Does IBE Require a 'Model' of Explanation?

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Abstract

In this paper, I consider an important challenge to the popular theory of scientific inference commonly known as 'Inference to the Best Explanation' (IBE), one which has received scant attention.[1] The problem is that there exists a wide array of rival models of explanation, thus leaving IBE objectionably indeterminate. First, I briefly introduce IBE. Then, I motivate the problem and offer three potential solutions, the most plausible of which is to adopt a kind of pluralism about the rival models of explanation. However, I argue that i) how ranking explanations on this pluralistic account of IBE remains obscure and ii) pluralism leads to contradictory results. In light of these objections, I attempt to dissolve the problem by showing why IBE does not require a 'model' of explanation and by giving an account of what explanation consists in within the context of IBE.

1. Introduction: IBE and the Plentitude Problem

Discussions of IBE trace back to Harman ([1965]), who appears to have coined the term. IBE is often formalized as a four-step argument pattern (Psillos [2002]; Lycan [1988]), such as:

(1)   F is some fact or collection of facts

(2)   Hypothesis H_1, if true, would explain F

(3)   No competing explanations H_2, H_3,...H_n would explain F better than H_1

(4)   Therefore, one is justified in believing that H_1 is true over its competitors

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[1] I gesture at some of the ideas in this paper in Cabrera ([2017]).

According to IBE, a hypothesis is justified in virtue of its ability to explain better than its competitors some fact or set of facts. We must be careful not to trivialize IBE as 'inference to the likeliest explanation' (Lipton [2004], p. 60; Psillos [2002], p. 617). Rather, IBE claims that justificatory status is determined, or at least closely tracked, by explanatory considerations.

In addition to being 'so routine and automatic that it easily goes unnoticed' (Douven [2011]), proponents of IBE, or 'explanationists', often maintain that prominent episodes from the history of science should be regarded as instances of IBE. For example, Lipton ([2004], pp. 74–90) argues that the research conducted by Ignaz Semmelweis in the 1840s on the causes of childbed fever provides a superb case of IBE in action. So too, in a detailed case study of the reasoning of John Snow—a mid-nineteenth century physician who investigated the causes and transmission of cholera— Tulodziecki ([2011], p. 315) argues that Snow's reasoning makes 'appeals to explanatory power at virtually every juncture'. Other examples, such as Darwin's argument for the theory of common ancestry, or Lavoisier's argument in favour of the oxygen theory of combustion, have also been asserted to be instances of IBE (Thagard [1978]).

Despite its apparent ubiquity in science and ordinary life, the second and third steps of the IBE schema raise an immediate problem because what counts as an explanation is the subject of long-standing philosophical debate. In 1965, Carl Hempel and Gilbert Harman each put out important works of philosophy of science relating to explanation. While Hempel published *Aspects of Scientific Explanation*, which contains his most refined formulation of the theory first put forward by Hempel and Oppenheim ([1948]), Harman published his seminal article titled simply 'The Inference to the Best Explanation', which has become the *locus classicus* of work on IBE. But, in spite of originating around the same time, these distinct research traditions in which explanation takes center stage have developed largely independently of one another.

Indeed, recent proponents of IBE tend to say relatively little about what constitutes an explanation and actively avoid discussing IBE in light of the various models of explanation (Psillos [2002], p. 606). This is likely because the literature concerning explanation is enormous, with more than a half dozen models having been defended.[2] Each of the various approaches to explicating the concept of explanation has spawned a literature of its own, in which attractions and objections are debated. Although Lipton ([2004], p. 57), in his book-length defense of IBE, favours a causal model of explanation, his account of IBE does not commit itself to the causal model or any model at all.

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[2] See Salmon ([1989]) for a critical survey of the attempts to analyse the concept of explanation in the twentieth century.

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Furthermore, Lipton does not discuss other prominent models of explanation or how they cohere with IBE at length, admitting that his treatment must be brief ([2004], p. 28).

Even though they have different goals, it is natural to think that the two research programs initiated by Hempel and Harman respectively must have some close connection, since they both pertain to explanation (Salmon [1989], p. 8). If IBE is not to be a misnomer, then presumably IBE must make use of some substantive concept of explanation, and therefore must ultimately commit itself to some model of explanation. On this point Lipton ([2001], p. 100) agrees, making clear that these two research traditions, in the final analysis, must be brought together.

However, one might reasonably object—as Salmon ([2001a], p. 68) does—that until the disputes regarding the nature of explanation are resolved, IBE can really have 'no clear meaning'. The fact that what constitutes an explanation is a matter of contention remains a problem for IBE because if it is unclear what it means to explain some phenomena, then what IBE consists in will likewise be rendered indeterminate. If it is unclear what it is to explain some phenomena, then we cannot follow IBE as a method of inference, or at the very least we won't know whether we have employed IBE correctly. I call the fact that there exists a diverse array of sophisticated, competing accounts of explanation, about which there is much disagreement, the 'plentitude problem'.[3] If the nature of explanation remains embroiled in controversy, then, one might think, so much the worse for IBE. This is a reason for methodologists to look elsewhere for an account of scientific inference.

2. Three Potential Solutions

In this section, I'll consider three potential solutions to the plentitude problem. As I'll argue, the third of these solutions looks to be the most promising.

2.1 Solution #1: primitivism

On the assumption that defending one account of explanation and exhaustively showing why that account is preferable to all the others is too labour-intensive, one might instead object that the plentitude problem is not really a problem. One might claim instead that IBE does not require an analysis of explanation after all, at least not at this stage of inquiry. Rather, we ought to treat

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[3] Here, the focus will be on IBE as a theory of scientific inference, but it's becoming increasingly common in meta-philosophical discussions to defend IBE as an important or even indispensable tool for philosophical theorizing. See, for instance, Williamson ([2016]), Hawley ([2006]), Sider ([2009]), Paul ([2012]), Nolan ([2015]), Biggs and Wilson ([2016]), and Morganti and Tahko ([2016]). A response to this problem is, arguably, more pressing given this recent trend.

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instances of 'explain' and 'explanation' in the IBE schema as primitive terms, at least until the debates surrounding the nature of explanation are resolved. I'll call this response to the plentitude problem 'primitivism'.

The primitivist response is akin to the position that Lipton ([2001], p. 100) takes up in his reply to Salmon's challenge that IBE lacks meaningful content, maintaining that:

> [w]hether or not explanatory considerations are a guide to inference does not depend on whether we have an adequate account of explanation, any more than our use of a grammar to understand our language depends on our ability to give an adequate explicit account of the structure of that grammar.

Of course, a complete account of IBE should include a substantive account of the nature of explanation—a point which Lipton ([2001], p. 100) acknowledges—but, according to the primitivist view, that is a separate philosophical project that the explanationist need not yet engage in. [4]

What motivates primitivism is that 'explain' and 'explanation' are not technical terms, but rather terms of ordinary language, and so the concept should be sufficiently familiar, even in the absence of a fully developed philosophical account. As further evidence of this claim, one might point to research in developmental psychology (for example, Gopnik [1998]), which suggests that explanation-seeking and -construction emerges at an early age, and is thus a salient aspect of human cognition. Additionally, the primitivist response exploits the fact that every philosophical theory leaves certain concepts unanalysed, which thus makes it seem unfair or overly-demanding to dismiss IBE as a failure for doing what every philosophical theory does.

To give an analogy, we might imagine some hard-nosed skeptic who objects to all competing analyses of knowledge, most of which include belief as a constitutive component, precisely because they fail to provide a substantive account of belief. To be sure, there are many competing views about the nature of belief, but it seems reasonable for epistemologists concerned with the nature of knowledge to leave the concept of belief unanalysed. So, the primitivist might argue, just as accounts of knowledge need not take a stand yet on the correct theory of belief, so too accounts of explanatory inference need not take a stand yet on the correct theory of explanation. If primitivism is a cogent response, then it would be unnecessary to further discuss the various models of explanation, and thus our inquiry into the relationship between Hempel's project and Harman's project could end now.

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[4] Poston ([2014]) also appears to accept primitivism, although he argues for the stronger claim that the concept of explanation actually is unanalysable.

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While it would be unfair and overly-demanding to insist that explanationists first settle completely the question of what constitutes an explanation in general before discussion about the epistemic merits of IBE can take place, even so, there's good reason to reject primitivism. The primary reason is that taking 'explanation' as a primitive in this context would be dialectically illegitimate. Compared to other epistemological frameworks, IBE is distinctive and controversial in its central thesis that many inferences are justified owing to the explanatory relations that hold between the hypothesis inferred and the phenomena explained. Other views of scientific inference or theory confirmation, such as Bayesianism, likelihoodism, hypothetico-deductivism, and falsificationism, do not assert, at least in their canonical formulations, that explanation has this sort of epistemically significant role. On these views, scientific inference does not take the explanatory detour that is characteristic of IBE. Indeed, it is often the case that proponents of these alternative epistemologies explicitly reject, for various reasons, the fundamental epistemic role that IBE assigns to explanation (see, for example, Roche and Sober [2013]; Salmon [2001a], [2001b]; van Fraassen [1980]). Since explanatory considerations do significant justificatory work according to IBE, and since competing accounts of scientific methodology either do not assert or overtly deny the central claims of IBE, the primitivist response to the plentitude problem fails.

Given the current dialectical landscape, the analogy made above to the fact that competing accounts of knowledge leave belief unanalysed is flawed. Almost all accounts of knowledge include belief as a constitutive component, whereas only IBE claims that an inference is justified in virtue of the explanatory quality of its conclusion. Instead, a more accurate analogy is to liken IBE to some substantive view about the nature of knowledge, such as reliabilism, roughly, the view according to which knowledge is true belief produced by a reliable process (Goldman [1986]). Clearly, the concept of reliability does significant, distinctive conceptual work in reliabilist accounts of knowledge. The idea that knowledge is partly determined by a reliable belief-forming process is not something that features in other competing accounts of knowledge, and so naturally the reliabilist owes us some account of what reliability consists in. It would be dialectically illegitimate if the reliabilist were to refuse to offer an account of what makes a belief-forming process reliable. Likewise, explanation does significant, distinctive conceptual work in explanationist accounts of scientific inference. It is not a notion that features in other accounts of scientific inference, and so naturally the explanationist owes us some account of what an explanation is. Thus, it is not a legitimate move for the explanationist to simply refuse to offer us such an account.

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2.2 Solution #2: accomodationism

Another response similar to primitivism, which seems more promising, is for the explanationist to claim that IBE is neutral with respect to all, or at least the most plausible, extant models of explanation. To claim that IBE is neutral is to say that it does not matter which account of explanation one 'plugs into' the IBE schema. All of the plausible accounts of explanation can be equally accommodated by IBE; and thus, we may choose whatever account of explanation is preferable. Just as the epistemologist concerned with the nature of knowledge can simply advise that we plug in our 'favourite' theory of belief into her account of knowledge, so too the explanationist can simply advise, on this response, that we plug in our 'favourite' account of explanation into the IBE schema above. I'll call this response to the plentitude problem accommodationism.

Unfortunately for the explanationist, IBE cannot be neutral with respect to the competing analyses of explanation in this sense. This is due to the fact that the prominent models of explanation defended by philosophers in the last several decades disagree drastically on the extension of the concept. Owing to space constraints, let's restrict our focus to three prominent models of explanation: the deductive-nomological model (Hempel and Oppenheim [1948]), the causal model (Salmon [1984]; Lewis [1986]; Lipton [2004]; Woodward [2003]), and the unificationist model (Friedman [1974]; Kitcher [1981], [1989]; Schurz [1999]). According to the deductive-nomological (DN) model, an explanation is a sound deductive argument, one of whose premises makes essential reference to a law of nature. According to the causal model, in its many versions, an explanation cites information about the causal profile of the fact to be explained. Finally, according to the unificationist model, an explanation unifies the phenomena with the rest of our knowledge.[5]

Suppose we adopt accommodationism. Now, consider these three different versions of IBE: 'Inference to the Best Deductive-Nomological Explanation', or 'IBE$_{DN}$', which employs the DN model as the operative notion of explanation, 'Inference to the Best Causal Explanation', or 'IBE$_C$', which employs some version of the causal model, and 'Inference to the Best Unificatory Explanation', or 'IBE$_U$', which employs some version of the unificationist model. If the accommodationist response were a cogent solution to the plentitude problem, then it should make no difference which of these three versions of IBE we employ. Yet, it clearly does make a difference. Since each of the three models of explanation puts restrictions on what sorts of propositions can

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[5] In Kitcher's popular account, unification involves deriving the phenomenon from an argument pattern that is part of the best deductive systematization of our knowledge, where the best deductive system is one that includes arguments that 'instantiate a few, stringent patterns' ([1981], p. 520).

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feature in the explanans, this limits the sorts of conclusions that can be drawn, in principle, by the corresponding version of IBE.

It will suffice to look at just the DN version of IBE to establish this point. Since the explanans of a DN explanation is a conjunction of laws and other antecedent conditions, the H_1 concluded by IBE_{DN} cannot be some singular causal or existence claim, but must be some complex conjunction of laws and other facts. Often, however, the sorts of examples upheld as paradigm instances of IBE have conclusions that are singular causal or existence claims, which do not refer to laws of nature at all. Consider some paradigm instances of IBE: Darwin infers that all organisms on Earth are descended from a common ancestor, astronomers infer the existence of Neptune to explain the aberrant orbit of Uranus, and Semmelweis infers that errant cadaverous material explains childbed fever in maternity wards. In all of these cases, the conclusions do not look at all like the explanans of a DN argument. These paradigm instances of IBE don't have as their conclusions that some law of nature holds true, and so they don't count as explanations according to the DN model.[6] Thus, a large number of inferences that are often regarded as good cases of IBE in action will not be permitted by IBE_{DN}. Indeed, these inferences will be ruled out, objectionably, at the second step of the IBE_{DN} schema. Of course, IBE_C will, in principle, be able to justify inferences to singular causal claims, but even IBE_C falls short when it comes to non-causal, theoretical explanations in science, such as the explanation of one set of laws from a more fundamental set of laws, as in the case of the explanation of the laws of chemical bonding in terms of the laws of quantum theory. The latter type of explanation is most easily accommodated by the unificationist model, and therefore permitted by IBE_U. Thus, we can see that it matters what model of explanation is adopted by the explanationist. It is not the case that any model of explanation is equally good as any other for being plugged into IBE because the different models do not, in principle, permit the same sorts of explanatory inferences to be drawn.[7]

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[6] At best the singular causal claim will be a DN 'explanation-sketch' (Hempel [1965], p. 423). But just as proof sketches aren't proofs, explanation sketches aren't explanations, and so even good cases of the latter won't be licensed by IBE_{DN}.

[7] Recently, variations of a quite general account of explanation have been put forward, one which might seem to avoid the problems considered here. Consider, for instance, that of Kim ([1994], p. 68), who proposes that 'explanations track dependence relations', and therefore, 'G is an explanans of E just in case e, the event being explained, depends on g, the event invoked.' Other defenders of this sort of account include McCain ([2016], p. 143), Strevens ([2008], p. 179–80), Ylikoski ([2013], p. 295), and Ruben ([1990], p. 231). However, since there will be multiple, compatible dependence relations associated with a particular phenomenon, this view is tantamount to a kind of pluralism about explanation, and thus will be subject to the same sorts of objections as the pluralistic account of IBE that I criticize is section 3.

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2.3 Solution #3: pluralism

In light of the inability of any specific version of IBE to cover all the cases that might be identified as instances of inference to the best explanation, there is one last position that we should consider. Rather than claiming that it doesn't matter which model one plugs into the IBE schema, perhaps we should say that IBE doesn't constitute a single inference method *per se*. Instead, IBE should be regarded as a collection of related inference methods, all of which are united in their insistence on the epistemic relevance of some concept of explanation. On this view, IBE_{DN}, IBE_C, IBE_U, and any other version of IBE that we might construct are not competitors; rather, all of the versions of IBE are compatible. I'll call this response to the plentitude problem 'pluralism'.

With this picture in mind, it is not a problem that IBE_{DN} cannot allow us to infer singular casual or existence claims. There is available another species of IBE, namely IBE_C that will allow the inference to singular causal explanations. Similarly, even though IBE_C has trouble accommodating non-causal, theoretical explanations in science, there is available another species of IBE, namely IBE_U that will, in principle, allow inferences to some more general law on the basis of its ability to unify two disparate sets of derivative laws. Thus, the problems of accommodationism are avoided.

According to Psillos ([2002], p. 606), who briefly considers something akin to pluralism, what determines the version of IBE we ought to use depends on the 'relevant notion' of explanation. It's not entirely clear what Psillos means by the 'relevant notion' of explanation, but this seems to suggest that the various models of explanation are in some sense compatible. Perhaps the sense in which this is true is that our concept of explanation is complex and multi-faceted, and so distinct models of explanation illuminate distinct, but compatible aspects of the same phenomenon.

At the end of his important historical survey of attempts to analyse the concept of explanation in the twentieth century, Salmon ([1989]) suggests that this sort of pluralism may be the best way to make sense of the popularity and prevalence of the notion of explanation *qua* unification and explanation *qua* causation. To illustrate the possibility of a rapprochement between the causal model and the unificationist model, Salmon ([1989], p. 183) provides the following helpful example:

> Why did the balloon move toward the front of the cabin? Two explanations can be offered, both of which are correct. First, one can tell a story about the behavior of the molecules that made up the air in the cabin, explaining how the rear wall collided with nearby molecules when it began its forward motion, thus creating a pressure gradient from back to front of the cabin. This pressure gradient imposed an unbalanced force on the back side of the balloon, causing it to move forward with respect to the walls of the cabin. Second, one can cite an

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extremely general physical principle, Einstein's *principle of equivalence,* according to which an acceleration is physically equivalent to a gravitational field. Since helium-filled balloons tend to rise in the atmosphere in the earth's gravitational field, they will move forward when the airplane accelerates, reacting just as they would if a gravitational field were suddenly placed behind the rear wall.

Here, Salmon countenances the view that there are simply two distinct senses of explanation—explanation$_1$ in terms of causal-mechanical principles and explanation$_2$ in terms of theoretical unification. If there is more than one distinct, though compatible notion of explanation, then it would only make sense that there is more than one distinct, though compatible notion of inference to the best explanation. As a result then, pluralism with respect to the different possible versions of IBE is plausible in light of the plausibility of pluralism with respect to the extant models of explanation. Instead of claiming that any model of explanation that is a live option will do, the more plausible response is that all the prominent models of explanation can be combined with the four-step IBE schema to form a version of IBE, and moreover these versions of IBE are all compatible.

3. Two Problems for Pluralism

Despite the initial plausibility of pluralism as a response to the plentitude problem, the pluralist response faces a number of obstacles. First, the way in which explanations are to be ranked in standard accounts of IBE cannot be adopted wholesale by the pluralist; as a result, it remains obscure how ranking explanations works upon shifting to a pluralistic account of IBE. Second, admitting a multitude of different versions of IBE raises the pressing question of when one version applies rather than another, and moreover introduces the inevitability of contradictory verdicts.

3.1 Difficulties with Ranking Explanations

While IBE is often criticized for not spelling out what being the 'best explanation' consists in, explanationists have not been silent on how competing explanations should be ranked. Typically, explanationists propose an independent list of so-called 'explanatory virtues', which are thought to determine the quality of an explanation. Accordingly, H_1 is a better explanation than its competitors H_2, H_3,...H_n to the extent that H_1 exhibits these virtues to a higher degree, overall, than H_2, H_3,...H_n.

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Of course, proponents of IBE disagree about what belongs on the list of explanatory virtues, although there is much overlap in their lists, and some differences are merely terminological.[8]

Among explanationists, Thagard ([1978]) defends three virtues: consilience, which corresponds to how much a theory explains and the extent to which it unifies disparate domains of evidence; simplicity, which corresponds to the size of the set of auxiliary assumptions needed by a hypothesis in order to explain the data, and perhaps the number of entities postulated; and analogy, which corresponds to a preference for old, already accepted mechanisms and processes. Similarly, Psillos ([2002], pp. 614–6) discusses the virtues of consilience, which corresponds to fit with background data; completeness, which corresponds to explaining all the relevant data; importance, which corresponds to explaining 'salient' phenomena; parsimony, which corresponds to the size of the set of auxiliary assumptions needed by a hypothesis to explain the data; unification, which corresponds to bringing together disparate bodies of data under one explanatory hypothesis; and precision, which corresponds to articulating a precise causal-nomological mechanism to explain the data. Finally, Lipton cites many of the same virtues, such as 'mechanism, precision, scope, simplicity, fertility or fruitfulness, and fit with background belief' ([2004], p. 122).[9]

Here, a problem arises for the pluralistic account of IBE. The problem is that the standard account of ranking explanations in terms of a single list of explanatory virtues cannot be adopted wholesale by the pluralist. While a unitary list of explanatory virtues suits the canonical account of IBE, which presupposes a univocal sense of explanation, it is implausible that the pluralistic account of IBE would include only one list of explanatory virtues. As discussed in section 2, the various models of explanation differ quite drastically, both in extension and intension. Since DN explanations are quite different entities from causal explanations and unificatory explanations, plausibly, the explanatory goodness of a DN explanation won't be determined in exactly the same way as the explanatory goodness of a causal explanation or a unificatory explanation.

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[8] It should be noted that the standard account of ranking explanations in terms of a plurality of explanatory virtues is far from uncontroversial. For one thing, the virtues are often discussed in vague and imprecise terms. For another thing, the epistemic relevance of some of these virtues, such as simplicity, has been questioned i) on the grounds that they are merely pragmatic, and thus 'cannot rationally guide our epistemic attitudes' (van Fraassen [1980], p. 87) and ii) on the grounds that they are 'laden with socio-political values' (Longino [1996], p. 52), and thus crowd out other virtues such as 'ontological heterogeneity' and 'novelty', which are more important in certain contexts. While the challenges to the epistemic relevance of commonly cited explanatory virtues should be taken seriously, a satisfactory defense of the explanatory virtues from these critiques lies outside the scope of this inquiry. Henceforth then, I will assume that the explanatory virtues actually are epistemically relevant and not merely pragmatic or reflective of certain parochial socio-political biases.

[9] See also Beebe ([2009], pp. 609–11) for a more lengthy list of frequently invoked explanatory virtues.

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Consider, for instance, IBE$_{DN}$ and the DN model. While a virtue like fit with background data or conservatism seems widely applicable enough to feature on the list of virtues that goes along with IBE$_{DN}$, the relevance of other virtues for IBE$_{DN}$, such as mechanism, is less obvious. Indeed, Hempel is clear that causality does not play any essential role in the DN model of explanation, writing that 'even when used to account for individual events, D-N explanations are not always causal' ([1965], p. 352). While Hempel countenances the possibility of causal explanations, on his view 'causal explanation is, at least implicitly, deductive-nomological' ([1965], p. 349). If we were to provide Hempel with two explanations E$_1$ and E$_2$, which were equal in every other respect, in the sense that both fulfilled the standard criteria for a DN explanation, but E$_1$ provided a causal mechanism and E$_2$ did not, it is unlikely, based on these remarks, that Hempel would favour privileging E$_1$ over E$_2$. Given that an essential feature of the DN model is that causation plays no critical role, it would be strange and contrary to the spirit of the DN model—at least in its canonical formulation—to rank competing DN explanations in some application of IBE$_{DN}$ by reference to the virtue of mechanism.

So then, supposing that pluralism is right, it would be a mistake to use the same list of virtues to rank explanations on IBE$_{DN}$, IBE$_C$, and IBE$_U$ respectively. Rather, there should be a list of virtues that ought to be employed for IBE$_{DN}$, a different list for IBE$_C$, another list for IBE$_U$, and so on for each version of IBE that we can imagine. But if there are some virtues that are not relevant to the success of certain types of explanation, and thus would not be included on the list that goes along with the corresponding version of IBE, then the pluralist has the burden of providing an account of what explanatory virtues go along with each plausible candidate version of IBE and why.

In response to this challenge, the pluralist might reply that a unitary list of explanatory virtues is not as problematic as it might appear. While it is implausible that the quality of a DN explanation is determined in exactly the same way as the quality of a unificatory explanation or a causal explanation, this concession need not entail that each version of IBE includes a list that features different explanatory virtues. Instead, the differences in how explanations are ranked across the various versions of IBE will consist solely in how the explanatory virtues are emphasized.

To put the point more formally, let's think of each of the explanatory virtues $\{v_1, v_2,...,v_n\}$ as suggesting some corresponding two-place function, which takes in a hypothesis H and evidence E as arguments. So, then, v_{SIMP} is the function corresponding to the virtue of simplicity, v_{CONS} is the function corresponding to the virtue of consilience, and so on, where—let's stipulate—each v-function returns some real-valued number from the interval [−1, 1]. For instance, if v_{SIMP}(H, E)=1,

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then H is maximally simple relative to E, if $v_{SIMP}(H, E) = -1$, then H is maximally complex relative to E, and so on for the other v-functions. Furthermore, we can think of each v-function as contributing to some normalized 'explanatoriness' function $\mathcal{E}$, which similarly takes in H and E as arguments, and is some complex function of v_{SIMP}, v_{CONS}, and so on, returning some real-valued number on the interval $[-1, 1]$.[10] On this picture, each pair (H, E) could—in principle, though perhaps not in practice—be assigned some score supplied by $\mathcal{E}$ representing, overall, how explanatorily virtuous that hypothesis is relative to the evidence. With this in mind, we can define a 'ranking scheme' as an ordered pair $\langle \mathbf{V}, \mathcal{E}_k \rangle$, where $\mathbf{V}$ is some subset of explanatory virtues $\{v_1, v_2,...,v_k\}$ and $\mathcal{E}_k$ is some definite explanatoriness function.

Now then, the pluralist can claim that the different versions of IBE will indeed contain different ranking schemes, but this is not because the first item in the ordered pair differs. All of the versions of IBE can make use of the same set of explanatory virtues $\mathbf{V}$. What differs in the ranking schemes across the many IBE-variants is the shape of the explanatoriness function, which is what determines how the various explanatory virtues are weighted. In this way, the quality of different types of explanations can be determined differently without requiring different lists of virtues.

To return to the issue of the DN model and the virtue of mechanism, even if Hempel would most likely disapprove of privileging explanations simply for articulating a causal mechanism, it wouldn't be too far a divergence from the canonical formulation of the DN model to make competing DN explanations beholden, to some non-zero degree, to the virtue of mechanism. If it is true that this virtue matters less for IBE$_{DN}$, then this just means that the relative lack of importance of mechanism should be reflected mathematically by some offsetting constant in the corresponding explanatoriness function $\mathcal{E}_{DN}$. Likewise, consider the case of IBE$_C$ and a virtue such as unification. It is often the case that what makes some causal-mechanical explanation a good one is that it articulates a precise and accurate description of the underlying mechanisms involved in some higher-level function. The more the inner workings of the 'black box' are revealed, the better. However, giving a detailed description of a causal mechanism often makes that description less applicable to other circumstances and thus less unifying. Now, provided two mechanistic explanations M$_1$ and M$_2$ are equally detailed, precise, and so on, then the pluralist can privilege the one that is more unifying, even if it's true that this is a context in which unification matters less (Sober [2003]). In this case then, as above, the relative lack of importance of unification for evaluating causal-mechanical

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10 This catch-all notion of explanatoriness seems to correspond to what Lipton ([2004]) has in mind when he talks of 'explanatory loveliness'.

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explanations would be reflected mathematically in the explanatoriness function $\mathcal{E}_C$ within the ranking scheme of IBE$_C$.

The response that we have considered here on behalf of the pluralist is far from satisfactory, however. Even if the pluralist is right that all the traditional explanatory virtues are epistemically relevant in all versions of IBE, and so the differences in ranking consist merely in differences in emphasis, without some account of how the various virtues are supposed to be weighted in each version of IBE and why this should be the case, pluralism proves to be an objectionably underdeveloped view, one whose philosophical credentials are difficult to evaluate.

Granted, a common criticism of IBE is that what counts as the 'best' explanation is unclear owing to the unclarity of the virtues themselves; however, the pluralistic account of IBE makes matters worse. The standard version of IBE, which presupposes a univocal sense of 'explanation', has the option of weighting all the virtues equally. This can be done by making its explanatoriness function $\mathcal{E}$ be a simple additive function of the v-functions. While this solution would require more defense than I can offer here, at the very least, the standard version of IBE can potentially avoid the problem of how and why the virtues are to be weighted differently. But, this avenue is unavailable to the pluralist. As I pointed out above, the ranking schemes for the different IBE-variants must differ in some way, either with respect to which virtues belong on the corresponding list, or with respect to how the virtues are emphasized. In either case, an account of how and why the ranking schemes differ across the many IBE-variants is required, without which pluralism remains obscure.

3.2 The Inevitability of Conflicting Verdicts

Once we admit a plethora of distinct inference methods, IBE$_{DN}$, IBE$_C$, IBE$_U$, and so on, we have to wonder when it is that we ought to opt for one species of IBE rather than another. If it were the case that every fact required an explanation of each type, then the question of which version of IBE we ought to use and when would not arise. Suppose it's true for every fact F that F requires a DN explanation, a unificatory explanation, a causal explanation, and so on, and that moreover, all these explanations are compatible. Then, as to the question of when we ought to apply which version of IBE, the answer is simple: we apply IBE$_{DN}$ to F just in case we have yet to uncover the best DN explanation of F, we apply IBE$_C$ to F just in case we have yet to uncover the best causal explanation of F, and so on for every model of explanation, until F is exhaustively explained.

But the problem with this view is that it is controversial that every fact F is such that F requires an explanation in all these different senses. For example, while this claim is not universally

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endorsed it's, widely accepted that some facts and events do not admit of a causal explanations, but must be explained in some non-causal way (for example, structurally, geometrically, or reductively).[11]

Now, the problem of when the different versions of IBE apply is not so devastating. One might argue that it will be intuitively obvious that some facts are such that it makes no sense to demand a certain type of explanation of them. It's clearly wrongheaded, for instance, to ask for causal explanations of mathematical facts, or to ask for causal explanations of some of the phenomena considered by philosophers, such as in meta-ethics, the fact that some acts are morally right and some are morally wrong. Similarly, following Scriven ([1959], p. 456), one might say that it's clear that certain mundane phenomena, such as the tipping-over of an inkwell, can be given simple causal explanations, but not complete DN explanations, and so it would be futile to demand a DN explanation of such facts. In general then, the pluralist might say that we should apply each version of IBE to each fact F, unless it's clear that a particular type of explanation of F is impossible.

Even so, once we start considering the application of different versions of IBE to the same fact, and once we see the difficulty of coming up with criteria for when each version of IBE is supposed to apply, it's easy to imagine the possibility that the different versions of IBE will issue conflicting verdicts. Suppose that C_1 is the best of a set of competing (potential) causal explanations $\{C_1, C_2,..., C_n\}$ of some fact F and suppose that C_1 is sufficiently good *qua* causal explanation. Thus, according to IBE_C we ought to infer C_1. Now, suppose that U_1 is the best of a set of competing (potential) unificatory explanations $\{U_1, U_2,...,U_n\}$ of the same fact F and suppose that U_1 is sufficiently good *qua* unificatory explanation. Thus, according to IBE_U we ought to infer U_1. Now, simply suppose that U_1 entails $\sim C_1$. The reason why U_1 is incompatible with C_1 could be that U_1 entails that there is no causal explanation of F. In the case of IBE_C and IBE_U, this conflict is especially easy to imagine, since the unificationist model, unlike other models of explanation, makes explanation out to be a global affair. It's not some small set of propositions that do the explaining, but rather entire systems of propositions, or in the case of Kitcher's account ([1981], [1989]), systems of argument patterns. It's certainly possible that the deductive system into which F is best situated is incompatible with, say, the best (potential) singular causal explanation of F. Perhaps modifying U_1 to include C_1 would lead to a system U_k that simply does more poorly according to however unifying explanations are ranked. In this case then, IBE_C and IBE_U would have us believe contradictory hypotheses concerning the same fact F.

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[11] See Ruben ([1990], pp. 209–33) for a helpful discussion of this issue, including a series of oft-cited examples and references. See Reutlinger ([2017]) for a more recent survey of the growing literature on non-causal explanation.

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Indeed, this does not appear to be just a conceptual possibility; rather, this describes precisely the situation in which we find ourselves in quantum physics with respect to the puzzling, correlations observed between distant, previously interacting particles. As is well-known, it is difficult to come up with a common cause model to explain these correlations. The sort of deterministic, local hidden variables theory imagined by Einstein and his colleagues (Einstein, Podolsky, and Rosen [1935]) was put into serious doubt by J.S. Bell's well-known argument ([1964]) and the several dozen experimental verifications of Bell's inequalities that followed in the subsequent decades (Aspect [1992]). Many physicists and philosophers have concluded from Bell's argument that there cannot be a local, causal explanation of certain quantum phenomena, such as the perfect correlations between electrons in the 'singlet state'.

Nevertheless, since quantum mechanics can be formulated as a small set of extremely general principles, which makes precise predictions, and accounts for the laws of chemical bonding, the photoelectric effect, and a number of other phenomena from diverse domains, we might follow Salmon ([1998], p. 76), in thinking that 'quantum theory provides explanations of the unification type, but does not provide those of the causal/mechanical sort.'

But, crucially, it is not as though causal explanations are definitively ruled out by the experimental verifications of Bell's inequalities. One can supplement quantum theory with further auxiliary hypotheses such that the striking correlations are causally explained; it is just that these non-standard theories are not as attractive as the standard, non-causal interpretations.[12] Even so, when considering the space of causal explanations, it might be, say, that some retro-causal theory, such as that of de Beauregard ([1977], [1979]), according to which the act of measurement in the future causally influences the past state of the correlated particles, is the best (potential) causal explanation of these puzzling correlations, and would thus be licensed by IBE_C. This non-standard quantum theory which supplies the causal explanation, would, however, be inconsistent with the deliverances of IBE_U, if standard quantum theory is interpreted as a unificatory explanation, as Salmon suggests, and if, plausibly, quantum theory is the best unificatory explanation of these puzzling correlations and other physical phenomena. Thus, it's plausible that, when applied to contemporary fundamental physics, pluralism about the different versions of IBE would lead to contradictory verdicts.

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[12] See, for instance, Forster ([unpublished]) for an accessible exposition of a closely related version of the argument contained in Bell ([1964]) and for a brief discussion of some of these alternative, causal explanations.

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Although, for reasons of space, I've focused on only three versions of IBE, there are likely other legitimate senses of explanation, such as, constitutive explanation or metaphysical grounding, and thus even more versions of IBE that the pluralist should countenance. Absent some positive reason to believe otherwise, it would be highly unlikely if pluralism did not lead to more conflicting verdicts. Thus, in an attempt to be maximally ecumenical about all the different possible versions of IBE, pluralism leads to problems because best potential explanation of one type will sometimes contradict the best potential explanation of another type.

Now, it should be granted that the objections considered in this section may not be insurmountable. Those who are attracted to the pluralistic account of IBE might take up the challenges that I have raised here and tackle these problems. Indeed, little attention has been paid to the pluralistic account of IBE, and to the plentitude problem, and so maybe the necessary philosophical work can be done. Regarding the first problem, perhaps a theoretically motivated ranking scheme could be defended by the pluralist, which would prove to be superior to the standard account of IBE. Similarly, perhaps there is some principled way to manage conflicts between the different IBE-variants when they arise.[13] Nevertheless, it seems that adopting pluralism as a response to the plentitude problem ultimately exchanges one problem for a whole set of new ones. It is worth considering whether there is some alternative solution that avoids these difficulties.

4. Dissolving the Plentitude Problem

Up until now, I've considered various responses to the plentitude problem, all of which have proved deficient in some way. The most plausible response is to be a pluralist about the various possible versions of IBE; but, as I've shown, pluralism faces some substantial objections. The

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[13] Along these lines, an anonymous reviewer suggests weakening the conclusion of each version of IBE to say something like 'Thus, there is some reason to believe H', as a way to avoid the problem of conflicting verdicts. Call this the 'modest view'. If the pluralist adopts the modest view, then one might think we are just left with the familiar, general problem of working through an ambiguous set of evidence, which is a problem for every theory of scientific inference. However, for a number of reasons, I find this response unsatisfactory. First, as Psillos ([2004], p. 83) points out, 'IBE is typically seen as a rule of acceptance.' This understanding is reflected in Harman's ([1965], p. 89) initial articulation of the view, according to which 'one infers[. . .]to the conclusion that the given hypothesis is true', as well as in other prominent discussions of IBE, (for example, Boyd [1983], p. 74; Lycan [2002], p. 413; Psillos [2002], p. 614), and continues to be assumed in recent work on IBE (Roche and Sober [2013], p. 665). So, even if the second objection depends on a conception of IBE *qua* rule of acceptance, this does not seem especially problematic given the widespread tendency to interpret IBE in this way. Second, it's not clear that the modest view even counts as a version of explanationism, at least according to Lycan's ([2002]) typology, since the modest view denies that IBE can justify full-fledged belief in a hypothesis. Finally, even if the pluralist adopts the modest view, it seems we are still owed some account detailing how to manage conflicting verdicts, especially since conflicts are likely; otherwise, the pluralist version of IBE won't amount to a unified theory of non-demonstrative inference. But it is at present unclear what such an account would look like.

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difficulties engendered by the plentitude problem need not be fatal to IBE, however. In what follows, I will offer and defend a novel solution, or rather dissolution, to the plentitude problem.

4.1 The explanatory virtues screen-off the model of explanation

It is noteworthy that both opponents and proponents of IBE assume that some model of explanation needs to be 'plugged into' the four-step IBE argument schema. This is the assumption that has led to numerous problems, and ultimately it is this assumption that ought to be rejected. We should reject this assumption because IBE does not require a 'model' of explanation. The reason that IBE doesn't require a model of explanation is that whether some hypothesis H is an explanation according to any of the various models of explanation does not do any justificatory work.

To see why this is so, first it is crucial to recognize that the explanatory virtues are properties that can be possessed by theories of many different types: those that are causal or non-causal, those that entail or confer some statistical probability on the phenomena, those concerned with particular events or with nomic generalizations, and even theories that are philosophical rather than scientific. For instance, consider that in physics, Newton's theory of gravitation was praised for its unification of disparate sets of physical facts (Whewell ([1968/1840], p. 153), and so too, in philosophy of science, Armstrong ([1983], p. 105) defends a conception of laws of nature as necessitation relations between universals by citing, among other things, the unifying power of this theory.[14]

Consequently, it is not the case that a hypothesis needs to satisfy the conditions of some one particular model of explanation in order to be explanatorily virtuous. Indeed, what is common in all of the many instances of explanatory inference cited across a wide array of different domains is not some model of explanation, but rather a set of widely applicable explanatory virtues. In my view, this suggests that what does all the justificatory work in any application of IBE is just that H does well with respect to the explanatory virtues relative to some evidence E. Hence, whether a hypothesis satisfies the conditions of any particular model of explanation is, epistemically, beside the point.[15]

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[14] The attribution of the explanatory virtues to philosophical theories is not a habit only of metaphysicians. Interestingly, even in epistemology, Bayesian confirmation theory is often championed for its unification of disparate sets of scientific principles, methodological rules, and other facts about our inductive practices (Kelly and Glymour [2004], pp. 100–1).

[15] It is telling that explanationists often use 'explanation' and 'hypothesis' interchangeably. For instance, Lipton ([2004], p. 60) describes Newtonian mechanics as 'one of the loveliest explanations in the history of science', and later on refers to Newtonian mechanics as 'an old hypothesis'. Similarly, Psillos ([2002], p. 615) when discussing the virtues, moves fluidly between talk of 'hypotheses', 'explanations', and 'explanatory hypotheses'.

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To further clarify this thesis, we can formalize it in the language of probability theory.[16] Let H be a hypothesis, let E be some evidence, let $\mathcal{E}(H, E)=r$ mean 'H is explanatorily virtuous, relative to E, to degree r', and finally let X be the proposition 'H constitutes an explanation according to the correct model of explanation'. Then, consider the following screening-off claim:

(VSM) $\Pr(H\,|\,[\mathcal{E}(H, E)=r]\ \&\ X)=\Pr(H\,|\,\mathcal{E}(H, E)=r)$ [17]

What this probabilistic equality says is that H's having some particular degree of explanatoriness, relative to E, screens-off H's constituting an explanation according to correct model of explanation from H. That is to say, knowing that H constitutes an explanation according to the correct model of explanation is evidentially irrelevant, once we take into account how explanatorily virtuous, overall, H is relative to E. In a slogan, 'the virtues screen-off the model' (hence 'VSM'), and so the model of explanation is epistemically idle once the evidential impact of the virtues is taken into account.

It is worth noting that VSM conflicts with a thesis that the explanationist might be attracted to, but which ought to be resisted.[18] According to this thesis, as a minimal condition of adequacy, H must satisfy the conditions of the correct model of explanation. From this, the following holds:

(MIN) $\Pr(H\,|\,[\mathcal{E}(H, E)=r]\ \&\ X)>\Pr(H\,|\,\mathcal{E}(H, E)=r)$

According to MIN, the model of explanation is evidentially relevant, and thus it follows from MIN that VSM is false. However, this thesis, along with MIN, ought to be resisted because its acceptance requires linking IBE to a model of explanation—or a set of models, if pluralism is right—which, as we saw in section 3 faces various obstacles. In any case, as will soon become clear, it is not a problem for my solution that VSM conflicts with MIN.

4.2 The virtue-centric conception of explanation

If we take seriously the idea that the explanatory virtues do all the intended justificatory work in any application of IBE, and thus we adopt VSM, then clearly we don't need to settle upon any of the extant models of explanation to plug into the IBE schema. Still, a full solution to the plentitude problem should give some account of what the second step in the IBE schema means, that is 'H₁, if

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[16] A few clarificatory points are in order. First, the interpretation of probability that I employ is that of rational credences, that is, the credences an agent ought to have. Second, casting IBE in probabilistic language need not conflict with the view that IBE is a rule of acceptance. It remains plausible that there is a close conceptual connection between probability and rational belief, lottery-paradox-style worries notwithstanding. In any case, appealing to probabilistic concepts is not necessary to get the main argument off the ground, but serves simply to make the main point more perspicuous.

[17] This way of putting the thesis and some of the subsequent discussion is inspired by, but is quite different from, the claim defended by Roche and Sober ([2013]), according to which $\Pr(H|O\&E)=\Pr(H|O)$, where E is the proposition 'H would explain O if H and O were true'.

[18] Thanks to an anonymous reviewer for suggesting that I discuss this thesis.

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true, would explain F'. While I've argued that IBE should not be combined with any of the models of explanation, we can clarify what this step involves by reference to the explanatory virtues.

 To that end, I propose the following 'conception' of explanation for the purpose of being employed in IBE, which I'll call the 'Virtue-Centric Conception' of explanation (VCC):

(VCC) H is an explanation of E if and only if $\mathcal{E}(H, E) \geq r$, where r is some threshold According to the VCC, the virtues both determine what constitutes an explanation within the context of IBE and how competing explanations ought to be ranked. As a result, the third step in the IBE schema is conceptually prior to the second, despite being syntactically represented earlier.

Before further spelling out the features of the VCC, it is necessary to make a few clarificatory remarks. I've purposefully called the VCC a 'conception' of explanation, rather than a 'model' of explanation to differentiate the VCC from the DN model, the causal model, the unificationist model, and other attempts to respond to Hempel and Oppenheim ([1948]). The VCC need not be regarded as a competitor to any of the models of explanation, although I'll discuss this possibility below. As I've suggested, the VCC is supposed to give content to the second step in the IBE schema and other uses of the term 'explanation' therein, which is necessary once we reject the assumption that some model of explanation should be plugged into IBE. If we'd like, we could, following Salmon ([1989]), introduce an 'explanation$_3$' to refer to an explanation within the context of IBE, which is filled out by the VCC, and which roughly means 'hypothesis that does appreciably well with respect to the explanatory virtues so as to warrant further consideration'.

Now then, what exactly the value of r should be may vary depending on the context. But, according to the VCC, for some H and some E, $\mathcal{E}(H, E)$ will be so low that H will not constitute an explanation of E within the context of IBE. In this way, we can see that it is not a problem that VSM conflicts with MIN, introduced at the end of section 4.1. With the VCC, we can capture the intuitive idea that, for IBE, a hypothesis first needs to be minimally adequate as an explanation, without having to commit to MIN or any of the models of explanation. For instance, if $\mathcal{E}(H, E) = -.9$, perhaps because the value of $v_{SIMP}(H, E)$ is so low, then H would not be a minimally adequate explanation. Of course, determining whether a hypothesis is minimally adequate may be difficult in practice, especially when the virtues pull against each other. For example, a precise, accurate description of a Rube Goldberg machine may well be very complex, and so the value of v_{SIMP} may be

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low. Even so, this need not entail that the description is not an explanation for the purposes of IBE, as the value of v_{PREC} might be more than high enough so that $\mathcal{E}$ is equal to or greater than r.[19]

Furthermore, it is worth highlighting the fact that some of the explanatory virtues concern the nature of H in itself, such as parsimony, and others concern how H is related to E, such as unification. So, whether H is an explanation of E, will depend on intrinsic and extrinsic features of H. If the VCC did not include extrinsic features, then absurdities would result. For instance, if H were some highly parsimonious, conservative sociological theory and E the fact stars collapse into black holes, then if we only looked at the intrinsic features of H and not how H is related to E, it would be possible for $\mathcal{E}$(H, E) to be much greater than r, and so for H to be a very good explanation E—much better than all its competitors—and thus licensed by IBE on the basis of E. However, since, plausibly, it will never be the case that a parsimonious, conservative sociological theory unifies or provides a precise causal mechanism for the collapse of stars into black holes or related cosmological phenomena, the problem that any sufficiently intrinsically virtuous H will be an explanation of any E is avoided.

Finally, whether the VCC can be pursued as a solution to Hempel's problem, and should thus be regarded as another rival model of explanation is an interesting question. We seem to have a reasonably sufficient grasp of the elements that constitute 'explanatoriness', and so perhaps it would be wise to analyse 'explanation' in terms of these good-making features, instead of searching for some elusive, extensionally adequate relation, which might possess these features. But, even if the VCC ultimately fails by the lights of those whose concern is to offer an adequate model of explanation, this would not undermine my solution to the plentitude problem. For, I've argued that we ought to reject the assumption that some model of explanation should be plugged into IBE. The VCC should be regarded as an expression of the rejection of that assumption. For the purposes of IBE then, whether or not we recast the VCC as a 'model' of explanation, the VCC should fill out what it means, where, in the second step of IBE schema, it says 'H₁, if true, would explain F'. In this way, the VCC, together with the thesis captured by VSM, dissolves the plentitude problem.

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[19] Since on my account, the virtues, in a sense, operate at both the second and third step in IBE, the resulting picture bears some superficial similarities to the 'two-filter' model of IBE defended by Lipton ([2004]). However, on Lipton's view, considerations of non-explanatory 'likeliness' are what first constrain the space of potential explanations, and then considerations of explanatory 'loveliness' are used to select the best explanation.

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5. Concluding Remarks

As I've argued, the existence of a diverse array of rival concepts of explanation poses a *prima facie* problem for IBE. Instead of adopting primitivism, accommodationism, or pluralism, all of which are subject to various difficulties, the best response is to deny that there is any intimate connection between the research programs initiated by Hempel and Harman respectively—that is, between the debates over the correct model of explanation and IBE. Importantly, this conclusion conflicts with what proponents and opponents of IBE have claimed, both of whom assume that some model of explanation needs to be plugged into IBE. This denial does not mean that IBE has nothing to do with explanation, however. The lists of explanatory virtues proposed by explanationists seem for the most part to warrant their name. This prevents IBE from being a misnomer, although perhaps a less misleading name for IBE would be 'Inference to the Hypothesis with the Optimal Combination of Explanatory Virtues'. As I've argued, the explanatory virtues do all the intended justificatory work in any application of IBE, and so commitment to a model of explanation is irrelevant and unnecessary. In order to give content to uses of the term 'explanation' in IBE, I've articulated and defended the VCC, which perhaps with further development could be marshaled as a solution to Hempel's problem. Of course, explanationists must tackle other obstacles, such as offering more detailed accounts of the virtues, of why those virtues are epistemically relevant, and of how the virtues are to be agglomerated and compared.[20] Still though, appealing to the explanatory virtues, manifested in both the VSM and the VCC, provides, in my view, an elegant solution to what would otherwise be a devastating objection to IBE.

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[20] One approach to solve these problems is to give Bayesian analyses of the virtues. See, for instance, Myrvold ([2003], [2016]) for a Bayesian account of unification. See also Cabrera ([2017]) for some brief Bayesian accounts of other virtues, although as I argue, not all of the explanatory virtues can be vindicated by Bayesianism.

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References

Armstrong, D. [1983]: *What is a law of nature?* Cambridge: Cambridge University Press.

Aspect, A. [1992]. 'Bell's Theorem: the naïve view of an experimentalist', in R.A. Bertlmann and A. Zeilinger (*eds*), *Quantum [Un]speakables.* New York: Springer, 119–53.

Beebe, J. [2009]: 'The Abductivist Reply to Skepticism', *Philosophy and Phenomenological Research*, **79** (3), pp. 605–36.

Bell, J.S. [1964]: 'On the Einstein-Podolsky-Rosen paradox', *Physics,* **1**(3), pp. 195–200.

Biggs, S. and Wilson, J. [2016]: 'The A Priority of Abduction', *Philosophical Studies*, pp. 1–24. <doi:10.1007/ s11098-016-0705-4>.

Boyd, R. [1983]: 'On the Current Status of the Issue of Scientific Realism', *Erkenntnis*, **19**(3), pp. 45–90.

Cabrera, F. [2017]: 'Can there be a Bayesian Explanationism?: On the Prospects of a Productive Partnership', *Synthese*, **194**(4), pp. 1245–72.

de Beauregard, C. [1977]: 'Time Symmetry and the Einstein Paradox', *Il Nuovo Cimento*, **42B**, pp. 41–64.

de Beauregard, C. [1979]: 'Time Symmetry and the Einstein Paradox–II', *Il Nuovo Cimento*, **51B**, pp. 267–279.

Douven, I. [2011]: 'Abduction', in E. Zalta (ed.), *Stanford Encyclopedia of Philosophy*, <http:// plato.stanford.edu/archives/win2012/entries/abduction/>

Einstein, A., Podolsky, B., and Rosen, N. [1935]: 'Can quantum-mechanical description of physical reality be considered complete?', *Physical Review*, **47**(10), pp. 770–80.

Forster, M. [unpublished]: 'The GHZ Version of Bell's Argument', <http://philosophy.wisc.edu /forster/220/BELL.PDF/>

Friedman, M. [1974]: 'Explanation and Scientific Understanding', *Journal of Philosophy*, **71**(1), pp. 5–19.

Goldman, A. [1986]: *Epistemology and Cognition.* Cambridge, MA: Harvard University Press.

Gopnik, A. [1998]: 'Explanation as Orgasm', *Minds and Machines*, **8**(1), pp. 101–18.

Harman, G. [1965]: 'The Inference to the Best Explanation', *Philosophical Review*, **74**, pp. 88–95.

Hawley, K. [2006]: 'Science as a Guide to Metaphysics?', *Synthese*, **149**, pp. 451–70.

Hempel, C. [1965]: *Aspects of Scientific Explanation.* New York: Free Press.

Hempel, C. and Oppenheim, P. [1948]: 'Studies in the Logic of Explanation', *Philosophy of Science*, **15**, pp. 135–75.

`

Kelly, K. and Glymour, C. [2004]: 'Why Probability Does Not Capture the Logic of Scientific Justification', in C. Hitchcock (ed.), *Contemporary Debates in the Philosophy of Science*. Oxford: Blackwell, pp. 94–114.

Kim, J. [1994]: 'Explanatory knowledge and metaphysical dependence', *Philosophical Issues,* **5**, pp. 51–69.

Kitcher, P. [1981]: 'Explanatory Unification', *Philosophy of Science* **48**(4), pp. 507–31.

Kitcher, P. [1989]: 'Explanatory Unification and the Causal Structure of the World', in P. Kitcher and W. Salmon (*eds*), *Scientific Explanation,* Vol. 13, *Minnesota Studies in the Philosophy of Science.* Minneapolis: University of Minnesota Press, pp. 410–505.

Lewis, D. [1986]: '[Causal Explanation', in *Philosophical Papers, Vol. II.* Oxford: Oxford University Press, pp. 214–40.

Lipton, P. [2001]: 'Is Explanation a Guide to Inference?: A Reply to Wesley C. Salmon', in G. Hon and S. S. Rakover (*eds*), *Explanation: Theoretical Approaches and Applications,* Dordrecht: Kluwer, pp. 93–120.

Lipton, P. [2004]: *Inference to the Best Explanation*, *2nd ed.* New York: Routledge.

Longino, H. [1996]: 'Cognitive and Non-Cognitive Values in Science: Rethinking the Dichotomy', in L. Hankinson Nelson & J. Nelson (*eds*), *Feminism, Science, and the Philosophy of Science.* Dordrecht: Kluwer Academic Publishers, pp. 39–58.

Lycan, W.G. [1988]: *Judgement and justification.* Cambridge: Cambridge University Press.

Lycan, W.G. [2002]: 'Explanation and Epistemology', in P. Moser (ed), *The Oxford Handbook of Epistemology.* Oxford: Oxford University Press.

McCain, K. [2016]: *The Nature of Scientific Knowledge: An Explanatory Approach.* Switzerland: Springer

Morganti, M. and Tahko, T. [2016]: 'Moderately Naturalistic Metaphysics', *Synthese*, pp. 1–24 <doi: 10.1007 /s11229-016-1068-2>.

Myrvold, W. [2003]: 'A Bayesian Account of the Virtue of Unification', *Philosophy of Science* **70**, pp. 399–423.

Myrvold, W. [2016]: 'On the Evidential Import of Unification', *Philosophy of Science*, **84**(1), pp. 92–114.

Nolan, D. [2015]: 'The A Posteriori Armchair', *Australasian Journal of Philosophy*, **93**(2), pp. 211–31.

Paul, L.A. [2012]: 'Metaphysics as Modeling: The Handmaiden's Tale', *Philosophical Studies*, **160**, pp. 1–29.

Poston, T. [2014]: *Reason & Explanation: A Defense of Explanatory Coherentism*. New York: Palgrave-MacMillan.

`

Psillos, S. [2002]: 'Simply the Best: A Case for Abduction', in A. C. Kakas and F. Sadri (*eds*), *Computational Logic: Logic Programming and Beyond*. Berlin: Springer-Verlag, pp. 605–26.

Psillos, S. [2004]: 'Inference to the Best Explanation and Bayesianism', in F. Stadler (ed.), *Induction and Deduction in the Sciences*. Dordrecht: Kluwer Academic Press, pp. 83–91.

Reutlinger, A. [2017]: 'Explanation Beyond Causation? New Directions in the Philosophy of Scientific Explanation', *Philosophy Compass*, **12**(2), pp. 1–12, <doi.org/10.1111/phc3.12395>.

Roche, W. and Sober, E. [2013]: 'Explanatoriness is evidentially irrelevant, or inference to the best explanation meets Bayesian confirmation theory', *Analysis*, **73**, pp. 659–68.

Ruben, D. H. [1990]: *Explaining Explanation*. New York: Routledge.

Salmon, W. [1984]: *Scientific Explanation and the Causal Structure of the World*. Princeton: Princeton University Press.

Salmon, W. [1989]: 'Four Decades of Scientific Explanation', in P. Kitcher and W. Salmon (*eds*), *Scientific Explanation,* Vol. 13, *Minnesota Studies in the Philosophy of Science*. Minneapolis: University of Minnesota Press, pp. 3–219.

Salmon, W. [1998]: *Causality and Explanation*. Oxford: Oxford University Press.

Salmon, W. [2001a]: 'Explanation and Confirmation: A Bayesian Critique of Inference to the Best Explanation', in G. Hon and S. S. Rakover (*eds*), *Explanation: Theoretical Approaches and Applications*. Dordrecht: Kluwer, pp. 61–91.

Salmon, W. [2001b]: 'Reflections of a Bashful Bayesian: A Reply to Peter Lipton', in G. Hon and S. S. Rakover (*eds*), *Explanation: Theoretical Approaches and Applications*. Dordrecht: Kluwer, pp. 121–136.

Schurz, G. [1999]: 'Explanation as Unification', *Synthese*, **120**(1), pp. 95–114.

Sider, T. [2009]: 'Ontological antirealism', in D. Chalmers, D. Manley, and R. Wasserman (*eds*), *Metametaphysics: New Essays on the Foundation of Ontology*. New York: Oxford University Press, pp. 384–421.

Sober, E. [2003]: 'Two Uses of Unification', in F. Stadler, (ed.*), The Vienna Circle and logical empiricism: Re-evaluation and future prospects*. Dordrecht: Kluwer Academic Publishers, pp. 205–216.

Strevens, M. [2008]: *Depth: An Account of Scientific Explanation*. Cambridge, MA: Harvard University Press.

Thagard, P. [1978]: 'The Best Explanation: Criteria for Theory Choice', *The Journal of Philosophy*, **75**(2), pp. 76–92.

`

Tulodziecki, D. [2011]: 'A case study in explanatory power: John Snow's conclusions about the pathology and transmission of cholera', *Stud. History Philos. Biol. Biomed. Sci.*, **42**, pp. 306–316.

van Fraassen, B.C. [1980]: *The Scientific Image.* Oxford: Oxford University Press.

Williamson, T. [2016]: 'Abductive Philosophy', *The Philosophical Forum*, **47**, pp. 263–80.

Woodward, J. [2003]: *Making Things Happen: A Theory of Causal Explanation.* Oxford: Oxford University Press.

Ylikoski, P. [2013]: 'Causal and Constitutive Explanation Compared', *Erkenntnis*, **78**, pp. 277–97.

`