed, in their writings quantum Bayesians never try to use “measurement” (or a related notion) to define a criterion of under which conditions which observables have determinate values. Rather, as Fuchs claims, “for the QBist, the real world ... —with its objects and events—is taken for granted”[48], which one may take to be saying that quantum Bayesianism presupposes the existence of “events” in which the values of observables become determinate as a primitive fact without any need of a further grounding. They might add that among these events are the “measurement events”—which are those which we use to obtain information as to what the values of observables really are. Phrased differently (and perhaps somewhat crudely): Observables do not assume determinate values *because* some process is a measurement process (an idea analogous to the one ridiculed by Bell), but we *call* certain processes measurement processes because the values of observables taken to be “measured” are determinate at their end (in such a way that we can obtain information about them). The quantum Bayesian account of “measurement” as an act of “birth” thus does not necessarily lead to the employment of anthropocentric notions at the object-level.

What quantum Bayesianism does not account for, however, is how physicists can be so confident as they manifestly are as regards in which setup the values of which observables come out determinate. The Rule Perspective is in a better position than quantum Bayesianism in this respect in that it construes quantum theory as entailing that determinate values of the observables meant to be measured are precisely what competent users of quantum theory *should expect.* To see this, we have to recall some elements of the discussion of what quantum probabilities are probabilities *of* in the Rule Perspective.

Here we may schematically think of a measurement setup as a two-part system,

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[48] See [Fuchs 2010] p. 7.

which consists of a “measured system” S_1 on the one hand and a “measurement apparatus” S_2 on the other, such that information about the value of the “measured observable” A (pertaining to the measured system) can be gained from taking in the value of the “pointer” observable X (pertaining to the apparatus and discriminating between different display configurations). Now, what it takes for a system to qualify as a candidate “measurement setup” is that effects from environmental decoherence, when they are taken into account, will render the density matrix assigned to the combined system $S_1 \cup S_2$ approximately diagonal in an eigenbasis of $A \otimes X$. As the Rule Perspective claims (following Healey, see Section 3.2.2), quantum theory in this case “licenses” (Healey’s wording) various NQMCs which state that the values of A and X lie in ranges Δ_A and Δ_X of possible values the observables A and X might assume. From the point of view of the Rule Perspective, to treat a NQMC of the form “The value of A lies in Δ_A” as “licensed” by quantum theory means to proceed by assuming that the value of A either determinately lies within Δ_A or determinately outside Δ_A. Quantum theory thus gives the agent an entitlement to treat the values of both the “measured” and the “pointer” observable as determinate (at least within bounds as determined by decoherence), so insisting that these observables do *not* have determinate values (whatever this would practically mean) would mean failing to apply the theory correctly.

The Rule Perspective, to sum up, not only dissolves the measurement problem by undermining its formulation in terms of quantum states quantum systems “are in” but allows the further claim that outcome determinateness in measurement contexts is precisely what competent users of the theory are entitled to assume. If an experimental setup is supposed to measure the value of an observable A of some system but is such that taking into account decoherence effects does *not* give agents an entitlement to treat the value of A as determinate, the setup simply does not qualify as a candidate “measurement setup” for A. Making sure that the setup qualifies as a “measurement setup” for A, in other words, is the same as making sure that one has an entitlement to assume that the value of A is going to be determinate in it. Without appealing to primitive anthropocentric notions at the object-level, this accounts for why outcome determinateness is something that physicists can be taken for granted in practice.

6 Challenging explanation without ontic quantum states

6.1 The micro/macro divide

One of the core elements of the epistemic conception of quantum states is that it conceives of quantum states as non-descriptive. In this section, I consider the criticism that *any* non-descriptive reading of quantum states entails an unattractive ontological quantum/classical divide, separating a realm of classical macro-objects the properties of which are susceptible to descriptions from a realm of quantum micro-objects the properties of which are not. The claim that an ontological divide of this kind comes hand in hand with an epistemic account of quantum states is made with respect to quantum Bayesianism by Timpson, who does not regard it as giving rise to an insuperable challenge to quantum Bayesianism, however. The ontological framework which, according to him, goes best with quantum Bayesianism comprises, on the one hand, a “micro-level we have dubbed unspeakable to which we are denied direct descriptive access"[49] and, on the other hand, a "macroscopic or classical level [which] will be a level of objects which do have unproblematically stateable truths about them."[50] Such a two-part ontological framework is confronted with obvious difficulties such as that of making sense of a world that comprises to such utterly different levels of reality in the first place as well as that of specifying where the line between the levels should be drawn. Drawing on ideas from Nancy Cartwright's philosophy of science, Timpson suggests that it can be made coherent if one admits at the macro-level "metaphysically emergent properties [which] a composite can possess but which its components cannot[,] and which are not conferred on it by the properties possessed by its components and the laws (if any) which they obey."[51] As he seems to suggest, accepting such properties and their anti-reductionist ramifications is the price to be paid for a non-descriptive reading of quantum states.

Despite the unorthodox character of the two-level ontology which he sketches Timpson claims that "[i]f called upon, ... the quantum Bayesian seems able to present an intelligible ontology to underlie their position."[52] Others are more sceptical as regards the intelligibility of a two-level ontology comprising a level of objects that admit a descriptive account and a level of objects which don't. Marchildon, for instance, regards the empirically manifest fact that macroscopic objects "are always in definite states"[53] as difficult to account for by epistemic accounts of quantum states. According to him, these have to choose between the three equally unattractive claims that either microscopic quantum objects "do not exist", that they "may exist, but have no states" or that they "may exist and may have states, but attempts at narrowing down their existence or specifying their states are useless, confusing, or methodologically inappropriate."[54] As he sees it, all these options are implausible, given that the "unspeakable" (Timpson's expression) microscopic objects are the (mereological) constituents of the macroscopic objects for which unproblematic "definite states" do exist. In response to this criticisms the option of resorting to a two-level ontology based on metaphysically emergent properties may come to the rescue for the quantum Bayesian, but the challenge of combining a macro-level of describable "classical" objects and a micro-level of "unspeakable" quantum objects in a coherent metaphysical framework remains formidable nevertheless. However, as I shall argue now, the example of the Rule Perspective shows that a two-level ontology of this kind is not necessarily part of an epistemic account of quantum states.

To see this, it is useful to recall that the contrast between the descriptive character of NQMCs and the non-descriptive character of quantum states refers to a difference in the linguistic roles of the statements, not to a contrast between distinct realms of objects they are about. Quantum states can legitimately (and with much theoretical gain) be assigned to objects of arbitrarily large "macroscopic" size, for instance by using the many-particle methods of quantum statistical mechanics, so their application is not confined to the micro-regime. At the same time, the most "microscopic" quantum objects elementary particle physicists have discovered

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[49] See [Timpson 2008] p. 597.

[50] Ibid. p. 598.

[51] Ibid. p. 599.

[52] Ibid. p. 600.

[53] See [Marchildon 2004] p. 1462.

[54] Ibid. p. 1462.

(quarks, leptons, and gauge bosons may be named) can very well be described in terms of NQMCs—with the caveat that not all NQMCs are licensed at all times—just as much as the largest objects of cosmology. There is even a close interplay between the application of NQMCs and the assignment of quantum states to one and the same quantum system: Agents assign a quantum state on the basis of their epistemic relation to the system—that is, on the basis of what NQMCs they know to be true of the system—, and the "licensing" of further NQMCs depends on the features of the quantum states they assign. The distinction between quantum states and non-quantum claims, on this view, corresponds to a difference in linguistic roles and tasks, not to a difference between different types of objects referred to.

As these considerations show, epistemic accounts of quantum states need not commit themselves to an ontological micro/macro divide. The Rule Perspective, in particular, does not lead to a two-level ontology where a "classical" macro-level contrasts with an "unspeakable" quantum micro-level. Furthermore, as I shall argue in what follows, from this perspective there is no particular problem in non-ontic accounts of quantum states to account for reductive explanation of macro-properties in terms of the behaviour of micro-objects.

6.2 Explanation without ontic quantum states

Quantum theory is perhaps the theory with the greatest explanatory success in the history of science, and any interpretation of it that is incapable of accounting for this success has serious shortcomings. The final objection against epistemic accounts of quantum states to be discussed here is that non-descriptive readings of quantum states (not involving hidden variables) are *in general* incompatible with quantum theory's incontestable explanatory force. Timpson has explicitly raised this charge against quantum Bayesianism by (rhetorically) asking "if quantum mechanics is not to be construed as a theory which involves ascribing properties to micro-objects along with laws describing how they behave, can we account for [its] explanatory strength?"[55] According to Timpson, the quantum Bayesian interpretation of quantum states as "states of belief" entails that all that can possibly be accounted for by means of quantum theoretical reasoning involving quantum states are agents' beliefs and expectations, not physical phenomena themselves. As an example, Timpson considers the explanation provided by quantum many-particle theory as to why some solid materials (sodium, in his example) conduct electricity well, whereas others don't, and remarks that "[u]ltimately we are just not interested in agents' expectation that matter structured like sodium would conduct; we are interested in *why in fact it does so*."[56] Quantum theory, as Timpson emphasises, helps us explain the behaviour of physical systems only because its vocabulary refers to these systems themselves, not to the scientists and their expectations and beliefs about them. Any interpretation of quantum theory that attempts to account for its explanatory force must respect this.

There is a natural response by means of which quantum Bayesians may attempt to address this challenge. It starts with the observation that on the quantum Bayesian account of the quantum theoretical formalism as a "manual ... to help make wiser decisions"[57] the theory does not say anything about what agents actu-

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[55] See [Timpson 2008] p. 600.

[56] Ibid. p. 600.

[57] See [Fuchs 2010] p. 8.

ally *do* believe, but rather about what they *should* believe in which circumstances to maximise their predictive success. On this reading, quantum theory does not so much *describe* our expectations and beliefs but rather *prescribes* what we should expect and believe under which conditions. At this point, one may ask why the reasoning which leads to the expectation that some physical phenomenon or regularity should occur cannot count as a candidate quantum theoretical explanation of precisely that phenomenon or regularity, contrary to what Timpson suggests.

Unfortunately, this question leads directly into the troubled waters of the longstanding debate in the philosophy of science concerning the general relation between explanation and prediction, which is far too involved to be entered in the context of the present investigation. To keep matters simple, however, we can proceed by assuming that the quantum Bayesian—or the proponent of any other epistemic account of quantum states facing the same challenge—may simply regard it as a *ramification* of her view that to account for why some phenomenon or regularity is to be expected when correctly applying quantum theory (and in that sense predicting it quantum theoretically) is just what it *means* to explain that phenomenon or regularity by means of quantum theory. In precisely this vein Healey bases his pragmatist account of "how quantum theory helps us explain"[58] on the idea that "[t]o use a theory to explain a regularity involves showing the regularity is just what one *should expect* in the circumstances, if one accepts that theory."[59] To apply this idea to the example proposed by Timpson, consider an agent who competently applies quantum many-particle theory in solid state theory and arrives at the expectation that matter having the structure and composition of sodium should conduct electricity well. There seems to be no categorical reason of why her reasoning should not qualify as a candidate quantum theoretical explanation of the phenomenon or regularity at issue. In any case, the quantum theoretical reasoning used is not *about* the agent's expectation and beliefs, even though it certainly functions as a guide for the agent when forming them. Quantum Bayesians may claim that in view of these considerations they can account very well for quantum theory's explanatory force since they do not construe the theory as describing what agents actually do belief and expect, but, instead, what they *should* belief and expect.

Unfortunately, however, this response is not open to them, and the main reason for why not is again their rejection of the notion of a state assignment being performed correctly. According to this rejection, it does not make sense to ask whether some quantum theoretical reasoning that involves the assignment of quantum states is correct or incorrect, so, according to this view, quantum theory does not actually have the prescriptive bite which the line of defence just considered assumes that it has. Moreover, for any supposed quantum theoretical explanation the question of whether it *correctly* explains what it is meant to explain cannot be meaningfully asked on this view, and this shows that quantum Bayesianism cannot account for the distinction between failed and successful explanations by quantum theory. Since it is difficult to see how one might account for the notion of a quantum theoretical explanation without being able to make sense of the distinction between failed and successful quantum theoretical explanations, Timpson's charge applies to quantum Bayesianism after all in that it cannot account for the tremendous explanatory force which the theory undoubtedly has.

The Rule Perspective, in contrast to quantum Bayesianism, acknowledges from

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[58] See the title of [Healey forthcoming b].

[59] See [Healey forthcoming b] p. 6, emphasis mine.

the start that the question of correctness does apply to quantum theoretical reasoning resulting in expectations about physical phenomena and regularities and in that sense has much better resources to account for the notion of a quantum theoretical explanation. In accordance with Healey's account of quantum theoretical explanation as formulated in [Healey forthcoming b], it emphasises the importance of NQMCs to describe both the phenomena and regularities for which quantum theoretical explanations are sought (the explananda) and the assumptions and background conditions on which the supposed explanations are based (the explanantia). In the example of explaining the experimentally determined conductivities of solid materials, the explanantia include descriptions of the internal composition and structure of the materials at issue together with the external conditions the materials are subjected to. Given these "known facts" of the systems at issue, the rules of state assignment dictate which quantum states to assign (even though approximations may have to be made due to insuperable difficulties involved in computing these states exactly). The Born Rule, in addition, permits to derive the probabilities which are to be attributed to the possible values of observables on the basis of these states.[60] So, according to the Rule Perspective, a physical phenomenon or regularity can be explained successfully by quantum theory just in case the phenomenon or the regularity is precisely what agents forming their expectations on the basis of these probabilities would expect.

To sum up, in contrast with quantum Bayesianism the Rule Perspective can account very well for the distinction between failure and success of supposed quantum theoretical explanations. Furthermore, as argued in the previous subsection, the Rule Perspective is not committed to an ontological micro/macro divide and is therefore no less compatible with reductionist accounts of quantum explanation than the most-discussed ontic accounts of quantum states. This has the interesting further ramification that epistemic accounts of quantum states need not embrace the explanatory anti-reductionism that is advocated by the quantum Bayesians.[61] Defending a non-ontic account of quantum states is perfectly compatible with defending strategies of explanatory reductionism in general philosophy of science.

7 Concluding Remark

The aim of this paper has been to make it plausible that the idea of a therapeutic account of quantum theory can be coherently articulated and defended in form of the Rule Perspective. As already remarked, this rather modest aim differs substantially from the much more ambitious one of showing that the Rule Perspective is superior to all rival accounts of quantum theory—something that I do not at all intend to suggest. Before closing this paper, I would like to acknowledge that accounts of the therapeutic stripe characterised in Section 1 are not the only ones which attempt to make sense of quantum theory without introducing additional technical vocabulary

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[60] Quantum Bayesianism concurs that the Born Rule has the normative role of prescribing which probabilities to assign on the basis of which quantum states (see [Fuchs 2010] p. 8). It denies, however, that the theory has any normative force concerning which states are to be assigned on the basis of which evidence. This denial creates the problems discussed in the previous paragraph.

[61] See [Fuchs 2010] p. 21 fn. 31 for a quantum Bayesian endorsement of explanatory anti-reductionism and [Timpson 2008] p. 592 and p. 600 for helpful remarks on the role and importance of anti-reductionism in quantum Bayesianism.

such as hidden variables or explicit dynamics of collapse. Similar things can be said of adherents of the Everett interpretation, who regard it as the most striking virtue of their interpretation that it does not attach any additional theoretical elements to the original formalism of the theory. In the words of David Wallace:

> If I were to pick one theme as central to the tangled development of the Everett interpretation of quantum mechanics, it would probably be: *the formalism is to be left alone*. What distinguished Everett's original paper both from the Dirac-von Neumann collapse-of-the-wavefunction orthodoxy and from contemporary rivals such as the de Broglie-Bohm theory was its insistence that unitary quantum mechanics need not be supplemented in any way (whether by hidden variables, by new dynamical processes, or whatever). (See [Wallace 2007] p. 311.)

The idea of "leaving the formalism alone", however, is much less straightforward than Wallace suggests. Taken by itself, the formalism is just an uninterpreted piece of mathematics, which then derives its extra-mathematical significance from its application by competent physicists in quantum theoretical practice. Wallace's case for the Everett interpretation as the single outstanding take on quantum theory which does not "supplement" the formalism "in any way" is valid only if one presupposes that the role of quantum states is to describe the physical facts. Making this assumption is a natural first step when interpreting the theory, and to outline its implications is both highly important and rewarding, as the work of Everettians impressively demonstrates. For those impressed by the problems encountered by Everettians when trying to "leave alone" the formalism while giving it a descriptive reading[62] a natural next step is to look for alternatives which also "leave alone" the formalism but refrain from construing quantum states as descriptive. The aim of the present paper has been to substantiate the claim that such an alternative is indeed viable and that it has to be taken serious as an approach to the foundations of quantum theory.

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[62] See, for instance, the criticisms of the Everett interpretation brought forward by Kent, Maudlin, and Price in [Saunders et al. 2010].

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