Effective Ontic Structural Realism

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Abstract

Three accounts of effective realism (ER) have been advanced in this journal to solve three problems for scientific realism: Fraser and Vickers ([forthcoming]) develop a version of ER about non-relativistic quantum mechanics that they argue is compatible with all the main realist versions ('interpretations') of quantum mechanics avoiding the problem of underdetermination among them; Williams ([2019]) and Fraser ([2020*b*]) propose ER about quantum field theory as a response to the problems facing realist interpretations; Robertson and Wilson ([forthcoming]) propose ER to deal with the dubious ontological status of the entities belonging to superseded theories. This paper argues for the unification of these proposals based on realism about modal structure and the idea of scale relativity of ontology developed by ontic structural realists. This solves problems some or all the accounts of ER face, especially that of making explicit in what way they are realist. Furthermore, we respond to a recent critique that has been raised against the ontic structural realist account of quantum mechanics that we employ.

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1 Introduction

Effective realism (ER) is a form of scientific realism about effective theories, which have a limited range and domain of applicability. An effective ontology is the ontology of an effective theory. Three accounts of ER have been advanced to solve problems for scientific realism raised in recent literature: Egg ([2021]) and Fraser and Vickers ([forthcoming]) develop a version of ER about non-relativistic quantum mechanics that they argue is compatible with all the main different versions ('interpretations') of quantum mechanics avoiding the problem of underdetermination among them; Williams ([2019]) and Fraser ([2020*b*]) propose ER about quantum field theory as a response to the problems facing realist interpretations; and Robertson and Wilson ([forthcoming]) propose ER to deal with the dubious ontological status of the entities belonging to superseded theories, defending the possibility of retaining in our ontology 'theoretical relicts', that is the ontological posits of old and superseded scientific theories, via an effective ontology account.

This paper connects effective realism to ontic structural realism (OSR) because some of the key features of the latter seem to have been forgotten in the most recent literature, and in particular OSR can unify the above forms of ER – and their different kinds of effective ontologies – with the theses of realism about modal structure and the scale relativity of ontology. Indeed, although it goes unremarked in the literature on ER, the idea of effective ontology is explicitly invoked by Ladyman and Ross, and their collaborators, in their programme to provide a unified realism that addresses both quantum physics, and the problem of theory change and theoretical relicts for scientific realism. Their OSR involves realism about modal structure, combined with the theses of scale-relativity and the theory of real patterns (Ladyman and Ross [2007], Ladyman [2011], [2015], [2017], [2018], Berenstain and Ladyman [2012]).[1] OSR treats the entities of superseded theories and the entities of the special sciences, which are often the same things, as part

[1]An important terminological point should be noted. The combination of scale relativity of ontology and the theory of real patterns, developed in the context of realism about modal structure and the rejection of self-subsistent individuals, is called by Ladyman and Ross 'Rainforest Realism' and is applied to the ontology of special sciences. The term 'Ontic Structural Realism' is sometimes taken as a view restricted to realism about modal structure within fundamental physics, and also understood in other ways (see Ladyman [2020]). Here, by 'OSR' we denote the general framework proposed by Ladyman and Ross ([2007]), and Ladyman ([2017]) which comprises a core commitment to modal structures both within physics and special sciences, and we understand Rainforest Realism as part of the OSR programme. Ladyman's and Ross's ER about the special sciences contrasts with French's eliminativist form of OSR (cf. French [2014]).

of effective ontology vindicated by the theory of real patterns.[2] Taking effective entities as scale-relative real patterns in the modal structure of the world is clearly a realist position, and OSR thus provides a metaphysics for ER and clarifies it.

Some but not all of the authors discussed in what follows already make commitment to modal structure explicit, and doing so addresses problems that otherwise face their accounts, especially that of making clear in what way they are realist. Furthermore, some but not all of the authors discussed in what follows make a commitment to the scale relativity of ontology explicit, and doing so addresses problems that otherwise face their accounts, and in particular, it provides the basis for a reply to Saatsi's ([2022]) criticism of ER. To be more specific: (i) realism about modal structure can be linked to Fraser and Vickers' scientific realist account of quantum mechanics and to the debate on realism within quantum field theories; (ii) the scale-relativity of ontology is explicit in ER applied to quantum field theories, and implicitly assumed by Robertson and Wilson in their account of theoretical relicts in terms of ER, and it can also be shown to solve the problem of the ontology of quantum mechanics raised by Saatsi; finally (iii) the notion of real patterns can be linked to all the debates addressed here. Connecting OSR with these debates is a very natural and profitable move that fills a gap in the discussion in the recent literature. Furthermore, in relation to the debate on the ontology of quantum mechanics as discussed by Fraser and Vickers, we respond to Egg's ([2019]) challenge that structural realism cannot provide an adequate ontology and a realist account of quantum mechanics. Overall, by linking the complex literature on OSR with the emerging literature on ER, this paper shows that structural realism should not be neglected in this context, and provides a starting point for further lines of research.

The structure of the paper is as follows. Section 2 focuses on ER as applied to quantum mechanics. In particular, Section 2.1 shows how OSR can underpin this form of ER, also responding to Saasti's challenge. Section 2.2 then specifically addresses an objection by Egg ([2019]) to the account we defend about quantum mechanics. Section 3 focuses on ER about quantum field theories and shows how consideration of OSR advances the debate. Section 4 shows how accounting for the ontology of a superseded theory by regarding it as effective is improved by reframing ER in terms of OSR.

[2]By 'special sciences' we include also quantum mechanics as discussed by the mentioned authors since it is not the most fundamental physics. Indeed, arguably every theory in physics is currently effective since none of them apply in every domain (with the possible exception of thermodynamics).

2 The Effective Ontology of Quantum Mechanics

2.1 On Fraser and Vickers' effective realism about quantum mechanics

Quantum mechanics is a challenge for scientific realism.[3] Several different versions of quantum mechanics have been proposed to solve the notorious measurement problem, and they share the same empirical consequences at least in respect of the current experimental evidence.[4] The standard realist options are dynamical collapse theories, Bohmian mechanics and Everettian quantum mechanics. These versions of quantum mechanics say very different things about how the world is. Hence the issue of underdetermination. One option for the realist advocated by Callender ([2020]) among others is to appeal to extra-empirical features in favour of a particular version.

On the other hand, philosophers such as Egg ([2021]) and Fraser and Vickers ([forthcoming]) have recently advanced another strategy. According to this approach, we should be realists only about specific aspects of quantum mechanics. More precisely, we should treat quantum mechanics as an effective theory that is correct only about particular regimes and domains, for which it provides an effective ontology. They do not take quantum mechanics to tell us about the fundamental nature of the world, but just about certain non-fundamental features.

Egg ([2021]) argues that we can explicate this form of ER by appealing to so-called 'textbook quantum mechanics', that is, the kind of quantum theory we find in textbooks, which is neutral with respect to the realist versions of quantum mechanics mentioned above. However, Fraser and Vickers ([forthcoming]) convincingly argue that it is vague what should count as textbook quantum mechanics, and that appealing to this kind of 'theory' would eventually lead us to adopt a specific interpretation of quantum theory, as "the measurement problem arguably shows that attempts to precisify what is meant by textbook quantum mechanics turn out to be either inconsistent or incoherent" (Fraser and Vickers [forthcoming], p. 14).[5]

Fraser and Vickers point out that different versions of quantum mechanics, despite being different in many respects, share certain commitments, and they

[3] See for instance the debate between Hoefer ([2020]) and Callender ([2020]), and the essays in Saatsi and French ([2020]).

[4] Collapse models make different predictions in principle to standard quantum mechanics, but standard formulations of Bohm theory agree with it completely. Note though that any claim of empirical equivalence is restricted to the domain of the theory which is much more limited than that of quantum physics in general, hence Wallace ([unpublished*b*]) argues that there is no real underdetermination. The present paper accepts the underdetermination for the purposes of engaging with the literature that presupposes it.

[5] Also Callender ([2020]) criticises the appeal to textbook quantum mechanics.

argue that scientific realists should restrict their realist commitments to those common aspects. One of their key claims is that there is:[6]

> a powerful sense in which we can associate non-trivial physical content with the wave function without committing ourselves to a particular interpretation. [...] we can take the decoherent branches of the wave function to represent 'possible' outcomes for quantum observables on all three interpretations. [...] Our suggestion then is that we can understand statements about the wave function as encoding claims about the physically possible states and evolutions of a quantum system while remaining open to different, more precise, analyses of the nature of these 'possibilities' provided by particular ontic interpretations. (Fraser and Vickers [forthcoming], pp. 20-21)

This is the kind of commitment they recommend if we want to be realists about quantum mechanics without endorsing a specific version. In this way, one can be neutral about claims on which different versions disagree, and yet assign some physical meaning to claims made in terms of the wave function. Another commitment shared by all versions that we should therefore similarly endorse stems from the theory of quantum decoherence and from the fact that for each observer, thanks to decoherence, it is an objective fact which branch is effectively selected. That is, decoherence brings about an effective collapse of the wave function, and this mechanism is shared by all versions of quantum mechanics, and we can thus be realists about this as well. Fraser and Vickers argue that, by focusing on the common commitments that are shared by all the main versions of quantum mechanics, we can arrive at a set of statements about which we can be realists, so building a form of ER about quantum mechanics.

However, the metaphysics of this view is not specified. Indeed, Fraser and Vickers consider (Section 3.4) the objection that to assign genuine physical meaning to those statements we need to provide a metaphysics, and grant that their account does not do this. As they point out, Egg ([2021]) puts forward an ontology. In particular, Egg proposes a functionalist ontology for ER:

> Questions about the ontology of effective theories must be answered in *functional* terms. They cannot be answered by any reference to the nature of their theoretical posits, insofar as that would require knowledge about how these posits emerge from a fundamental theory, which is just what the effective theory does not provide. Instead, the posits of an effective theory are characterized by what they *do* (effectively), rather than by what they *are* (fundamentally). (Egg [2021], p. 7)

[6] On this point they closely follow Rosaler ([2016]).

For instance, the spin quantity performs some explanatory work in quantum mechanics taken as an effective theory, and all quantum theories agree on the key behaviour of spin systems. That is, they all agree to say that quantum systems instantiate spin properties that perform certain roles. The realist should therefore be committed to those features, without having to step into the debate concerning which quantum theory is the right one, i.e. we should simply be realists about spin as that property of systems that play the thus-and-so role as required by all versions of quantum mechanics.[7] In this sense, we should treat quantum mechanics as an effective theory providing an effective ontology.

However, some issues can be raised concerning this proposal. First, remember that we are trying to define an account which can provide a metaphysical underpinning for Fraser and Vickers' effective realism. Even though Egg's proposal is *prima facie* supposed to provide such an account – via functionalism – it is very difficult to see in practice how we could use this framework to supply Fraser and Vickers' realism with an adequate ontology. Recall the quote we mentioned above, where they argue that scientific realists should be committed to physically possible states as described by wavefunctions. The question is how can a functionalist account of the kind sketched by Egg provide an ontology for such claims. Secondly, as stressed by Fraser and Vickers ([forthcoming]) too, Saatsi ([2022]) has recently raised an important objection to Egg's account of effective ontology. Saatsi argues that, on a general level, Egg's ontological account is too permissive and can potentially allow for the reification of inconsistent entities, thereby undermining the proposal.[8] Saatsi takes for instance Newtonian gravitation as a counterexample to Egg's form of effective realism. He claims that, given that Newtonian gravitational forces play a role in Newtonian gravitation, and this can be considered an effective theory which is correct in a certain regime, an effective realist like Egg should be committed to gravitational forces. However, Saatsi continues, General Relativity tells us that gravity is not a force and being realists about both Newtonian gravitational forces and general relativistic gravitation would lead us to accept inconsistent ontological elements in our theory. Because of this general problem with Egg's account, Fraser and Vickers ([forthcoming]) discard that account as unsuitable to provide an adequate ontology for their view.

Hence, although Fraser and Vicker's recent proposal for an effective scientific realist account of quantum mechanics looks promising, it lacks a clear account of the metaphysical consequences of this form of realism, given the failure of Egg's proposal of an effective ontology for effective realism. However, given that the topic is scientific realism, the need for a clear account concerning ontology is arguably

[7]Here Egg appeals to textbook quantum mechanics to define the role of spin, and we have stressed how referring to this allegedly neutral theory can be problematic. However, we set this problem aside, since we are just interested here in describing his functionalist effective ontology.

[8]See also (Ruetsche [2018]) on a related critique to effective ontologies.

very pressing. Without a metaphysics, it is not clear that their account is really a form of scientific realism, as opposed to a position along the lines of van Fraasen's constructive empiricism, according to which accepting a theory involves believing in its empirical adequacy, as well as being pragmatically committed to its ontology for the purposes of scientific practice, but does not require genuine ontological commitment to unobservables.

Ontic structural realism provides a metaphysical picture that can supplement Fraser and Vickers' account. In particular, it is based on realism about modal structure, which clarifies the ontology we should be committed to and links it with a developed account of scientific realism that is highly coherent with the realism endorsed by Fraser and Vickers. Indeed, as granted by Fraser and Vickers, their account also lacks a clear metaphysical underpinning. Furthermore, and crucially, OSR avoids the issues faced by Egg's effective realist account, since it provides a more refined account of effective ontology.

Structural realism, in its ontic form defended by Ladyman and Ross ([2007]), is a scientific realist position that is committed to the existence of modal or nomological structures in the world: "Ontic Structural Realism (OSR) is the view that the world has an objective modal structure that is ontologically fundamental, in the sense of not supervening on the intrinsic properties of a set of individuals." (Ladyman and Ross [2007], p. 130).[9] This picture fits particularly well with Fraser and Vickers' realist account. Consider Berenstain's and Ladyman's ([2012], p. 153) claim that "If theoretical claims about electrons are to be taken literally as referring to unobservable entities bearing certain properties, then so too should claims about laws, causes, and other modalities.". In this case, Fraser and Vickers argue that we should be committed to the claims shared by all the interpretations about the possible branches quantum states can embed. If we further ask about the metaphysical implications of such a scientifically realist commitment, embracing structural realism is a natural strategy: those modal claims should commit us to objective modal structures in the world that are represented by the mathematical formalism of branching structures. OSR is an ideal option for an effective realist and commitment to modal structure can be shared by all interpretations.

Notably, it fits within Everettian quantum mechanics: *prima facie*, one could be puzzled by the claim that a theory like Everettian quantum mechanics, a theory in which modality is usually interpreted epistemically, should be committed to ontic modality, however, there is a sense in which also Everettian quantum

[9] It is important to stress that 'fundamental' does not mean here 'belonging to the fundamental ontological level'. Ladyman and Ross ([2007], Sect. 1.6) make clear they are not committed to the existence of a fundamental ontological level and take the ontology of physics as on a par with the ontology of special sciences (see Ladyman [2017], p. 151). The modal structures to which OSR is committed are instead fundamental in the sense of not being reducible to objects and their properties

mechanics embeds non-epistemic modality. As Wallace ([2010], p. 62-70) puts it: "Decoherence allows us to extract from the unitary dynamics a space of histories (strings of projectors onto decoherence-preferred states) and to assign probabilities to each history in a consistent way [...] Worlds are mutually dynamically isolated structures instantiated within the quantum state, which are structurally and dynamically 'quasiclassical'.". Thus, the quantum state embeds an objective structure of branches representing possible histories.[10] And, crucially for our purposes, all interpretations agree on those possibilities.

There are several reasons to prefer structural realism over Egg's proposal and in general to adopt OSR in this context. First, OSR fits very naturally with the modal claims at the centre of Fraser and Vickers' approach to quantum mechanics and provides a clearer metaphysics for effective realism than Egg's functionalist ontology. Second, adopting OSR makes sure that ER is genuinely realism. OSR requires that scientific realists should be committed to modal features of the world as they are described by the structure of theories and their scale-relative ontology. In this way, structural realism is a more refined kind of scientific realism that fits very nicely with Fraser and Vickers' account. Third, Fraser and Vickers are already implicitly committed to central tenets of OSR, as they are scientific realists but quietist about fundamental ontology, and they are committed to realism about objective modal claims: "Our suggestion then is that we can understand statements about the wave function as encoding claims about the physically possible states and evolutions of a quantum system while remaining open to different, more precise, analyses of the nature of these 'possibilities' provided by particular ontic interpretations" (Fraser and Vickers [forthcoming], p. 20). Finally, the last but crucial reason to adopt OSR in this context is that it provides an approach to effective ontology for quantum mechanics that avoids the challenge raised by Saatsi against Egg as argued below.

As discussed above, Fraser and Vickers discard Egg's effective account on the grounds that it falls prey to Saatsi's objection and thus is not a good candidate to be a general ontological framework for effective ontology. However, OSR provides an account of effective ontology that can address and avoid the challenge in terms of a scale-relative metaphysical picture based on the notion of real patterns. We present each notion in turn.

We have seen how OSR is committed to the existence of objective modal structures in the world. This kind of general commitment is suitable to account for the kind of modal claims endorsed by Fraser and Vickers, but it is hard to make sense of the existence of objects like viruses or even the existence of forces if our ontology is just spelt out in those terms. To make more precise the ontology of OSR, Ladyman and Ross ([2007]) employ the notion of real patterns, which is

[10]See (Ladyman and Ross [2007], p. 180) on the same topic in more detail.

an inherently modal concept inspired by the work of Dennett ([1991]), and claim that:[11]

> To be is to be a real pattern, and a pattern is real iff: (i) it is projectible under at least one physically possible perspective; and (ii) it encodes information about at least one structure of events or entities S where that encoding is more efficient, in information-theoretic terms, than the bit-map encoding of S, and where for at least one of the physically possible perspectives under which the pattern is projectible, there exists an aspect of S that cannot be tracked unless the encoding is recovered from the perspective in question. (Ladyman and Ross [2007], p. 226)

Thus entities earn their keep by being real patterns, and the real patterns account explains how we can make things out of the modal structure posited by OSR. The real patterns ontology is then naturally combined within standard OSR with a scale-relative view of ontology:

> Scale relativity of ontology is the [...] hypothesis that claims about what (really, mind-independently) exists should be relativized to (real, mind-independent) scales at which nature is measurable. (Ladyman and Ross [2007], p. 200)

According to this position, what exists should be indexed to the particular domain that is considered, because there are scales at which theories and their associated ontologies are not effective. In this sense, objects like mountains do not exist at the quantum scale, but exist at the macroscopic scale. If entities exist by virtue of being real patterns, and real patterns are carved out of specific scale-relative and domain-relative structures, then existence is relativized to the scale or domain considered. In this sense, the ontology of structural realism is clearly always effective ontology. Consider now how this makes OSR immune to Saatsi's challenge. As applied to gravitation, this view entails that being realist about Newtonian gravitational forces and about General Relativity's gravitation does

[11] It should be stressed that the definition of real patterns quoted here is the one originally provided by Ross ([2004]) and not the refined version developed by Ladyman and Ross ([2007]). We employ this version here because it is simpler and fulfils our goals. The improved version of the definition is: "To be is to be a real pattern; and a pattern x $\rightarrow$ y is real iff (i) it is projectable; and (ii) it has a model that carries information about at least one pattern P in an encoding that has logical depth less than the bit-map encoding of P, and where P is not projectible by a physically possible device computing information about another real pattern of lower logical depth than x $\rightarrow$ y." (p. 233), where 'logical depth' is "a normalized quantitative index of the execution time required to generate the model of the real pattern in question [by a computer program] not itself computable as the output of a significantly more concise program" (Ladyman and Ross [2007], p. 220).

not pose any threat of inconsistency. Newtonian gravity and General Relativity describe reality at different scales and they have different ontological implications at each scale. In this sense, the ontology of each theory does not rival the ontology of the other, and including both kinds of gravitation in our general ontology does not entail any inconsistency.

Summing up, OSR provides a suitable ontology for Fraser and Vickers' effective realism about quantum mechanics, making their account more precise and avoiding the issues that undermine Egg's account of effective ontology. More than this, as we have argued, Fraser and Vickers' own account can be deemed as a structural realist view, and thus we argue that the best current view about ER within quantum mechanics is easily accommodated within the structural realist framework. Overall, this improves the current debate on scientific realism concerning quantum mechanics by bridging it with the literature on structural realism.[12]

Having addressed this topic allows us also to address some of the more recent objections that have been raised against the original structural realist account of quantum mechanics. The next section reviews the critique by Egg ([2019]) and, in light of the present discussion, defends structural realism from his objections.

2.2 On Egg's challenge to structural realist quantum mechanics

We have shown how OSR is an ideal framework for an effective realist reading of quantum mechanics, and accommodates recent such accounts. However, Egg ([2019]) has raised an extensive critique of the structural realist approach to quantum mechanics. He argues that structural realism does not have the resources to provide a realist-enough view of quantum mechanics, and cannot be regarded as a viable position concerning the ontology of quantum mechanics. If Egg is correct this would undermine the arguments of the previous section, as structural realism would not be able to provide the required metaphysical underpinning for an effective realist account of quantum theory. This section defends OSR from this challenge.

The target of Egg's critique is the structural realist view that we can provide a realist account of quantum mechanics while remaining neutral concerning the measurement problem and thus the choice between different versions of quantum mechanics. This is basically the kind of strategy pursued by Egg ([2021]) himself and by Fraser and Vickers ([forthcoming]), which we have defended in Section 2.1, but his focus is on the specific way in which Ladyman and Ross ([2007]) implement the approach. The core of his objection is that "the dissolution of the measurement problem proposed by Ladyman and Ross undermines some specific commitments

[12] Note that the main goal of this section is to show how OSR can accommodate and improve the ER approach to quantum mechanics developed by Fraser and Vickers, and of course it does not provide an exhaustive structural realist picture of non-relativistic quantum mechanics.

that should be part of any position deserving to be called realism (even only a partial one).” (Egg [2019], p. 62).

He begins by pointing out that Ladyman and Ross ([2007]) sympathize with Bohr’s approach to quantum mechanics, but also believe that such a view is compatible with a form of scientific realism, and can be made explicit by structural realism. In this way they propose to be realist about quantum mechanics without being committed to any solution to the measurement problem. However, Egg stresses that the notion of measurement is problematically vague, which is the reason why the Bohrian interpretation of quantum mechanics is usually deemed as not viable. He grants that in some situations it is clear that the notion of measurement applies, but, he asks: “what about ambiguous cases, for example, a device that displays a measurement outcome which is not (even indirectly) observed by anyone?” (Egg [2019], p. 66). He then considers how this problem can be solved, and highlights how Ladyman and Ross opt for a verificationist approach to the issue, which considers

> [...] any question about unobserved measurements as a pseudo-question: Such events (by definition) do not make any difference to what we observe, hence we should not suppose that there are any matters of fact concerning them. However, this is hard to square with realism, understood as a stance that refuses to limit reality to what we can observe, or worse still, to what we actually *do* observe. (Egg [2019], p. 66)

Having raised this issue, Egg concedes that OSR is not a standard form of scientific realism, but a structuralist one, which is therefore committed to objective modal structures. He thus admits that structuralists do not share the same ontological commitments as standard scientific realists, and therefore that they could respond that non-structural features of quantum mechanics are outside the scope of realism. However, even granting this, he argues that a deeper issue lingers, i.e. the structural realist approach conflicts with aspects of realism that even structural realists like Ladyman and Ross endorse.

According to Egg, this stems from the anthropocentric reading of the notion of measurement in approaches to quantum mechanics such as Bohr’s. Even if structural realists are just minimally ontologically committed to objective modality as represented in Bohr’s rule, there would be situations in which OSR would not deliver a realist reading, but in which a realist reading seems uncontroversial, such as situations in which measurement occurs but there are no observers to register them. In Egg’s words:

> In order to satisfy OSR’s demand, the regularities need to be invested with modal force, which enables us to answer questions about counterfactual situations. Among such questions are those about what would

> have happened if we had not been around to observe the phenomena in question, and an explanation would hardly be deemed satisfactory if it postulated regularities that only obtain if some observer is present. But this is precisely what the Born rule does, if it is interpreted as a modally charged law but not supplemented by a non-anthropocentric account of "measurement". (Egg [2019], p. 66-7)

As a result, he claims OSR does not provide an adequate realist view of quantum mechanics, and cannot satisfy the desiderata for one. If this is right, OSR cannot be put on par with the accounts by Egg ([2021]) and Fraser and Vickers ([forthcoming]), and the proposal of the last section fails.

To respond to this objection, we argue that OSR can incorporate a kind of verificationist stance to quantum measurements, while also avoiding the charge of anthropocentrism. It can do this by adopting an account like the one defended in the previous section. Indeed, structural realism is not committed to any specific notion of measurement, and can instead be combined with an approach to quantum mechanics like the one proposed by Fraser and Vickers, to build a structuralist effective modal ontology based on that. In particular, concerning the specific challenge raised by Egg ([2019]), structural realism can adopt an approach based on decoherence and the effective collapse of the wavefunction, and employ objective modal structures and real patterns to build an adequate effective ontology. By appealing to decoherence, we avoid the need for an allegedly anthropocentric notion of measurement in the first place, while sticking with a verificationist approach which is also scientifically realist in a structuralist way. Summing up, Egg's challenge is based on the misguided opinion that an anthropocentric notion of measurement is mandatory for the structural realist, but the account developed in Section 2.1 demonstrates that this is not the case.

Note that adopting this strategy is not in contrast with Ladyman's and Ross' (2007) version of OSR, or with their defence of Bohr's approach, even though the latter is sometimes associated with an anthropocentric account of measurement. The structural realist view adopted here invokes decoherence, which Schlosshauer and Camilleri ([unpublished], [2017]) use to vindicate and make sense of the quantum-classical cut invoked by Bohr. So understood neither Bohr's nor Ladyman's and Ross' views are anthropocentric.[13]

[13]Naturally, if one disagrees with the arguments by Schlosshauer and Camilleri, one is free to take our response as incompatible with the Bohrian approach and as contrasting with it. Nothing substantial about our response hinges on this.

3 Effective Realism and Quantum Field Theories

It is clear that quantum field theories and the Standard Model of particle physics present specific problems for scientific realism (see Ruetsche [2011]). This section considers ER in this context as proposed by Fraser ([2018], [2020*a*], [2020*b*]) and Williams ([2019]) to develop a scientific realist account in the context of theories that are effective because there are intrinsic limits to their applications. We explain how bringing OSR into this discussion helps, especially by making clear how these views can qualify as realist, and by making explicit the notion of scale-relativity.[14]

The effective nature of quantum field theories is stressed by Wallace ([unpublished]) in his account of the emergence of particles in terms of quantum field theory and the way that cut-offs are introduced to renormalize the calculations of scattering amplitudes.[15] Perturbative quantum field theories and effective field theories are incredibly successful empirical theories but they only apply at certain energy scales. Fraser ([2020*b*]) points out that while they clearly satisfy the empirical criteria for scientific realism because they made some of the most accurate predictions in history, as well as novel predictions, there is no agreed characterisation of their physical content. Furthermore, many perturbative calculations seem *ad hoc* and renormalisation involves length-scale cut-offs that could be made differently. However, renormalisation group methods can be used to show that the results are independent of exactly how the cut-offs are made. Furthermore, the behaviour and nature of entities in particle physics is independent of the details of the structure of the physics at the length scales beyond current quantum field theories.

In the context of quantum field theories, as before, effective ontology is the ontology of an effective theory which has a limited range and domain of applicability, and ER is the form of scientific realism which is just committed to the entities and phenomena described by such theories. The 'Effective Realism' of Williams and the 'Renormalisation Group Realism' of Fraser are effective realist accounts which are intended as forms of selective realism. Selective realism is the defence of realism on the basis of criteria for picking out, in advance, the parts of the theories liable to be retained after otherwise radical theory change. However, it is important that this form of ER does not involve require a complete interpretation and ontology that is expected to survive theory change, just the claim that the theory will remain effective in its domain after future theory change (see below). This is surely so, although of course what is understood as the domain of the theory may change to some or indeed a considerable extent. Interestingly, in the case of perturbative quantum field theories it is built into the models that

[14] Ruetsche ([2011]) also criticises OSR but not in the form that we defend here. Dougherty ([forthcoming]) criticises other forms of ER and proposes his own involving scale-relative realism.

[15] See also (Wallace [2021]).

they only apply within certain scales.

However, at this point, an issue arises for these views, as Ruetsche ([2018], [2020]) points out. That is, ER so characterised does not seem different to accepting the empirical adequacy of the theories as well as pragmatic commitments to their ontology.[16] ER, as proposed by them, is vulnerable to the charge that it is compatible with structuralist empiricism and other forms of antirealism, because it does not amount to more than talking and reasoning as if entities are real for the purposes of scientific practice in some domain. For it to qualify as a form of realism we need to make clear the realist commitments of the account.

We argue that combining these views with OSR can dissolve the problem and hence improve this form of ER. The explicit commitment to realism about modal structure is the core component of OSR that makes it distinct from van Fraassen's structural empiricism and a scientific realist metaphysics. Furthermore, from the perspective of the OSR of Ladyman and Ross, the kind of realism prompted by quantum field theories and proposed by Fraser, Williams and Dougherty, is not special to quantum field theories but rather is an example of the scale relativity of ontology that they regard as ubiquitous and which is naturally embedded within OSR's ER.[17]

To see how OSR can improve ER about quantum field theories, let's start by looking more closely at how the charge pointed out above affects for instance Williams' account.[18] The ER he develops departs from standard versions of scientific realism. Instead of being committed to the whole theory of quantum fields at all scales, we just focus on certain limited domains, and consider the theory in its effective form. The realist is then allowed to use renormalisation group analysis to pick out those elements of the theory that are invariant under renormalisation groups flow, and to be committed to those. In particular, the renormalisation group analysis shows that certain quantities have their values independently of the exact choices made and so that they are 'robust'. Williams uses Wimsatt's definition of robust here: "accessible (detectable, measurable, derivable, definable, producible, or the like) in a variety of independent ways" (Wimsatt [2007] p. 95). These quantities are preserved by renormalisation group coarse-graining transfor-

[16] Fraser ([2020*b*], p. 290) explicitly mentions OSR while saying that "There are certainly frameworks on the table that the effective field theory realist might turn to in order to clarify their position" but does not elaborate. This is a point in favour of the worth of the present discussion.

[17] It should be noted again however that French, Ladyman and Ross do not understand structural realism as a form of selective realism, departing from the authors quoted above in this respect. Nonetheless, the present account of ER can frame Williams, Fraser and Dougherty's accounts, since these accounts can be classified as forms of effective realism, regardless of their relationship with the notion of selective realism. We thus stress that ER should be distinguished from selective realism. For more on this topic see (Ladyman [2021]).

[18] Fraser ([2020*b*]) follows a very similar strategy.

mations and encode the long-distance structure of quantum field theory models. As such, we should be 'effectively' committed to them.

Now, our point is that it is difficult to see how where exactly this account and a non-realist position such as e.g. van Fraassen's ([2006], [2008]) empiricist structuralism differ, since antirealists including van Fraassen allow that those accepting a theory can be pragmatically committed to the ontology of a theory, and that this has a role in the application and development of the theory. Since Williams' (and Fraser's) account are compatible with a view like this, it seems that his form of ER is realist in letter but not in spirit. To obtain a genuinely realist position, this approach to ER must be combined with some kind of realist metaphysics. This is basically the same point raised earlier in Section 2 about Fraser and Vicker's account of quantum mechanics, and is granted by some of the authors working on this debate as well, as mentioned. As such, just as in Section 2, we contend that bringing OSR into the picture – and in particular a metaphysics of modal structures and a scale-relative picture of ontology – can solve the problem.

As explained in Section 2, the present form of OSR involves scale relativity of ontology in general. Thus, the status of effective field theories is not special at all within this picture. Just as we can be realist about the modal structures that are represented in non-relativistic quantum mechanics models as described in Fraser and Vickers ([forthcoming]), we can be realist about the modal structures identified by renormalisation group techniques in quantum field theories. In this sense, ER applied to quantum field theories can easily become clearly a form of realism by granting that the elements of the theory that are invariant under renormalisation groups flow actually represent modal structures in the world, and those structures are to what we are ontologically committed. Realism about modal structure thus allows us to make ER about quantum field theories a genuine form of scientific realism. This structuralist version of ER about quantum field theories vindicates the general claim that ontology is scale-dependent and this accommodates the remark often made by the authors working on quantum field theory that the structures revealed by the renormalisation group techniques are essentially scale-dependent. These structures fit the criteria for real patterns since they capture projectible features of the world as discussed by Ladyman ([2015], p. 203-4): "The criterion of ontological commitment is as follows: real patterns (genuine individuals) must figure in projectable generalizations/causal laws that allow us to predict and explain the behaviour of the world."

Employing the OSR package of realism about modal structure, real patterns, and scale-relativity of ontology, thus provides a metaphysics to go with the ER for quantum field theories recently proposed.

4 The Effective Ontology of Old Theories

So far we have discussed the topic of effective ontology within the context of quantum physics, and have shown how OSR moves both the debate about realism about quantum mechanics, and the debate about realism about quantum field theories and the Standard Model forward. This section focuses on a different context in which effective realism has been discussed and argues that the same structural realist approach to effective ontology is applicable to and advances this debate as well.

The issue is the problematic ontological status of the entities of superseded theories that were once held to be true. The scientific realist must say whether we should keep them in our ontology given that they were once considered to be real, and, if so, how they should be understood. Robertson and Wilson ([forthcoming]) have recently argued against the common view that the entities of superseded theories (that they call 'theoretical relicts') should simply be eliminated, and provided an effective realist account of them. They argue that we can retain them, provided that we can appropriately restrict the old theory to which they belong to a domain in which it holds, and if we can show that those entities still play a relevant explanatory role in currently accepted explanations. As they put it, these effective and non-fundamental entities "earn their keep through playing a role in our best explanations" (Robertson and Wilson [forthcoming], p. 22). They thus consider those entities to be emergent, and on a par with the entities posited by special sciences. One example is space (as opposed to spacetime), which can be recovered and therefore considered as an entity of the same kind of higher-level items like viruses or gasses. It should be highlighted that by pursuing this strategy they are following OSR's idea that "entities that are now regarded as emergent are also often the entities of past theories" (Ladyman [2018], p. 102) (this statement is quoted by Robertson and Wilson).

Crucially, they argue that their framework is better than Egg's account concerning effective ontology. Recall Saatsi's objection that if we liberally include in our ontology any entity that plays a role in some explanation then we can end up with inconsistent ontological commitments, e.g. by being realists about both Newtonian gravitational forces and General-relativity gravitation. Robertson and Wilson's account avoids the problem, as they stress, since the domain-restriction step removes the inconsistency: the theories are made to agree as the old theory is now restricted in a way that makes it true only in a limited domain. Therefore, when we reify the entities of the restricted old theory they do not conflict with the entities of the new theory, because they exist as effective and higher-level entities:

> On this approach, Galilean spacetime (for example) is no longer understood as merely a useful fiction; we understand Galilean spacetime

> as a description of spacetime structure at a 'classical' level of abstraction. Likewise, Newtonian gravity and general relativity characterize different structural features of gravitation located at different levels of abstraction. (Robertson and Wilson [forthcoming], p. 25)

OSR's ER offers an equivalent ontological account of theoretical relicts and Robertson and Wilson's proposal can thus be easily embedded within the structural realist framework. Structural realism is motivated in part by the problem of reconciling scientific realism with the history of changes in the ontology of science. Furthermore, OSR implements structural realism with an ontological account of higher-level entities and entities of superseded theories in terms of real patterns that perfectly fits in the present context and naturally accommodates Robertson and Wilson's proposal. As pointed out, Robertson and Wilson explicitly refer to OSR and Ladyman's work, and making clear the full connection between their account and OSR fills a gap in their discussion. We also argue that OSR improves on their proposal by replacing reference to levels of abstraction with the notion of scale relativity.

To see how OSR fits into the picture let us first consider the topic of theory change, which is the starting point of the whole discussion about theoretical relicts. Briefly put, structural realism avoids the problem of theory change against scientific realism by arguing that even in cases of radical ontological discontinuity more than the empirical content of the abandoned theories is retained. For example, the theory of phlogiston has been discarded by modern science, but that theory did correctly capture the modal structure of the world by identifying that the processes of ordinary combustion, calcination of metals and respiration are all instances of the same kind of process, and there is a reciprocal kind of process exemplified by the smelting of ore using charcoal. Thus, instead of claiming that the phlogiston theory was completely wrong about reality, and concluding that scientific realism is undermined by the falsification of the theory, we can say that the theory was right about certain aspects of reality:

> We can say that phlogiston theory identified a number of real patterns in nature and that it correctly described aspects of the causal/nomological structure of the world as expressed in the unification of reactions into phlogistication and dephlogistication. (Ladyman [2011], p. 100)

Scientific realists should not simply be realists about the entities posited by theories, but should be ontologically committed to the causal/nomological structure represented by theory – as explained in the previous sections – which is likely to be retained within some domain or to some degree of accuracy even on radical theory change. In this sense, scientific realists should not be committed to entities as ontological posits understood independently from the structure of the theories.[19] This leads us to the connection between OSR and effective realism about theoretical relicts.

OSR delivers a metaphysical picture that accommodates in its ontology those elements described by old theories that play a relevant explanatory role and can be classified as modal structures or real patterns, thereby delivering an effective ontology. This effective ontology is scale-relative, as illustrated in Section 2, and this idea can serve instead of that of 'levels of abstraction' described by Roberson and Wilson (more on this below), and is importantly tied with the explanatory power of the entities at stake that we want to retain (another key feature in Robertson and Wilson's account) via the criteria for real patterns. Furthermore, just like Robertson and Wilson's framework, OSR provides a unified picture of old theories' entities and special sciences' entities, in this case via the notion of real patterns. Indeed, the real patterns ontology can account both for elements like Newtonian forces and for entities like viruses, provided that the entities of special sciences are projectible and explanatory useful. Moreover, OSR has the additional advantage of placing its account of theoretical relicts within a clear and broader strategy accounting for theory change as related to scientific realism and effective realism, as in the example about phlogiston. Finally, OSR accommodates all the features of Robertson and Wilson's account and thus can account for Saatsi's challenge against effective ontologies too, as also independently argued in Section 2.1. We thus claim that Robertson and Wilson's proposal is perfectly accounted for by OSR and can be embedded within it.

But we also argue for the stronger thesis that OSR delivers an account of effective realism that satisfies all the desiderata of Robertson and Wilson's account while also improving it. The main point concerns the notion of levels of abstraction employed by Robertson and Wilson, for instance in the quote above. We contend that such a notion can muddy the waters, and appealing to the concept of scale relativity improves the view. Recall for instance their claim that "Newtonian gravity and general relativity characterize different structural features of gravitation located at different levels of abstraction.". Employing the notion of 'abstraction' in this context is not the best way to explain the relationship between the theories. Rather, saying that Newtonian gravity and general relativity describe reality at different energy scales is more appropriate. Mathematically, the Poisson equation of Newtonian gravitation is the low-energy limit of General relativity's gravitation and Einstein constructed it to be so. In this sense, it is better to think of Newtonian gravity as defined at a different energy scale to General Relativity and to claim that each theory is correct about reality at that scale. If we link this scale-relative approach to theories with the structural realist's account

[19] See also (Ladyman [2020], Sect. 2) for more discussion of scientific realism and OSR.

of real patterns and scale-relative ontology presented in Section 2, we can claim that Newtonian gravitational forces and General Relativity's gravitation both exist at different scales. This is the way in which OSR can reformulate the kind of emergent ontology proposed by Robertson and Wilson and embed it in a more precise framework.

5 Conclusion

This paper shows how OSR provides a framework for effective realism that links this form of scientific realism with a metaphysical picture, and readily addresses three different topics recently linked to ER, showing how three accounts that seemed to be disconnected from each other can be brought under the umbrella of structural realism to provide a comprehensive account of effective ontologies unifying three separate debates in the literature.

In particular, concerning quantum mechanics, OSR provides an ontological view that neatly fits with effective realist readings of quantum theories such as the one proposed by Fraser and Vickers, while avoiding challenges like Saatsi's. Moreover, Egg's ([2019]) objection against structural realist quantum mechanics can be rebutted. Concerning quantum field theories, OSR provides a realist metaphysics and can account for the effective realist accounts developed in this area. Concerning the ontology of old theories which were once regarded to be true, OSR can readily account for Robertson and Wilson's proposal and reformulate it in structuralist terms. Using OSR's view of modal structures, real patterns and scale-relative ontology, structural realism can also improve the account and replace emergent entities and levels of abstraction with scale-relative real patterns. Structural realism should thus be brought back into the debate to develop further these fruitful lines of research.

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