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Should scientific realists be platonists?

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Abstract Enhanced indispensability arguments (EIA) claim that Scientific Realists are committed to the existence of mathematical entities due to their reliance on Inference to the best explanation (IBE). Our central question concerns this purported parity of reasoning: do people who defend the EIA make an appropriate use of the resources of Scientific Realism (in particular, IBE) to achieve platonism? (§2) We argue that just because a variety of different inferential strategies can be employed by Scientific Realists does not mean that ontological conclusions concerning which things we should be Scientific Realists about are arrived at by any inferential route which eschews causes (§3), and nor is there any direct pressure for Scientific Realists to change their inferential methods (§4). We suggest that in order to maintain inferential parity with Scientific Realism, proponents of EIA need to give details about how and in what way the presence of mathematical entities directly contribute to explanations (§5).

Keywords Indispensability · Platonism · Inference to the best explanation · Philosophy of science · Philosophy of mathematics · Scientific realism

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1 Introduction

The Explanatory or Enhanced Indispensability Argument (EIA) claims that since mathematical objects feature in the best explanations of empirical phenomena, we should believe in their existence.[1] EIA is supposed to give empirical reasons, of the sort normally used in arguing for the existence of physical entities, to think that *abstracta* exist, and as such it is targeted at Scientific Realists. We can state this argument more perspicuously as follows:[2]

1. Scientific Realists maintain that scientific observations are rationally sufficient for believing in the existence of unobservable entities.
2. Scientific Realists employ Inference to the Best Explanation (IBE) to show how their Realist commitments to the existence of unobservable entities are rationally defensible on the basis of the scientific observations.
3. There is at least one Genuine Mathematical Explanation of scientific observations. ('GME').
4. Mathematical Realists, like Scientific Realists, can employ IBE; to do so is to use the same epistemic or inferential resources as Scientific Realists. ('Parity').
5. Mathematical Realists employ IBE to show how their Realist commitments to the existence of abstract entities are rationally defensible on the basis of Genuine Mathematical Explanations of scientific observations. (EIA)
6. Scientific Realists should be Mathematical Realists.

In effect, the conclusion, 6., says that we have the same indirect, inferential epistemic access to unobservables (such as electrons or black holes) as we do to *abstracta* (such as numbers), and so anyone who believes in the existence of the former should also believe in the existence of the latter: Scientific Realists' should be platonists and not nominalists about mathematical objects. While the presentation of the argument above is distinctive, any variety of EIA which employs IBE, and does so on the basis of its role in Scientific Realism more generally, will be subject to our concerns. Our argument is primarily directed at denying 'parity', and its main effect is to increase the burden of proof required for defending 'GME'.

In Sect. 1 we will introduce the key components of this argument (IBE, 'GME' and 'parity') in closer detail. In Sect. 2 we investigate the relationship between IBE and EIA. In part, both of these sections explore whether IBE involves a causal model of explanation, and what consequences this has for 'parity' in the case of EIA. The supposition is that if Scientific Realists only use a causal model of explanation when they rely upon IBE, then since *abstracta* are causally-inefficacious, considerations of 'parity' will prevent EIA from delivering platonism. The challenge to this supposition comes in two parts. The first question is whether Scientific Realists actually restrict

[1] We will proceed on the assumption that EIA is employed to argue in favour of platonism: the claim that mathematical objects exist and that mathematical objects are *abstracta,* as this makes EIA more interesting than if it is used to argue for mathematical realism construed non-platonistically. If EIA is supposed to be used to argue for a non-abstract ontology for mathematics, it is unclear exactly why we would need it, since presumably there are alternative epistemic routes for establishing this conclusion.

[2] We have in mind the EIA that appear in the work of, among others, Alan Baker (Baker 2001, 2005, 2009), Mark Colyvan (2001, 2002, 2006), Lyon and Colyvan (2008), and Bangu (2013).

their inferential resources to causal models of IBE. The second challenge (prompted by Mark Colyvan) is whether Scientific Realists should use non-causally based IBE. In Sect. 3 we suggest that when it comes to arguing for the existence of entities, Scientific Realists employ causal versions of IBE, and this blocks the possibility of 'parity' in EIA. In Sect. 4 we address the question of whether Scientific Realists should change their inferential practices to permit a non-causal model of IBE for inferring to the existence of entities; we argue that the cases proposed by Colyvan are insufficient. We conclude that 'parity' between Scientific Realist's inferential practices and those used in EIA will not entail platonism.

While these are the details of our argument, from a greater distance this paper is more generally concerned with how debates in the philosophy of science about ontological commitments might develop. If someone wants to argue that Scientific Realists should be Mathematical Realists because the step to Mathematical Realism is just another application of things that Scientific Realists already do, then they need to pay closer attention to what Scientific Realists already do. What we show is that, on closer inspection, Scientific Realists: are high selective about what they are realist about (they rarely endorse the existence of everything in a theory, for example); employ different inferential strategies in different places (moves they make to neutralise sceptical examples aren't moves they would make to infer the existence of a new thing); have a strong preference for identifying causes and cause-based reasoning. Our narrower goal is to highlight how these features suggest that the argument (1–6 above) to convince Scientific Realists to be Mathematical Realist by some sort of parity-of-reasoning will not work. But the broader goal here is to draw attention to the idea that while other Indispensability Arguments focus on what practising scientists do (how do they infer the existence of new entities), the focus is actually about paying attention to what Scientific Realists do.[3] Much of the discussion of Indispensability Arguments has focussed on how scientists reason, and whether the same inferential strategies that they use could deliver platonism. Here, we view the metaphysical issue as concerning what the arguments do in the philosophy of science, and not about how the evidence gets used in the field of science.

2 Some components of the argument

Accounts of IBE differ in a range of important respects, but we take the following to represent its general form:[4]

1. E is a collection of data (facts, observations etc.).
2. H explains E, or H would, if true, explain E.

[3] These two populations may overlap.

[4] This suggestion is similar to formulations found in (Lycan 1988; Josephson and Josephson 1994; Psillos 2002, 2007; Mackonis 2013). We will not evaluate what the correct formulation of IBE should be. The qualification that 'H would, *if true*, explain E' reflects Lipton's (2004) qualification based on the observation that we only take hypotheses or theories to be actual explanations in so far as they are true. Any hypothesis that acts as an explanation for some E is a potential explanation but only true hypotheses can be actual explanations. Sorin Bangu (2008, 2012) and Mary Leng (2005, 2010) suggest that construing explanation factively is question-begging in this context.

3. No other hypothesis explains E better than H does.
4. Therefore there is reason to believe that H is (at least) approximately true.

The argument we have reconstructed in the introduction above claims that if Mathematical Realists can defend the existence of mathematical objects using IBE, then our subsequent commitment to *abstracta* is just as legitimate as any commitment to unobservable objects that is arrived at on the basis of IBE. We have labelled the pivotal premises in this argument ‘parity’ and ‘GME’.

GME claims that there is at least one case (and potentially more than one case) in which a mathematically-committed hypothesis H explains a collection of data E, and for which no other hypothesis explains E better than H does. Several such cases of purported Genuine Mathematical Explanations are discussed by mathematical realists and anti-realists; these include Baker’s (2005) example concerning the prime life-cycles of periodic North American cicada, and Lyon and Colyvan’s (2008) example of the role that Hales’ proof of the Honeycomb Conjecture plays in the best explanation of bees’ hive-building behaviour.[5]

Baker’s (2009) responses to criticisms of his cicada example are instructive in clarifying what’s required for a Genuine Mathematical Explanation. For example, it seems clear that the *explanandum* involved in a case of GME has to describe ‘purely physical’ phenomena, since otherwise the EIA will be question-begging by invoking *abstracta* to describe mathematical phenomena that a Scientific Realist might not recognise as a legitimate *explanandum* in the first place (2009, 619).

An additional requirement that Baker discusses is whether the mathematically-committed hypothesis, the *explanans* of a Genuine Mathematical Explanation, must be ‘explanatory in its own right’ (2009, 622). Must the mathematics in the *explanans* be directly responsible for the hypothesis’ ability to explain the physical phenomenon? It seems *prima facie* insufficient, for the purposes of the GME, that the mathematics features as an indispensable but non-explanatory component of a wider explanation. This is agreed on both sides of the debate between nominalists and proponents of EIA.[6] But, Baker argues, there are no adequate grounds for distinguishing whether the mathematics directly (or even indirectly) contributes to the explanatoriness of an *explanans* from the possibility that it plays an essential but non-explanatory role. Baker initially suggests that there is an impasse here: “Does the platonist need to give a positive argument for why the mathematics in the [GME] case is explanatory in its own right, or does the nominalist need to give a positive argument to the contrary?” (2009, 624). But on the grounds that a) there are no extant (nominalist) arguments for thinking that there cannot be cases in which the mathematical hypothesis is ‘explanatory in its own right’, and b) there are cases in which scientists seem happy to treat the mathematical hypotheses as genuinely explanatory, Baker concludes that platonists have no burden of proof here. That is, he thinks it is sufficient for the purposes of EIA that a GME can be given, and there is no further obligation to demonstrate that the mathematics are directly responsible for the explanatoriness of the *explanans* involved.

[5] Further GME cases are discussed in Batterman (2010).

[6] See the exchange between Colyvan (2002) and Joseph Melia (2002). Despite their differences, Melia (nominalist) and Colyvan (platonist) agree that if mathematics can be shown to be contributory “*in the appropriate way*,” then EIA should be considered persuasive (Colvyan 2002, p. 70).

In Sect. 4 we present some reasons for thinking that the burden does not fall wholly on the nominalist who wishes to block EIA, and that mathematical realist has an obligation to say more about how and when the mathematics is contributing to the explanatoriness of the *explanans*. We argue that these obligations follow from the conditions for meeting 'parity'.

'Parity' says that in using IBE to infer to the truth of mathematically-committed hypotheses that feature in GMEs, Mathematical Realists are using nothing but the inferential tools which Scientific Realists already keep in their inferential toolbox. The point of 'parity' is to show that the reason why Scientific Realists should accept the existence of numbers, sets, functions or other *abstracta* is no different from the reasons that they rely upon for believing in unobservable entities like black holes and electrons. If 'parity' is false – if the inferences employed in reasoning from observations of hexagonal beehives to the existence of *abstracta* are different from kinds of inferences employed in reasoning from observations of patterns on a monitor (or suchlike) to the existence of electrons – then there is no reason for scientific realists to be mathematical realists.

The role of 'parity' in the argument does not require complete equivalence of inferential resources between Mathematical Realism and Scientific Realism; all it needs is for the inferences employed by Scientific Realism (in this case, IBE) to be sufficient for arguing for Mathematical Realism. As such, 'parity' requires attention to the details of how IBE functions in arguments used by Scientific Realists, in order to identify the inferences that are being made and to see whether those same inferential strategies can also (with no additional inferential resources) be used to deliver mathematical realism. So an overarching question that guides our investigation here is: do proponents of EIA ('explanationists') make an appropriate use of IBE in order for them to argue for realism about mathematics? This question concerns whether the kind of parity of reasoning between Scientific Realism and Mathematical Realism is really present: do Mathematical Realists employ IBE in the same way as Scientific Realists do with respect to establishing existence claims, or do they use IBE differently in arguing for the existence of *abstracta*? We will argue that IBE is not used in arguments for Scientific Realism in the same way that it is used by mathematical explanationists, because Scientific Realists invoke a causal model of explanation when arguing for the existence of entities. Since *abstracta* are causally inefficacious, 'parity' with the inferential resources used by Scientific Realists will not deliver platonism. The subsequent question, for Sect. 4, is whether Scientific realists should change the way that they employ IBE, and permit a non-causal model of explanation when making inference about the existence of entities.

3 Inference to the best explanation in scientific realism

Mark Colyvan builds his (2006) case for Mathematical Realism on the basis that Scientific Realists use IBE when arguing from observations to the existence of unobservables. This is correct: IBE in one form or another is widely accepted amongst Scientific Realists. The general form of an Indispensability Argument for Mathematical Realism that he discusses counsels us to accept the existence of any entity which plays an indispensable role in science. He agrees with Hartry Field that "one way that an entity might play an indispensable role in a scientific theory is in virtue of it being indispensable for explanation", and also with Field's claim that "inference to the best explanation (IBE) is a special case of the indispensability argument" (Colyvan 2006: 227, Field 1989: 14–20).

However, it is important to be clear about what kind of IBE features in Scientific Realist arguments, and how it works. For one thing, it is crucial what kind of explanations feature in Scientific Realism. Colyvan is well aware that a number of Scientific Realists are happy to employ a particularly limited variety of IBE, inference to the most likely cause, and that those who do are not inclined to accepting abductive inferences that take them beyond inferences about causally operative entities. Baker's response to this kind of challenge is to suggest that to insist on causal explanations in science is to be question-begging against mathematical platonism (2005: 234), since *abstracta* are causally inefficacious. We note that such a complaint should not unduly worry Scientific Realists who insist upon causal explanation for what they perceive to be independent philosophically respectable grounds, such as not to risk making inferences that are unduly epistemically risky. Given the way that we have set up the EIA, and its explicit appeal to 'parity', that the platonist cannot convince the Scientific Realist using the Scientific Realist's own tools is primarily a problem for the platonist.

Colyvan, in contrast, has exploited this observation to design a dilemma for any kind of scientific realist intent on arguing for scientific realism by means of IBE (Colyvan 2001). The dilemma is as follows. On the one hand, Scientific Realists may choose to use only versions of IBE that are limited to causal explanations (IBCE). A number of Scientific Realists motivate their realist conclusions precisely on that basis, notably Cartwright (1983), Hacking (1983) and Cheyne (1998). However, Colyvan (2001) suggests that limiting the scope of Scientific Realism to those kinds of entities that one may causally interact with necessarily conflicts with the fact that there are plenty of entities about which, intuitively, one ought to be a realist. As examples of such putatively real yet causally-inaccessible objects, Colyvan mentions entities outside the lightcone, like planets and black holes, and offers the case of Mendeleev who, prior to the experimentally confirmed discovery of germanium (prior to 1878), was seemingly justified in believing that germanium exists, in virtue of having inferred to its existence by ampliative reasoning. One cannot be a realist in these cases while insisting upon a version of IBCE.

On the other hand, Colyvan argues that Scientific Realists can accept that inferring to the best explanation is guided by recognizing a whole range of variables can be 'better making' properties (or virtues) of explanations, and that identifying causes is only one virtue amongst many, and is not a necessary condition. Once Scientific Realists endorse this more general (because less restrictive) picture of IBE, they are in a position to account for knowledge of these kinds of objects that one might intuitively like to be a realist about. However, since accepting this general version of IBE effectively lifts any restriction on inferring to the existence of causally-inefficacious entities, it follows that there is nothing inherent in the Scientific Realists' exercise of IBE which prevents its being recruited to the Mathematical Realist's goal of inferring to the existence of abstract entities.

Colyvan's dilemma for Scientific Realists is between accepting IBCE and being realist about too little, or accepting a more general IBE and being realist about not only entities outside of the lightcone, but also about mathematical entities (and thus from the point of view of certain Scientific Realists, e.g. Musgrave (1986), altogether too much realism). Colyvan thinks they should accept the general (non-causal) version of IBE and the platonism that accompanies it. In this sense, Colyvan thinks EIA maintains parity with what Scientific Realists should say. In the next section we argue that Colyvan is right: that when it comes to arguing for the existence of entities, Scientific Realists restrict themselves to causal models of explanation. In Sect. 4, we argue that Scientific Realists can respond to Colyvan's dilemma without having to endorse a version of IBE for which considerations of 'parity' might entail that they should be Mathematical Realists. We note, for the time being, that it does not follow from that fact that Colyvan gives this advice or prescription that any Scientific Realists actually take it. That he thinks a general (non-causal) version of IBE is what Scientific Realists should endorse does not entail that any of them do endorse it; 'parity' requires that they do.[7]

4 Different inferences at work in scientific realism

Colyvan's recommendation for scientific realists was to accept a variety of IBE that works on a general criterion of goodness of explanation, severed from considerations about causes. It is certainly true that Scientific Realists do not always need to insist on a causal account of explanation, and superficially this looks like Colyvan is in line with how scientific realists have proceeded in the past. But there are several things to note about this point. The first is that there is an abundance of different varieties of ampliative reasoning. Schurz (2008) lists a catalogue of abductive inferences, all of which are identified as inferences that are used for the purpose of scientific discovery. That is, there is more than one way that actual scientists actually reason, abductively. Not only are there a range of different varieties of 'vertical' inductive inferences (rather than the straightforward 'horizontal' inferences that result from enumerative inductions[8]), but there are at least as many different varieties of IBE as there are criteria for selecting between theories. All of them are employed to make inferences which go beyond our immediately available observable evidence, and many of them are *prima facie* sufficient to make inferences which go beyond identifying causes.

The second thing to notice is that different types of ampliative reasoning serve different roles and purposes, not only in science but also in the kinds of debates in which Scientific Realists engage. For example, IBE is sometimes appealed to in

[7] Colyvan relies upon the idea that this is a genuine dilemma for Scientific Realists in order to set up a subsequent challenge for prospective nominalists. The subsequent challenge is that nominalists must either take an 'easy road' to nominalism, and deny that there are GMEs, or else take a 'hard road' and successfully carry out an ambitious nominalisation project (similar to Field's 1980 proposal), and he believes that there is no 'easy road' (Colyvan 2010, 2012). We argue below that Scientific Realists can avoid the initial dilemma, and so it follows that the 'easy' and 'hard' roads do not exhaust their options for being nominalists about mathematical entities.

[8] The horizontal/vertical inference distinction is discussed by Peter Lipton (Lipton 2000: 185–6).

answer to how we might select between competing empirically adequate theories. In other instances, other varieties of IBE might be used, such as when Scientific Realists argue that we have a reason to believe that a particular kind of entity exists. And the fact that a Scientific Realist might be willing to use one form of inference in one type of case does not entail that they are thereby committed to sanctioning its application in all or any other cases.[9] An IBE deployed to counter underdetermination problems is different to such an inference being employed for the purpose of accounting for the discovery of some phenomenon. The role of IBE in the 'No Miracles' argument is different once again; the inferences involved in defending a realist position from a skeptical challenge such as the Pessimistic Meta-Induction is not the same as the inference involved in concluding that without realism, much of science's ability to predict and explain would be 'miraculous'.[10]

As such, we should be very careful not to equivocate between different modes of ampliative reasoning, and we should be careful not to generalize too hastily from some particular applications of IBE in some particular instances to the conclusion that Scientific Realists are committed to the general form of inference on offer.[11] In order to show that Scientific realists are committed to Mathematical Realism in virtue of their reliance on IBE, it has to be established that the kind of IBE employed by Scientific Realists when arguing for the existence of entities is the same kind of IBE required for the EIA to work. That is: 'parity' must be observed to hold between EIA and the inferences that Scientific Realists rely on when working out whether some entity or other exists.

While Scientific Realists might in principle attempt to make use of more general (non-causal) versions of IBE in specific cases, when the existence of unobservable entities is concerned we see them using narrower (causal) versions of IBE. In fact, causes show up not only in arguments for the existence of entities, but also for other realist ontologies in the philosophy of science. Causally-grounded inferences are central in the work of Nancy Cartwright (1983, essay 5), Hacking (1983) and Giere (1988) in arguing for 'entity' realism. Causes are are similarly significant features of inferences for 'structural' realist positions.[12] Wesley Salmon appeals to the unifying properties of theories that invoke unobservable objects to explain particular phenomena, but even this is a causal account at heart (Salmon 1984: 213–227).[13] Stathis Psillos expresses the core of Realism thus:

[9] John Norton's 'material theory' of induction makes a case for this claim quite neatly – whether a particular ampliative inference is rationally defensible depends upon a 'material postulate' which is local to the domain within which the inference is being made. See Norton (2003).

[10] See Busch (2011) for a comparison between the role of IBE in defending Scientific Realism and its role in arguing for Scientific Realism.

[11] For discussion of a related point, see Saatsi (2009).

[12] Grover Maxwell (1970: 17) "Causal connection must be counted among these structural properties, for it is by virtue of them that the unobservables interact with one another and with observables and, thus, that Ramsey sentences have observable consequences." For discussion of this issue, and the general claim that the ontology of Scientific Realism is wedded to causal features, see Chakravartty (2007, esp. 27–45).

[13] Unification is often championed as one of the virtues that mathematics contributes to the bestness of an explanation or a theory (see Friedman 1974, Kitcher 1981). Note that Salmon's treatment of these cases does not explicitly appeal to IBE, but to the Common Cause principle.

> "When scientists talk about the nature of an entity, what they normally do – apart from positing a causal agent – is to ascribe to this entity a grouping of basic properties and relations. They then describe its law-like behaviour by means of a set of equations. In other words, they endow this causal agent with a certain causal structure, and they talk about the way in which this entity is structured." (1999: 155)

Furthermore, it is clear that arguing for Scientific Realism is a piecemeal exercise (Achinstein 2002; Psillos 2009, 2011a, b). Scientific Realism about a theory, or about a particular domain, is argued for by very specific arguments for each particular unobservable entity in that theory.

In one sense, the point raised here might seem moot: if most Scientific Realists only reason on the basis of causes, it is perhaps because they precisely wish to avoid risky commitments, and that may include the risk of commitments to abstract objects. This is the concern raised by Baker; that limiting Scientific Realism to inferences involving causes is to beg the question against platonism (see Sect. 1 above). But as we have seen, the platonist's central argument turns on whether Scientific Realists' own resources can be exploited to entail (by way of GME and EIA) mathematical platonism. If the resources of Scientific Realists do not include non-causal inferential strategies when it comes to determining what exists, then these resources cannot be used to reason for mathematical platonism.[14]

If this is correct, and the ampliative inferences that realists standardly use to argue for the existence of theoretical (unobservable) entities are causal inferences, it seems that Scientific Realists may face the first horn of Colyvan's dilemma; that they might end up being realists about too few things. He maintains that Scientific Realists should be Mathematical Realists on the basis that Scientific Realists should endorse a more liberal notion of IBE than they do. We address this issue next.

5 The first horn of Colyvna's dilemma and selective realisms

There are at least two strategies we wish to consider for addressing the concern that Scientific Realists who limit themselves to causal-based versions of IBE (which we label IBCE, 'inference to the best causal explanation') are in danger of being realist about too few entities. The first is to respond to each of Colyvan's examples (black holes, germanium) on a case-by-case basis. This strategy has the pleasing particularity that is associated with Scientific Realists' piecemeal approach. The second strategy is to try to make a more generic reply. We will attempt each in turn.

[14] Part of the debate here might turn on determining what is a permissible or acceptable set of operative norms for Scientific Realism: can there be a blanket ban on the involvement of any abstract objects? Bangu (2013: 257) makes this point: if our starting point is some form of philosophical naturalism that eschews any sort of involvement with *abstracta* then it is clear that the Indispensability Argument will not work. But both he and Baker seem to be at home with another version of naturalism, one that takes actual scientific practices seriously. They think that since practising scientists seem to be at home with invoking *abstracta* in their explanations of physical phenomena – not just mathematical objects, but such abstract objects as 'species' – then our Scientific Realist should have no a priori restriction against the involvement of *abstracta*. The methodology of the philosophy of science is not something we will explore further here.

The first strategy is to deal with the examples in Colyvan's dilemma on a case-by-case basis, and we will divide it into two distinct types of reply accordingly. The first horn of Colyvan's dilemma is to say that there are entities which *prima facie* it looks like Scientific Realists should want to be able to be realists about. Examples that he mentions are planets and black holes outside our lightcone, and that scientific realists should be able to account for how Mendeleev had reason to believe that germanium existed prior to its (experimental) discovery. However, if Scientific Realists insist on restricting their inferential resources to IBCE, then since these cases involve entities which go beyond the causally-constrained limits of scientists' epistemic and inferential abilities, the Scientific Realist will instead be limited to remaining agnostic about these entities. The loss, for the Realist, is that of not being able to respect the *prima facie* intuitive appeal of the claim that we do have good reason to believe that these entities exist.

There are a couple of things that the Scientific Realist can say here, and there is no particular reason to think that one or other kind of reply should generalise for both cases (or all possible cases). The first option for replying is for the Scientific Realist to give an account of the kinds of abductive inferences which would be sufficient for being realist about the existence of the entities in these cases, but which might nevertheless be inferential resources that are insufficient for EIA, in which case 'parity' would not be achieved. If correct, this reply would show that Colyvan's dilemma is a false dilemma: Scientific Realists can respect the intuition of realism about one or other of the cases while still not employing a version of IBE which permits realism about mathematical objects. We will suggest that this reply can be used in the case of knowledge about black holes and other entities outside the cone.

The second option for replying is to respond directly to the idea that Colyvan has identified a case in which we have a *prima facie* intuition of realism about kinds of entities like germanium. There is certainly something strange about the idea that Scientific Realists should endorse wide-ranging and perhaps overly-liberal inferential resources in order to account for an intuition of realism. In general (and it is hard to generalise), Scientific Realists attempt to amass a lot of detailed evidential reasons for inferring that an entity is real or known about, rather than relying on a *prima facie* intuition concerning the case history. What look like good reasons for belief might, upon closer inspection or hindsight, no longer seem worth pursuing; once the details of the situation are uncovered, the intuition that something is real or known about can disappear.

How can Scientific Realists be realist about objects outside the cone without endorsing a version of IBE sufficient for EIA to work? We sketch an argument to show that knowledge of entities beyond our causal reach (e.g. entities beyond our light cone) can be inferred on the basis of an enumerative induction. Achinstein argues that one can vary conditions on the properties in virtue of which something is observable (or unobservable) in virtue of their size, their distance from us in space and time, their duration, their interaction (or lack thereof) with other items, and so on. We can vary many of the conditions in virtue of which bodies are observable and throughout find no difference in whether those bodies have mass. On this basis, and if we have no contrary information, we have an empirical argument to support the claim that the fact that all observed bodies are observable does not bias the observed sample with regards to the property of having mass (Achinstein 2002, pp 484–485). For the Scientific Realist, (un)observability is irrelevant to objects having the kind of properties that we ordinarily attribute to them (spatio-temporal properties), while an antirealist takes 'observability/unobservability' to be a really important distinction. As our ability to extend our 'epistemic reach' has developed within the cone, we have experienced the existence of at least the same kinds of entities as we have encountered before. By enumerative induction we should expect the trend to continue, such that we should expect (inductively infer) that there are objects outside the cone which will also have mass. But this kind of inference cannot be exploited (by 'parity') in an EIA to establish the existence of numbers since they have no spatio-temporal properties. In this case, Colyvan's first horn is the first horn of a false dilemma.

In the second case that Colvan proposes, that Mendeleev's knowledge of the existence of germanium, a version of our reply to the point above could be employed here as well. In Scerri's (2007) detailed study of how Mendeleev came to construct his periodic table it is made quite clear that Mendeleev based his construction of the periodic table on the underlying premise that there exists a 'periodic law' that governed the distribution of chemical properties of elements, corresponding to their weight. Thus, the inference that Mendeleev made in order to conclude that there was good reason to believe that germanium exists can, in one sense, be reconstructed as an inference from a generalization.[15] In fact, Mendeleev wrote that what he took to be the deciding difference between himself and contemporaries like Meyer was his own firm belief in 'the periodic law'. On the methodological level, Mendeleev's method for calculating the weight of germanium involved dividing the combined weights of the four elements flanking germanium by four. If there is a kind of distinctively abductive inference involved, it perhaps best resembles an argument by analogy, in which Mendeleev reasoned that the properties of germanium could be derived using the same methods as he had used for calculating the properties of other elements (his reasoning being based on the assumption of the underlying periodic law), where in some cases those properties were known and could be used to test for the reliability of the procedure.

So in Colyvan's examples of how Scientific Realists seem to be committed to using ampliative modes of inference that extend beyond causally constrained varieties of IBE, we do see the need for a variety of a mode of inference that extends beyond causal inference. But the mere fact that scientific realists use ampliative modes of inference is not quite an argument in favour of them being committed to a variety of ampliative inference of the kind that Colyvan requires (that is: one sufficient for the EIA). Rather, in the case at hand, it is not at all clear how similar kinds of ampliative inferences might be employed in arguing for the existence of mathematical entities – 'parity' with these of Mendeleev's methods does not seem like a promising strategy for Mathematical Realists for showing that scientific realists are committed to mathematical entities in virtue of their reliance of ampliative modes of inference. For that argument to work, Colyvan needs to find examples of scientific realists actually employing ampliative modes of inference similar to the variety that he believes will

[15] Medeleev's inference to the existence of germanium was certainly more complicated than this, since it included attending to the gappiness of his table. But its gaps could only be identified as being gaps in virtue of the assumption of a periodic law.

advance mathematical realism and in a way that actually suggests that they take such inferences to be ontologically committing.

So much for the case-by-case strategy. The second strategy is to make a more generic reply to the kind of dilemma that Colyvan proposes. Suppose, counterfactually, that the Scientific Realist wants a halfway house: they acknowledge Colyvan's intution of realism in cases like black holes, agree that inferring to the existence of black holes necessarily goes beyond our causal connection to entities (in ways that inferring to the existence of future states of affairs seemingly does not?), and are willing to endorse inferential methods which are broader than IBCE, which permit them to make inferences without requiring causal explanations or causal features. We think that this does not mean that Scientific Realists need to endorse a version of IBE which has no further restrictions in place, and thus one which will also permit EIA to work. They can still insist on other restrictions on acceptable inferences, which, while not insisting on causal contributions, will make 'parity' slightly harder to achieve for proponents of EIA. And their insistence on these restrictions need not be motivated (question-beggingly) simply by a preference for avoiding ontological commitments to *abstracta*.

In fact, many Scientific Realists already do something like this. That is: they demand certain evidential standards of their inferential principles which make 'parity' slightly harder to achieve. Many Scientific Realists want to be Selective Realists. That is: they want to be realist about electrons and germanium while not being realist about frictionless planes and other 'scientific idealisations'. They want to be able to be realists about some-but-not-all of their theories, and, in addition, some-but-not-all of the properties of the things in their theories. Their selectivity comes precisely from requiring that they can identify, of the purported entity or property, what contribution it is making 'in its own right', to borrow Baker's idiom (see Sect. 1). Different Scientific Realist accounts attempt to achieve this differently, but they do attempt to achieve it.[16] The fact that the Scientific Realist actively takes up the burden here suggests that to maintain 'parity', the explanationist platonist must also specify how and in what way the mathematical *explanans* is 'explanatory in its own right'. That is: if mathematical explanationists wish to preserve 'parity' with Scientific Realists, they must ensure that their candidate *explanantia* are able to reach to the same explanatory standards as are required by Scientific Realists for their *explanantia.* In particular, it is insufficient for mathematical platonists to cite Genuine Mathematical Explanations in which they cannot specify how and in what way the mathematical entities involved directly contribute, in and of themselves, to the explanatoriness of the *explanans* that they put forward. In this way, concentration on the details of what it takes achieve 'parity' with Scientific Realism suggests that, *pace* Baker (2009), there is a burden

16 An anonymous referee suggested that we need to give some sort of justification as to why scientific realists are allowed to be selective, otherwise they may appear to be unprincipled or engaging in some sort of *ad hoc* practice. We shall attempt no defence here (although we note that the selectiveness is not motivated by or embarked upon in an attempt to avoid being committed to *abstracta*), the interested reader can consult Chakravartty (1998; 2007: 48–51) and Saatsi (2005) for examples of how to be selective. Rather, our point is a broader one: that the Mathematical Realist should not assume that the Scientific Realist has a general purpose strategy for inferring the existence of entities that can also be exploited to generate Platonism.

of proof on platonists to say more about the way that mathematical entities can be explanatorily effective.[17]

6 Conclusion

Our central question concerns the argumentative (and inferential) strategy of the Enhanced Indispensability Argument: do people who defend the EIA make an appropriate use of the resources of Scientific Realism to be able to achieve platonism? In this paper we have argued that just because some non-causal versions of IBE have been used in some arguments for Scientific Realism does not mean that it is these versions of IBE alone which deliver the (ontological) conclusions about which things we should be Scientific Realists about. We have suggested that explanationists should give some details about how and in what way mathematical entities are explanatory 'in their own right', since it is problematic if those mathematical entities do not directly contribute to Genuine Mathematical Explanations, since Scientific Realists already insist on this in their explanatory arguments for the existence of entities, and since it is in the strategic interests of mathematical explanationists that this kind of inferential parity with Scientific Realism should be maintained.

The discussions about the various Indispensability Arguments have moved on from trying to debate whether all Naturalists must be platonists (see Resnik 1997, Maddy 1997, Sober 1993), in part because Naturalism's purported commitments to holism and an unreflective endorsement of anything that features anywhere in science made them seem like easy targets; coupled with the Naturalist's disdain for ontology in the first place, the debates quickly stagnated. In contrast, trying to show that all Scientific Realists should be platonists seems to be a richer, more fertile ground for discussion, since Scientific Realists certainly take ontology seriously (cf. Morrison 2013). While parts of the debate take it for granted that Scientific Realists are simply Naturalists, it seems clear that Scientific Realists take on a heavier argumentative burden. What we have tried to show is that Scientific Realists take the existence of entities sufficiently seriously that there is no easy path to replicating their detailed, nuanced ontological conclusions in completely distinct contexts simply by wielding a generalised version of one of their inferential tools (IBE). We think it likely that only Scientific Realists who are unaware of the kinds of tools they actually use should endorse mathematical platonism on the basis of EIA.

[17] We note that Baker (2012) is a recent attempt to pin down the nature of mathematical explanation in science, and in this sense, Baker may be coming round to accepting a burden of proof that he has previously repudiated. In that paper, Baker suggests that, given the existence of GMEs, the nature of mathematical explanation in science poses a significant challenge to general accounts of scientific explanation. The point of our argument here is show that GMEs can only be used in EIA if parity with Scientific Realists accounts of explanation is maintained. Baker is right to try to pin down the nature of how mathematical entities can contribute to scientific explanations; our argument here is that, independent of anything else he might reveal about mathematical explanation in science, unless explanation functions in way which maintains parity, Scientific Realists have no reason to accept EIA. Thanks to Josh Hunt for encouraging this point.

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