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Emergent Quantum Indeterminacy

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Abstract
Many features of quantum mechanics (QM) suggest that, at the microscopic level, objects sometimes fail to determinately instantiate their properties. In recent years, many have argued that this phenomenon indicates the existence of an ontological kind of indeterminacy, often called *metaphysical indeterminacy*, which is supposed to affect the ontology of QM. As insisted by Glick (2017), however, once we look at the major realist approaches to QM we learn that the indeterminacy disappears from the description of the world at its most fundamental level. This absence might be taken as a good reason for adopting some form of *eliminativism* towards quantum mechanical indeterminacy. The aim of this paper is to distinguish three ways of defending eliminativism, and to argue that none of them eventually succeeds. The upshot is that QM does in fact suggest the existence of metaphysical indeterminacy, although only as an emergent phenomenon.

Keywords
Eliminativism. Emergence. Fundamentality. Metaphysical Indeterminacy. Quantum Mechanics.

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1 GETTING RID OF QUANTUM INDETERMINACY?

Proponents of metaphysical indeterminacy (MI) claim that there are cases of indeterminacy that we fail to explain as due to semantic imprecisions or lack of knowledge. In the recent debate, the most discussed of these cases is indeterminacy in quantum mechanics (QM). Many have shown that a crucial feature of QM is that we cannot always ascribe definite properties to microscopic systems, and have taken this as an instance of MI (Darby, 2010; Skow, 2010; Bokulich, 2014; Wolff, 2015; Calosi & Wilson, 2018; *inter alia*).

The line of thoughts that leads from quantum mechanics to the existence of MI has however been challenged. For instance, Glick (2017) has shown that by looking at the major realist approaches to quantum mechanics, the impossibility to ascribe definite properties never affects the fundamental ontology.

> [F]irst, and most straightforwardly, the Bohm theory endows particles with determinate positions and momenta at all times […] Second, the Everett interpretation, as developed by Wallace (2012), recognizes only the universal wavefunction in its fundamental ontology. The universal wavefunction is perfectly determinate at every time […] Finally, consider dynamical collapse theories such as versions of GRW. The two versions of the GRW adopted by most contemporary defenders are the mass-density and flash-ontology varieties. Neither contains fundamental indeterminacy: the distribution of mass-density and the location of the flashes are both perfectly determinate. (2017, p. 205)

The three interpretations considered by Glick—namely Bohmian, Everettian, and GRW—share a realist attitude towards the quantum state. Indeed, it could be argued that what makes an interpretation *realist* is precisely such a take on the quantum state (Miller, 2014). Glick shows that each interpretation describes a world that is perfectly determinate at its most fundamental level, from which he concludes that we can get rid of quantum indeterminacy altogether:

> If […] one took the properties to be ontologically derivative and quantum states to be fundamental, there would be little room for metaphysical indeterminacy […] any indeterminacy would occur at the non-fundamental level *and hence may be viewed as eliminable*. (206, italics mine)

In a similar vein, Chen (2020) has recently pointed out that the main realist approaches to QM, by making the theory precise, eliminate any indeterminacy.

> No physical theory has inspired more discussions about indeterminacy than quantum theory. It has been argued that ontic vagueness is a feature implied by quantum theory. However, we now have realist theories of quantum mechanics such as Bohm's theory, GRW collapse theory, and Everett's theory that make quantum mechanics precise. *In those precise theories, ontic vagueness disappears*: there is no indeterminacy in the fundamental ontology or fundamental dynamics. The world can be described as a universal quantum state evolving deterministically (or stochastically) and in some cases guiding and determining precise material objects moving along (deterministically or stochastically), all of which are exact. (12, italics mine)

Of course, contrary to what Chen seems to suggest, a theory could well be perfectly precise, and yet entail that the fundamental ontology is indeterminate. At least in principle, there is nothing that prevents this from happening. Nonetheless, I believe the main point here still stands: the fundamental ontology posited by the major realist approaches to QM is free from indeterminacy,[1] as both Chen and Glick point out.

The question to address now, is whether the absence of indeterminacy from the fundamental level entails any form of *eliminativism* towards quantum indeterminacy. In this paper I distinguish three varieties of eliminativism, and argue that none of them should be adopted. In section (2) I start by showing that the inference from derivative to eliminable is generally mistaken. I then focus on a more charitable reading of eliminativism, according to which quantum indeterminacy is only eliminable *qua* metaphysical. I distinguish two ways of doing so, which I call a *generalist* and a *particularist* strategy. According to the *generalist*, MI has to be fundamental, if it exists at all. I will argue in section (3) that this strategy is unmotivated. According to the *particularist*, quantum indeterminacy is not metaphysical, because it can be explained in semantic or epistemic terms. I will propose in section (4) a counterfactual definition for MI to show that quantum indeterminacy is neither semantic nor epistemic.

2 DERIVATIVE *VERSUS* ELIMINABLE

[1] I am going to grant this for the sake of the arguments, although I should mention that it is not entirely clear whether on the Mass Density approach to GRW (Ghirardi, Grassi, & Benatti, 1995) the fundamental ontology is indeed fully determinate. Allegedly, this is going to depend on how the tails problem is solved. According to views such as Monton's (2004, pp. 19-20), Bassi & Ghirardi's (2003, pp. 86-90), or Lewis' (2016), superposition states of mass being located at different regions cannot be entirely eliminated. And since the fundamental ontology of this theory is given by the distribution of mass in 3D space, it could be argued that the indeterminacy affects even the fundamental level.

In the interpretations of quantum mechanics considered above, the indeterminacy only affects the derivative properties, whereas the quantum state is entirely determinate. What is the relation between the fundamental quantum state and the derivative properties, and does it allow for eliminativism towards the latter? I will restrict my attention to *reduction*, *emergence*, and *grounding*.[2] A quick review will suffice to show that none of them justifies eliminativism.

As regards to reduction and emergence, we can preliminary set aside the *inter-theoretic* understanding of these relations (see e.g. Butterfield, 2011). In the case at hand, clearly we are not talking about reduction/emergence of one theory to the other, since both the quantum state and the derivative properties belong to the same theory. To argue for the contrary would be (at the very least) a highly revisionary way of thinking about what it means to elucidate what is the ontology of quantum mechanics. So I will not consider this option further, and focus instead only on the *ontological* understanding of reduction/emergence.[3]

Ontological reduction can be of two kinds, *eliminativist* or *conservative*. Here is van Riel & Van Gulick (2003):

> Reductivists are generally realists about the reduced phenomena and their views are in that respect *conservative*. They are committed to the reality of the reducing base and thus to the reality of whatever reduces to that base. Though conservative realism is the norm, some reductionists take a more anti-realist view. In such cases the reducing phenomena are taken to replace the prior phenomena which are in turn *eliminated* [...] The oxygen theory of combustion replaced the phlogiston theory and phlogiston was eliminated. Whether to count such *eliminativist* views as a variety of reduction is a matter of theoretical choice. Some might argue reduction entails realism about the reduced phenomena. *If so, elimination is not reduction*. (italics mine)

Even accepting that reduction can sometimes be eliminativist—as perhaps it is in the case of phlogiston—this does not seem to be the case for quantum properties. Since they are not *replaced* by new properties, we have good reasons for being *conservative* reductionists here. To better see why, notice that a major problem faced by all those who are realist about the wave function (Ney & Albert, 2013) is, if all there is fundamentally to the world is the wave function living in a multidimensional space, how we get to the ordinary 3D space in which we live. Indeterminacy is no exception here, since the quantum properties that we usually

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[2] I am in debt with Claudio Calosi and Jessica Wilson for the discussion that follows.

[3] Ney (2013, p. 173) makes a similar point while discussing the reduction of 3D space to the multidimensional wave function.

take to be indeterminate only appear in the 3D space. To solve this problem Albert (1996) proposed an *error theory* according to which for the wave function realist, 3D space is nothing but an illusion. This view is perhaps one way to go for the eliminativist on quantum indeterminacy, because it would allow her to claim that indeterminate properties are illusory. However, today's consensus seems to have turned to a *functionalist* approach, defended by Albert himself (2015), on which instead the ordinary 3D space is not eliminated. If the 3D space is part of our ontology, then so are the properties that we find in it, along with their indeterminacy.

Another idea to which defenders of eliminativism could appeal, is the possibility of a *translation procedure*. Once a reduction is successfully achieved, it should come with an *in principle* way of translating the objects of one level of discourse (the *target* of reduction) into those of the other level (the *reductive base*). In the quantum case this can be done by showing that every quantum property, whether indeterminate or not, can be translated into a property of the quantum state. Once again though, it is not clear why such translation procedure would imply any form of eliminativism. Translation procedures are clearly symmetric. In order to argue that one side of the reduction is ontologically privileged, we need further constraints. An example of how to provide constraints can be seen in Churchland's (1986) reduction of the mental to the physical,[4] where it is argued that purely qualitative mental properties should be eliminated because they are problematic. I am open to the possibility that an independent ground for thinking that quantum properties are problematic can be given. However, simply saying that they are problematic *because they are indeterminate* would be question begging.[5]

Turning to emergence it is even clearer that eliminativism is unjustified. Metaphysical emergence of new properties can be of two types, *weak* and *strong*, neither of which allows for eliminativism. Emergence (both weak and strong) is associated with two components, *synchronic dependence* and *ontological autonomy* (for an overview, see: Gibb, Hendry, & Lancaster, 2019). The latter component is crucial in seeing why eliminativism cannot be applied to emergence. Regardless of how the details are spelled out,[6] *autonomy* would not make sense if

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[4] I thank Jessica Wilson for suggesting this example.

[5] David Glick (p.c.) suggests that the independent ground could be methodological: physical theory should, at least ideally, avoid to posit indeterminacy in the ontology. This is an interesting suggestion, but I shall notice that last century developments in physics have shown how damaging it can be to put constraints on our ontology. I believe that indeterminacy is no exception.

[6] For a detailed discussion of the various approaches for understanding ontological autonomy for emergent properties, see Wilson (2015).

the emergent properties were eliminated from the ontology.

Finally, let us consider *grounding* as a way of understanding the relationship between properties and the quantum state. Ney (2013) has adopted such a view in the context of wave function realism. As regards to eliminativism though, we shall notice that the notion of grounding has been introduced precisely *in contrast* to it. Fine (2001) introduces *ground* to provide a middle way between realism and eliminativism about ontological dispute. And Schaffer (2009) is even more explicit when he claims 'I am invoking the one and only sense of existence, and merely holding that very much exists' (p. 360).

The standard ways of thinking about the metaphysical relation between quantum state and properties do not support the claim that the derivative ontology is to be eliminated. Thus, unless an independent reason is given for revising these notions when it comes to indeterminacy, the first kind of eliminativism should be rejected.[7] There is however a more charitable reading of his view in the vicinity, which will be my focus for the rest of this paper. To recall, the idea is that quantum indeterminacy is eliminable *qua* metaphysical, and if this were the case it would follow that quantum mechanics does not motivate MI. There are two strategies for defending this view, a *generalist* and a *particularist*. In the next section I shall discuss the former, while in section (4) I will turn to the latter.

3 METAPHYSICAL INDETERMINACY NEEDS NOT BE FUNDAMENTAL

The generalist maintains that when it comes to indeterminacy, *derivative* and *metaphysical* are mutually exclusive. Therefore MI is fundamental, if it exists at all. But why should we think that this is the case? Plausibly, the generalist should come up with an argument to show that derivative MI is inconsistent. To my knowledge, the only such argument can be found in Barnes (2014). However,

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[7] As a reviewer of this journal correctly notices, the argument in this section only establishes a conditional claim, namely: *if* there is derivative quantum indeterminacy, *then* this is not eliminable. Clearly this does not say much about whether the antecedent is true. While this is certainly correct, I shall stress that my aim here was not to establish the truth of the antecedent, but rather to argue for the conditional. The antecedent has been extensively defended in various works (e.g. Skow, 2010; Darby, 2010; Calosi & Wilson, 2018; Calosi & Mariani, 2021; *inter alia*), and this paper does not intend to provide further arguments for it. Of course, one could disagree, and argue that there is no indeterminacy whatsoever in quantum mechanics, not even derivative or representational. The reviewer also suggests that Glick's *Sparse View* (2017) might be a way to defend this claim. Roughly, according to this view, systems that are not in an eigenstate for a certain observable do not possess the corresponding property altogether (neither the determinate nor the determinable), and so, *a fortiori*, they are not indeterminate. While it is my own belief that the lack of determinable properties in Glick's view could also be taken as a form of indeterminacy, I admit that in this paper I cannot render full justice to this view, so I will not discuss it further.

Barnes heavily relies on her own approach to MI, which happens to be very different from the one that is most discussed in the context of quantum indeterminacy, namely Wilson's (2013) *determinable-based* approach. Let us focus for a moment on this distinction.

In recent discussions, a consensus has emerged that two quite different approaches to MI can be adopted. Wilson (2013) has labeled them *meta-level* and *object-level* approaches. On the former approach, MI has to be understood as worldly unsettledness between fully precise options: there is MI when it is indeterminate which (determinate) state of affairs obtains. On the latter, *object-level* approach, MI consists in the (determinate) obtainment of indeterminate state of affairs. The first approach will generally be coupled with a logic and semantics for the sentential indeterminacy operator (for instance mimicking modal logic, as in Barnes & Williams, 2011). The second approach does without the operator, and adds instead some metaphysical machinery in order to distinguish determinate states of affairs from indeterminate ones. For instance, Wilson (2013) works on the assumption that determinable properties are not reducible to the disjunction of their determinates, and then reduces MI to the obtainment of state of affairs constituted by objects instantiating determinable without a unique corresponding determinate. For instance, in the paper I already mentioned Glick (2017) does not discuss the *meta-level* approach, and focuses his attention on the account defended by Calosi & Wilson (2018), which builds upon Wilson's (2013) *object-level* approach. The main reason for the restriction is that it has been shown in various ways that the *meta-level* approach to MI is ill suited to treat quantum indeterminacy (Skow, 2010; Darby, 2010; Bokulich, 2014; Wolff, 2015; Calosi & Wilson, 2018).[8]

Is there any reason to believe that, on an *object-level* approach to MI, merely derivative MI is inconsistent? Glick does not say explicitly, but when introducing Wilson's account he claims the following:

> For one who adopts Wilson's approach to metaphysical indeterminacy, [quantum indeterminacy] can be understood as a particle with the determinable *position* but lacking a (unique) determinate of position. If this is the correct understanding of QM, it follows that there is widespread indeterminacy at the fundamental level of reality. (2017, p. 204)

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[8] To be fair, the debate on this issue is still open. Torza (2017), and Darby & Pickup (2019) both attempt to revise Barnes & Williams (2011) meta-level account to fit quantum indeterminacy. In this context the eliminativist could appeal to Barnes (2014), who argues that merely derivative MI is inconsistent. I briefly notice though, that Barnes' (2014) argument has been criticised by Eva (2019) and Mariani (2020) on solid grounds. Therefore, it is not clear whether the *generalist* eliminativist could successfully appeal to Barnes (2014).

The idea here is that if we assume, for the sake of the arguments, that quantum mechanics is a fundamental theory (as Glick does in a footnote), then Wilson's approach would entail a 'widespread indeterminacy at the fundamental level'. However, I think that Glick here is confusing between fundamentality *of theories* and fundamentality *of entities* or states of affairs. Even on the assumptions that (i) quantum mechanics is a fundamental theory, and, crucially, that (ii) the fundamental entities are described *only* by fundamental theories, the argument does not go through. The reason is that (ii) leaves open (and rightly so!) the possibility for fundamental theories to also entail the existence of derivative entities. In order for the eliminativist to argue that quantum indeterminacy has to be fundamental, she needs to assume that quantum mechanics describes fundamental entities only. However, this assumption looks unmotivated, and Glick, for instance, does not give further support to it.

Is there a better argument for the claim that MI has to be fundamental on an *object-level* approach? I do not think there is, since the very metaphysical structure of this view is silent about whether the indeterminate states of affairs obtain at a fundamental level or not. Consider an indeterminate state of affairs *S* that is constituted by an object, say my shirt, that has the determinable 'red', and no unique corresponding determinate. Suppose the shirt is both scarlet and crimson. *S* counts as indeterminate, and yet it is not a fundamental state of affairs.

The confusion might arise from thinking that, according to Wilson's (2013), determinable properties are *as fundamental as* determinates. But the notion of fundamentality at work in this claim is a merely *relative* one. For example, to say that the determinable *colour* is as fundamental as its determinates *red* or *blue*, is clearly not to say that *colour* is *absolutely* fundamental. On an *object-level* view, fundamentality does not enter into the definition of indeterminacy. For the indeterminacy to be fundamental on such a view, we need the further claim that the relevant states of affairs are themselves fundamental.

A lingering doubt could remain if we now ask: *where does the indeterminacy come from, if the more fundamental level is fully determinate?*[9] Independently from the specific instances of indeterminacy (the quantum mechanical one, or anything else), it looks like in Wilson's view we could face a situation where certain derivative states of affairs are indeterminate, despite the fact that the lower-level states of affairs are not. And if this is possible, then arguably the *source* of the indeterminacy should in some sense be located in the inter-level relation between the relevant states of affairs. In recent papers it has been argued that, under very plausible assumptions, this is not particularly problematic (Eva 2019; Mariani, 2020). The core idea in these works is that in order to argue that

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[9] I am thankful to an anonymous reviewer of this journal for raising this issue.

the inter-level relation does not allow for derivative indeterminacy, we would either need to assume that the relation itself is fundamental, or that the relation is such to preserve determinacy from one level to another (as assumed by Barnes, 2014, in the context of the *meta-level* approach to MI). Both assumptions are however problematic, either because they go against the received views on the status of inter-level relations (the former), or because they appear to be question begging in a context where we are attempting to establish whether merely derivative indeterminacy is possible (the latter). While I cannot do full justice to these arguments here, I think it is safe to say that, as of now, nobody has given good motivations for thinking that emergent metaphysical indeterminacy is intrinsically problematic.

4 TESTING QUANTUM INDETERMINACY

Finally, let us consider whether the eliminativist can appeal to the *particularist* strategy. To recall, the idea is to show that epistemic or semantic approaches to indeterminacy can account for quantum indeterminacy once we have established that this is merely derivative (which we are assuming here).

Let me first make a small dialectical point. As I see it, the burden of the proof here is not on the defender of quantum indeterminacy. If you believe that a semantic or epistemic account of indeterminacy will do for the quantum case, it is up to you to show how. The reason for thinking this is because, at least on a first inspection, quantum indeterminacy is quite different from the phenomena usually targeted by semantic/epistemic accounts. It does not concern vague predicates, and so it is not susceptible to Sorite's paradox (as shown in details by Darby, 2014). Consider that, in standard cases targeted by semantic account of indeterminacy, the relevant predicates are vague in the sense that they admit of *borderline cases*, meaning they can be precisified so that the sentences containing them get assigned determinate truth values. Is *spin* such a vague predicate? At least *prima facie*, it does not seem that precisifying the predicate *spin* would be helpful in assigning determinate truth values to sentences expressing cases where (given for instance the EEL) *spin* is not in an eigenstate. But if a predicate like *spin* is not a vague predicate, what reason is there for thinking that standard semantic or epistemic accounts will work? In any case, I think we can do more than simply shifting the burden of the proof.

Barnes (2010, p. 604) has given a useful way to individuate, given a certain phenomenon, if it is to be considered indeterminate in a metaphysical sense. Take the following counterfactual test (**CT**):

> **CT**. Sentence *S* is metaphysically indeterminate *iff*: were all representational content precisified, there is an admissible precisification of *S* such that according to that precisification the sentence would still be non-epistemically

indeterminate.

The main strength of this definition is that both the epistemicist (who thinks that all the indeterminacy can be explained as a lack of knowledge; e.g. Williamson, 1994) and the semanticist (who thinks that all the indeterminacy can be explained as semantic indecision; e.g. Fine, 1975) will agree on the truth of **CT**. Disagreement arises when evaluating single sentences.

In the quantum case, the disagreement would arise with sentences like 'the spin-*x* of the electron *e* is *up*'. Let us call this sentence *S**. If we assume that the property (observable) 'spin-*y*' of *e* is in an eigenstate, then *S** has an indeterminate truth-value,[10] since 'spin-*x*' and 'spin-*y*' are incompatible properties (observables). We can run **CT** for *S**. First, we check whether the language in which *S** is expressed has all its content precisified. In this case, the obvious candidate for the content that needs to be precisified is that corresponding to the predicate 'spin-*x*'. Clearly though, no matter how precise the content corresponding to this predicate is, the indeterminacy would not disappear. In fact, the predicate is fully precise and unambiguous, we can read it off the quantum state, and in some cases we have probabilistic information about future measurements. Contrariwise, think of a predicate such as 'bald'. 'Bald' is a vague predicate for which the precisificational strategy can be used to block the Sorite's paradox. We can imagine an ideal language with a predicate for each number of hairs, instead of the predicate 'bald', and no paradox would arise. An analogous

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[10] Notice that, at this stage, by saying that the sentence *S** has an indeterminate truth-value (in a sense that is yet to be established) I do not mean to assume anything particularly crucial about such indeterminacy. In a way, I am here using *indeterminacy* just in its pre-theoretical, intuitive sense, and the indeterminacy might well turn to be epistemic or semantic. The idea behind the claim that *S** somehow expresses indeterminacy just relates to the thought that superposition states cannot be accounted for in terms of conjunctions of false sentences. To see this, suppose *S** is false; then presumably so is the sentence—call it *S***—'the spin-*x* of the electron *e* is *down*'. Now notice that, if both *S** and *S*** are false, a sentence expressing a superposition state such as 'the spin-*x* of the electron *e* is *up* + *down*' would turn out to be false as well, while it is not. More generally, it is well-known that the '+' expressing a linear superposition cannot be understood as the classical logical connectives ('and' and 'or'). To make but one example of this, consider that in quantum logic sentences expressing superposition states are accounted for either in terms of a many-valued logic (e.g. Dalla Chiara & Giuntini, 2001; Pykacz, 2000; *inter alia*), or with truth-value gaps (e.g. Griffiths, 2002; Bolotin, 2017; *inter alia*). Now, having started from the intuitive idea of indeterminacy as related to sentences expressing superposition states, one could go a step forward and take such indeterminacy seriously in order to provide a metaphysical account of superposition states. It is precisely this approach that I consider in the paper. The disagreement then arises regarding how we should account for such indeterminacy, and about the philosophical understanding of it. I am thankful to an anonymous reviewer of this journal for inviting me to be explicit about this.

strategy cannot be applied to predicates like ‘spin-*x*’, since in the language of the theory they already have a perfectly precise meaning. No semantic manoeuvre can turn *S** into a sentence with a determinate truth-value. Finally, to see if *S** is metaphysically indeterminate given **CT**, we only need to prove that the indeterminacy is not epistemic either. Many no-go theorems in quantum mechanics, such as Kochen-Specker’s, have shown that we cannot take the value indefiniteness as a limitation on our knowledge of the system. The indeterminacy of *S** is not epistemic either.

The main problem with the analysis just proposed is that **CT** was developed by Barnes (2010) within the framework of the *meta-level* approach to MI. It explicitly refers to sentences, and we know that no sentence is indeterminate according to the *object-level* approach. So let us consider instead the following revised version of **CT**:

> **CT-Revised**. The state of affairs expressed by a sentence *S* is metaphysically indeterminate *iff*: were all the semantic content of *S* precisified, *S* would still express an indeterminate state of affairs.

The precisificational strategy is still available for the semanticist and the epistemicist, who can therefore accept the truth of **CT-Revised**. According to the semanticist and the epistemicist, once the semantic content of a sentence is precisified there is no room for the possibility that a state of affairs is indeterminate. As before, any disagreement will emerge when evaluating singular sentences, along with the state of affairs expressed by them.

So let us now consider a sentence expressing an indeterminate state of affairs in quantum mechanics. Take for instance the sentence *S*°: ‘the spin-*x* of electron *e* is 50% *up*’. On the assumption that *e* is in an eigenstate of the observable spin-*y* (incompatible with spin-*x*), *S*° can be derived from the quantum state. Is the semantic content of *S*° fully precisified? Once again, the only candidate is the property corresponding to ‘being 50% *up* in spin-*x*’. Clearly though, this predicate is already fully precise, and there is no further content that could be precisified in *S*°. To conclude the **CT-Revised**, let us ask whether the content of *S*° expresses an indeterminate state of affairs. Quite obviously, the answer to this will depend on what state of affairs we take *S*° to express, as well as on what one takes an indeterminate state of affairs to be. On the former issue, a natural candidate is to interpret the *probabilities* encoded in the quantum state to correspond to *degrees* *of instantiation* of the relevant properties.[11] On the latter issue, notice that it would be question begging to simply assume the definition of an indeterminate state of affairs given by Wilson. However, no matter how exactly we spell out what an indeterminate state of affairs is, it surely looks like properties instantiated in *degrees* indicate the presence of indeterminacy.[12] Indeed, Wilson's account is not the only one which takes *degrees of instantiation* as a distinctive mark of indeterminacy. Another notable example is in Rosen & Smith (2004), where similarly it is argued that metaphysical indeterminacy could be taken to reduce to objects instantiating properties in degrees.

Therefore, independently from what we take an indeterminate state of affairs to be, it seems that in order to deny that the state of affairs expressed by *S*° is indeterminate we would have to accept that *degrees of instantiation* have nothing to do with indeterminacy. While I am open to the *in principle* possibility for this strategy to be pursued, I nonetheless believe that its conceptual appeal is very low. Indeed, if *degrees of instantiation* have nothing to do with indeterminacy, one could wonder what does. Perhaps one could insist that with *degrees of instantiation* we are not in fact dealing with indeterminacy properly understood, because any corresponding sentence would always turn out to be either true or false. Notice however that such an objection *assumes* that metaphysical indeterminacy has to be understood in *meta-level* terms, while someone like

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[11] This is admittedly an assumption I am making. It is an open issue how to provide a full justification to the claim that the probabilities encoded in the quantum state match with the degrees of instantiation. In other words, we have to assume that having the probability to be found *up* after a measurement, say, 30% of the time (statistically) corresponds to possessing the property *up* with degree .3. An argument for this claim has not been provided in the literature so far, and it is an open issue whether it could be. I shall stress however, that one thing is to say that the connection between degrees and probabilities has to be spelled out in details, and another one is to say that there is no connection whatsoever. At least on a first inspection, it seems that probabilities and degrees could go hand in hand. I therefore take it that, although this is an open issue, the assumption I am making is not entirely unjustified either.

[12] Here the *particularist* could protest that we are not entitled to interpret *S*° as expressing *degrees of instantiation*, since the quantum state only gives us probability for future outcomes. Although this is an assumption I am making (see footnote 11), we have to consider that this is justified on the thought that there *could* be a state of affairs corresponding to *S*° to begin with. Otherwise, a test like the **CT-Revised** could not be performed in the first place. And if there is a state of affairs corresponding to *S*°, then a plausible option is to interpret the probabilities ontologically as degrees of instantiation. Notice also that, if instead we were to give a purely *operationalist* reading to *S*° (as suggested by an anonymous reviewer), we would not be able to provide an ontological picture behind superposition states. Clearly *operationalism* is always an option, but in this paper I am explicitly setting this option aside. On this issue, and more generally on many crucial parts of this section of the paper, I am in profound debt of gratitude with an anonymous reviewer of this journal for insightful comments and objections.

Wilson or Rosen and Smith will disagree. In any case, if one were entirely convinced that *degrees of instantiation* of properties do not reflect the standard usage of the notion of indeterminacy, I believe the dispute would be just a verbal one. Whether you call it ‘indeterminacy’ or something else does not really matter here. And presumably, if we take the notion of indeterminacy in its pre-theoretical, intuitive sense, it most certainly seems that *degrees of instantiation* fit at least part of this idea.

If we try and move a step forward from the pre-theoretical idea of indeterminacy, we would then need to provide a definition of metaphysical indeterminacy that correctly accounts for *degrees of instantiation*. As I said, Wilson’s view (2013) is not but one way of doing so, and yet it could be helpful to look at it in more detail in order to provide a concrete example. Here is Wilson’s definition of MI:

> *Determinable-based MI*: What it is for an SOA to be MI in a given respect *R* at a time *t* is for the SOA to constitutively involve an object (more generally, entity) *O* such that (i) *O* has a determinable property *P* at *t*, and (ii) for some level *L* of determination of *P*, *O* does not have a unique level-*L* determinate of *P* at *t*. (2013, p. 366)

Clause (ii) of the above definition is the requirement of *non-uniqueness* of instantiation of the determinate properties. It can be satisfied in two ways, which Wilson calls *gappy* and *glutty*. The *gappy* has it that *no* determinate is instantiated, while the *glutty* has it the *more than one* determinate is instantiated at the same time. What is crucial for us is that while applying the account to quantum indeterminacy, Calosi & Wilson (2018) give good motivations for taking *glutty* as the correct implementation. Moreover, they also suggest that the best understanding of *glutty* is a *degree-theoretic* one, in which determinate properties are jointly instantiated, each with a degree less than 1.

Therefore, Calosi & Wilson’s account clearly tells us that quantum indeterminacy is metaphysical. Of course, the epistemicist and the semanticist could still try to argue that the *glutty degree-theoretic* approach does not capture the indeterminacy of sentences like *S*°. Notice though, that even if they were to succeed, they would not thereby also show that a sentence like *S*° does not express *any* indeterminacy. As I mentioned above, in order to argue for this one needs to defend the claim that *degrees of instantiation* have nothing to do with indeterminacy, which I admit could be the last resort for the eliminativist.[13]

5 CONCLUSION

Quantum mechanics was designed to account for the anomalous behaviour of microscopic objects. Much of the later philosophical contrivances have been attempts to cover up the weirdness of the experimental results. We are free to believe that what really is out there is a multidimensional wave function living in configuration space. However, no matter how far we depart from what we have experienced in the labs, we still cannot get rid of the very reason why the theory was designed. The weird behaviour of quantum particles indicates that a portion of reality, where things get very small, is not always determinate as we would have expected. I have argued that it does not really matter whether this indeterminacy is fundamental or rather it emerges from an indeterminacy-free underlying reality. What really matters is that we should blame the world itself for its existence.

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[13] A reviewer of this journal stresses that both **CT** and **CT-Revised** start from controversial assumptions, namely they assume that there is some indeterminacy in sentences like *S** and *S*°. This is correct, in the sense that this paper does not provide further arguments in support of the idea that there is indeterminacy in quantum mechanics, but simply assumes it. That being said, recall that such an assumption is shared by the *particularist*, who is my opponent here, and it is therefore dialectically acceptable.

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