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Contingent and Inevitable Elements of Quantum Mechanics: The Lacking Tension of the Contingency/Inevitability Debate

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Abstract

This paper addresses the contingency/inevitability debate, which asks essentially whether scientific theories are epistemically guaranteed given successful inquiry, or partially determined by unguaranteed social and psychological factors. In other words, participants in the debate ask whether changes to historical conditions might feasibly have resulted in the development of scientific theories alternative to our own. Here, I address the issue in regard to the extant alternative non-relativistic quantum theories of the standard and de Broglie-Bohmian quantum models. The existence of these long-term viable, alternative theories regarding the same phenomena has made quantum mechanics a seminal case study for the debate. Taking James Cushing and Lena Soler as representative of contingentists, and Ian Hacking and Steven Weinberg as representative of inevitabilists, I argue that contrary to appearances contingentists and inevitabilists are not in substantive disagreement regarding quantum mechanics. Contingentists hold that quantum ontologies are contingent, whereas inevitabilists hold that empirical results and the nomological structure provided by Schrödinger's equation are inevitable. These views are mutually sustainable. Thus, the philosophical tension of the debate evaporates, leaving us with a surprisingly large degree of contingency that is nonetheless consistent with inevitabilist claims.

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1. Introduction

The contingency/inevitability debate is a recalcitrant problem in history and philosophy of science. The contingentist Lena Soler frames the problem by asking: "Could our taken-as-established scientific conclusions, theories, experimental data, ontological commitments, and other scientific 'results' (in a broad sense of result) have been significantly different?"[2] The heterogeneity of the philosophical targets indicated by Soler — and the heterogeneity of the sciences themselves — suggest that her question may have no single answer. This is borne out by the diversity of scope and target represented in the positions that constitute the debate, which cannot be addressed in full here.[3] But in general terms, the debate can be summated in that contingentists take certain aspects of science to partially depend on historical factors that are *unguaranteed*, i.e. extant only by coincidence. This might include social or psychological factors, e.g. the intellectual climate of a given period. If the results (in Soler's broad sense of the term) of scientific research partially rely on such factors, then it stands to reason that such results might feasibly differ had these unguaranteed factors differed. Inevitabilists, meanwhile, typically hold that the results of scientific research are determined by immutable factors. Most typical of inevitability arguments is the claim essentially that 'how the world is' determines the content of scientific claims. Thus, regardless of historically unguaranteed factors, any successful scientific enterprise will return inevitable results. Resolving this tension is held to have important ramifications for how we consider scientific claims — e.g. whether as a unique account of nature, and hence (traditionally formulated) 'knowledge', or as a mutable means of producing accurate predictions, with an unclear relationship to 'how the world is'. Here, in regard specifically to quantum mechanics, I argue that nominal inevitabilism permits a surprisingly high degree of contingency, on the basis that contingency/inevitability claims aim at alternative philosophical targets, rendering their arguments mutually consistent.

In addressing contingency/inevitability, I take up four participating theorists: James Cushing and Lena Soler as representative of contingency, and Ian Hacking and Steven Weinberg as representative of inevitability. Taking these four as representative of the debate as a whole is necessarily an oversimplification, but their views together confer an impression of the breadth, if not the depth, of the issue in general. My argument is essentially that a lack of conceptual clarity within the contingency/inevitability debate has resulted in an *appearance* of philosophical conflict, between 'contingentists' and 'inevitabilists,' when in fact these supposedly

[2] Soler, L. (2015). 'Introduction: The Contingency/Inevitability Debate.' *Science as It Could Have Been: Discussing the Contingency/Inevitability Problem*, p. 1.

[3] For a well-realised summation of these diverse positions, see Kinzel 2015. The issue, essentially, is that speaking to 'science' in general terms might render the question insoluble, due to the enormous disparities between activities typically accounted for as constituting scientific research.

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oppositional parties fail to contradict one another. This is the result of a failure to be explicit about the specific elements of 'science' that they target in their arguments.

I develop this thesis in particular reference to Cushing's 1994 study of quantum mechanics. Quantum mechanics provides a particularly fruitful example when discussing contingency/inevitability, in that there are two extant and arguably underdetermined[4] alternative quantum theories — the standard quantum model (henceforth SQM) and the de Broglie-Bohm quantum model (henceforth BQM). Thus, my argument here is that, *in the case of quantum mechanics*, contingentists and inevitabilists are not in substantive or significant disagreement. Through careful comparison of the consequences of the arguments considered here, it becomes apparent that contingentists are chiefly proposing contingency in regard to scientific *ontology,* wherein SQM and BQM display significant and perhaps irreconcilable differences. Inevitabilists emphasise *empirical claims and nomological structure*, which are shared between SQM and BQM. If these views are mutually sustainable — and they appear to be — the philosophical tension of the contingency/inevitability debate in regard to quantum mechanics more or less evaporates. Interestingly, this means that the claim that scientific ontologies — attempts to make descriptive sense of predictive success regarding unobservables — might be historically contingent, and therefore epistemically unguaranteed, appears uncontested within the debate.

2. Quantum Mechanics as Contingent

In this section, I first discuss Cushing's case for contingency, before recounting Soler's approach, which constitutes essentially accounting for Cushing's contingency as a permanent feature of the unfolding of research. Regrettably, I am unable to provide a complete summary of Cushing's historical work regarding quantum mechanics here. A brief sketch must suffice. First, it is important to note that Cushing is primarily interested in the processes underlying the acceptance or rejection of theory within the scientific community. Regarding scientific acceptance, Cushing holds that certain *non-evidential* factors play a role. In instances of actual underdetermination — wherein empirical recourse fails to decide between two theoretical options — Cushing argues that these non-evidential factors, characterised as typically social or psychological, become decisive for the historical course of scientific acceptance and continuing research.[5] Cushing's study of the history of quantum mechanics is thus intended to present a case of actual underdetermination, and then to show which non-evidential factors contributed to the scientific community's preference for one underdetermined option over another.

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[4] 'Underdetermined' scientific accounts, as the term is used here, refers to instances wherein empirical evidence fails to decisively favour one competing theoretical alternative over another.
[5] Cushing, J. (1994). *Quantum Mechanics: Historical Contingency and the Copenhagen Hegemony* pp. 7-8.

These apparently underdetermined alternatives, SQM and BQM, can be understood in simplistic terms as follows. The two alternatives are means of interpreting empirical data regarding quantum systems. They thus constitute descriptive accounts of these unobservable systems, extrapolated from empirical evidence. SQM, being the traditional approach to quantum mechanics, holds that quantum systems are *discontinuous* (the so-called quantum postulate). Thus, micro- and macro-systems are non-analogous, and microsystems cannot be described in the terminologies of experience. The epistemological consequence of this is that quantum systems cannot be described unless they are observed. Thus, SQM posits 'superpositions,' multiple states in which quantum systems are held to simultaneously exist, prior to observation. Note that accounting for this statistical model as a descriptive account is sometimes rebuffed on the basis that the discontinuity of quantum systems under SQM is in fact a *lack* of description resulting from a reluctance to make non-empirical claims. However, the common sentiment that microsystems cannot be described in continuous terms belies this.

BQM, meanwhile, produces a causal and hence continuous description of the microlevel, therefore able to be expressed more or less in the terminologies of experience. This is at the expense of accepting non-local correlation or entanglement between quantum systems. Although perhaps problematic, it has been shown by Bell's theorem that maintaining both determinacy and locality in quantum mechanics is untenable. Moreover, the no-signalling theorem indicates that non-local entanglement does not constitute non-local causality. Although it has been argued that, due to the empirically unfounded character of BQM's descriptive interpretation, the model constitutes something like a metaphysics rather than a recognisably scientific account, SQM's indeterminacy is no more empirically demonstrable.[6]

So, as per Cushing, in the case of quantum mechanics, we have available two empirically equal yet divergent quantum models in SQM and BQM. SQM enjoys significantly more currency amongst the scientific community both historically and currently. Schrödinger's equation, the formalism which facilitates reliable prediction regarding quantum systems, is shared between the two. But interpretatively and ontologically, they differ significantly. SQM is statistical and indeterminate, whereas BQM is explicitly causal.[7] The indeterminate ontology of SQM seems to make fewer ungrounded suppositions but leaves us "effectively stranded with the formalism and its predictions,"[8] in that it lacks descriptive content. BQM, meanwhile, is able to produce a coherent — yet empirically undemonstrated — description of particle trajectories at the microlevel. If the two are empirically equal, then the widespread

[6] Bricmont, J. (2016). *Making Sense of Quantum Mechanics*. p. 179.
[7] Cushing 1994, *Quantum Mechanics: Historical Contingency and the Copenhagen Hegemony*, pp 53-5.
[8] Ibid., p. 82.

acceptance of SQM rather than BQM — and the arguably subsequent increased elaboration of SQM at the expense of a causal quantum model — is not demanded by logic or evidence. Note that this equivalence is somewhat exaggerated by Cushing, as it seems that BQM exhibits certain *practical* disadvantages.[9] However, in that valuing factors such as fruitfulness remains at least plausibly non-epistemic, and empirical equivalence between SQM and BQM as non-relativistic quantum theories is evident, I proceed in alignment with Cushing.

Cushing subsequently develops an account of the sociological and psychological factors that 'tipped the balance' in favour of SQM over BQM, resulting in SQM's ascendancy. In historical terms, the emergence of SQM as the dominant model was *contingent* in that it was sensitive to the initial sociological conditions wherein the early history of quantum mechanics occurred, due to an absence of decisive (insensitive) epistemic factors. Had these sociological conditions differed, Cushing argues that the historical unfolding of quantum mechanics might subsequently have differed also, in that BQM would be a) significantly more developed than it is, more indeed than SQM; and b) the quantum model most widely accepted by the scientific community.[10]

Significantly, Cushing does *not* appear to support any claim to the effect that the mathematical structure underpinning both SQM and BQM is contingent.[11] His contingency thesis is limited to the theoretical interpretations that were constructed around the formalism of Schrödinger's equation. Speaking generally to the contingency/inevitability problem, then, it appears that Cushing's claim is that in cases of actual underdetermination (i.e., wherever evidence fails decisively to recommend one theory over another), contingent psychological and sociological factors may prove decisive for theory acceptance. Ultimately, however, standards

[9] For instance, BQM suffers from difficulties regarding its extension into the relativistic domain, whereas SQM allows for this with comparative ease. Following Wolfgang Pauli's (1927: 619) observation that a relativistic extension was necessary for SQM in order to account for electron spin, Paul Dirac (1928) was able to produce such in under a year. In contrast, despite an early assurance from David Bohm (1952) that an analogous account was possible under BQM, the causal formulation of Dirac's equation did not begin to emerge until more than three decades later (Bohm et al 1987). Even in contemporary literature, there are questions regarding whether or not BQM has actually been, or even *could* be, made relativistic (see e.g. Durr et al 2014). On the other hand, there are some indications that BQM has the capacity to make predictions in circumstances where SQM cannot (Cushing 1994: 55). There are also certain experimental issues that seem more easily accounted for under the descriptions provided by BQM, especially in the case of quantum cosmology (Falciano et al 2015). But these possible advantages of BQM have not been empirically demonstrated. The upshot is that SQM and BQM must be suspended from broader resultant theory, and treated as isolated non-relativistic quantum theories, in order to be considered equivalent. It is not at all clear that theories ought to be isolated in such a fashion. However, addressing this problem would require engaging in a broader debate that I cannot address here, regarding whether the empirical domain ought to be extended to address factors such as fruitfulness.

[10] Cushing 1994, *Quantum Mechanics: Historical Contingency and the Copenhagen Hegemony*, pp. 185-6.

[11] Ibid., p. 100.

internal to science prove decisive for the development of basic predictive formalisms.

Soler makes no such explicit concession, although she gives no specific attention to formalisms and emphasises the importance of theoretical interpretations and scientific ontologies to her contingency thesis.[12] Soler argues that SQM and BQM are contingent scientific alternatives on the basis that they both a) appear genuinely scientific, insofar as their modelling and investigative practices conform to the norms of the scientific community; b) seek to provide explanations for the same set of phenomena; and c) insofar as they are approached as non-relativistic quantum theories independent of related theory,[13] are empirically equivalent and constitute actively progressive programs.[14] Moreover, Soler takes SQM and BQM having been co-existent, active, and progressive programs at least since 1952 to indicate that scientific alternatives can be independently successful in the *long-term*. Soler maintains that there is no reason to expect that the differences between SQM and BQM will be resolved, framing them as "irreducibly different" and "contradictory."[15] Thus, Soler concludes that SQM and BQM might be independently viable *indefinitely*. This would mean that Cushing's historical contingency expresses itself as a permanent feature of the unfolding of quantum mechanics.

As stressed by Steven French, the problem of theory individuation is relevant here.[16] Many attempts to refute a contingency thesis made on the basis of BQM, and also to dispute BQM itself, rely on attacking BQM's status as a legitimate alternative *theory.* Instead, BQM is often framed as a mere *reformulation* of SQM. An early example is Werner Heisenberg's assertion that BQM is SQM's "exact repetition in a different language."[17] The key evidence for claims such as this is the shared formalism of SQM and BQM. Also relevant are the symmetries that Soler's criteria appeal to, especially that SQM and BQM are empirically equivalent and share comparable goals. The challenge for contingency is therefore that SQM and BQM may not constitute legitimate scientific alternatives. If this is the case, then Soler's claim that SQM and BQM are evidence of the potential for long-term contingent scientific progress is undermined, in that the continued progressiveness of SQM and BQM is only a result of their being the same theory.

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[12] Soler, L. (2008). 'Revealing the Analytical Structure and Some Intrinsic Major Difficulties of the Contingentist/Inevitabilist Issue.' *Studies in History and Philosophy of Science.* Vol. 30, no. 2, p. 233.
[13] So that e.g. we do not treat quantum field theory as an element of SQM.
[14] Soler 2015, 'Contingentists Should Not Care About the "Put-Up-Or-Shut-Up" Demand,' p. 70.
[15] Ibid., p. 70.
[16] French, S. (2008). 'Genuine Possibilities in the Scientific Past and How to Spot Them.' *Isis*. Vol. 99, no. 3, pp. 568-575. 'Theory individuation' is just the means by which scientific theories are characterised in order to be individually distinguished.
[17] Heisenberg, W. (1955). 'The Development of the Interpretation of the Quantum Theory.' *Niels Bohr and the Development of Physics: Essays Dedicated to Niels Bohr on the Occasion of his Seventieth Birthday.* P. 18.

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Such arguments rely upon an instrumentalist approach, i.e. on the assertion that theories are defined by the relationship between techniques and results. Thus, SQM and BQM might be accounted the same theory in that they employ the same formalism and make the same predictions. But this seems problematic, as an instrumentalist approach to theory individuation risks making physical ontology redundant, and more or less "neglect[s] the intellectual contents" of 'theory' in general.[18] Also problematic is that there appears to be inconsistency insofar as how such an instrumentalist approach is applied. For instance, if we assume instrumentalism, then the measurement problem[19] for SQM evaporates. However, amongst those that seek to dismiss BQM as a reinterpretation of SQM, the measurement problem is not thus dismissed.[20] Although this inconsistency does not fully repudiate an instrumentalist approach, it does indicate a reluctance to render physical ontology completely redundant — a necessary step if SQM and BQM are to be understood as interpretations of the same theory. This reluctance is reasonable, since it seems uncontroversial to assert that theories ought to be considered meaningfully descriptive. At the least, descriptive elements such as physical ontologies ought to be acknowledged as theoretical elements.

Despite this, it seems likely that decisive theory individuation is unreachable, on the basis that such is clearly value-reliant regarding "what essentially matters in physics."[21] But even if SQM and BQM *are* alternative formulations of the same theory, questions regarding the contingency or inevitability of these formulations remain. The divergent ontologies of SQM and BQM, in particular, might suggest that scientific practice, and thus at least potentially the unfolding of quantum mechanics in general, could be influenced by contingent preference for one formulation over another. With this caveat in place, I will continue to refer to SQM and BQM as distinct theories.[22]

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[18] Levy-Leblond, J. (2015). 'On the Plurality of (Theoretical) Worlds.' *Science as It Could Have Been: Discussing the Contingency/Inevitability Problem*. P. 341.

[19] The descriptive gap between the superpositions posited by SQM and the exact values produced when measurement occurs, a significant conceptual issue if research on the basis of SQM is taken to be capable of producing a complete description of quantum systems.

[20] See e.g. Legget, A. (2002). 'Testing the Limits of Quantum Mechanics: Motivation, State of Play, Prospects.' *Journal of Physics: Condensed Matter*. Vol. 14, no. 15, pp. R415-451; Leggett, A. (2005). 'The Quantum Measurement Problem.' *Science*. Vol. 307, no. 5711, pp. 871-872.

[21] Soler 2015, 'Contingentists Should Not Care About the "Put-Up-Or-Shut-Up" Demand,' p. 73.

[22] Theory individuation is not so problematic for Cushing. Cushing's thesis is that in cases of actual underdetermination, contingent sociological and psychological factors can play a decisive role regarding which underdetermined alternative is accepted by the scientific community. This thesis remains intact regardless of whether 'theory' is supplanted by 'formulation', or 'interpretation.' Soler, while referring to these sociological and psychological factors as a *source* or mechanism of contingency, asserts that SQM and BQM are evidence of the potential for alternative theories to be equally successful programs in the long-term. That is, Soler sees the divided state of quantum mechanics as providing evidence for the contingent nature of science in general, that contingent factors can and will lead to alternative theories and ultimately shape the course of scientific progress.

Regardless, the important difference between Cushing's claim and Soler's utilisation of his case-study can be characterised as follows: Cushing proposes that, in cases of actual underdetermination, whichever alternative is ultimately accepted by the scientific community might be contingent. Soler, meanwhile, asserts that Cushing's case study is an example that can serve as evidence for a broader thesis regarding contingency — that contingent factors might always or often have the potential to produce alternative theories and research programs, and that these alternatives have long-term ramifications for scientific courses of events. Soler thus views Cushing's case as indicative of a general principle about scientific progress — she appears to hold the view that contingent initial conditions are always, or at least often, relevant to the historical progression of science.[23] In contrast to Cushing, for Soler, this claim appears to hold firm regardless of whether or not contingent alternatives can be specifically identified.

3. Inevitabilism and its Contingent Implications

In this section, I detail Hacking and Weinberg's accounts of inevitability in order to demonstrate how inevitabilism functions in the context of SQM versus BQM, and also to show how inevitabilism appears cogent with contingentism as presented above. If Hacking and Weinberg's arguments are accepted, even Soler's more general and long-term contingency thesis is affected only to the extent that (relatively minor) limitations upon *what* can be contingent in the long-term must be imposed.[24] In accomplishing this objective, I first identify what Hacking and Weinberg *take to be inevitable*. I then infer what seems permitted as contingent on that basis.

Hacking and Weinberg are representative of strong inevitabilism, based on Hacking's scale of contingency, which ranges from one (strong inevitability) to five (strong contingency).[25] Hacking places his arguments at two on this scale, and notes that Weinberg makes even stronger claims.[26] Presumably, Hacking would rank Weinberg's arguments as one on this scale. This seems plausible since Weinberg himself asserts that science follows the "pull of reality"[27] and appears to adhere to

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This can be observed in Soler's (2015: 98) conviction that a "pluralist regime" could produce multiple scientific alternatives that are currently stymied through scientific monism

[23] Soler 2008, 'Revealing the Analytical Structure and Some Intrinsic Major Difficulties of the Contingentist/Inevitabilist Issue,' p. 232.

[24] Soler does not *specifically* advocate for what I take to be her 'unlimited' account, but she is somewhat non-specific regarding what she takes to be contingent. That being so, I frame my proposed reformulation of long-term contingency as amendments to Soler's account. Soler (2008: 233) does emphasise contingent ontologies as being particularly important to her argument. Since the amendments that I propose (below) specifically maintain that ontology can be radically contingent in the long-term, I anticipate that Soler would not object to the limitations that I place on her account.

[25] Hacking, I. (1999). *The Social Construction of What?* P. 99.

[26] Ibid., pp. 89-92.

[27] Weinberg, S. (2001a). *Facing Up: Science and Its Cultural Adversaries*. P. 103.

convergent realism, as indicated by the title of his 1994 book, *Dreams of a Final Theory: The Scientist's Search for the Ultimate Laws of Nature*.[28] Weinberg is arguably "as boldly inevitabilist as it gets."[29] This circumstance is significant if, as I aim to demonstrate, even these strong inevitabilists permit a reasonably high degree of potential contingency.[30]

Hacking's focus is on the contingency or inevitability of scientific *results*. Hacking asks:

> If the results R of a scientific investigation are correct, would any investigation of roughly the same subject matter, if successful, at least implicitly contain or imply the same results?[31]

He responds:

> The answer to a clear question about some aspect of the world is determined by how the world is. When a question is a live one, and there is a context in which there are ways of addressing the question… then aspects of the world determine what the answer is, even though only people in a scientific society find out the answer. That is a difference… between metaphysics, what the answer is, and epistemology, whether we find the answer. The content of possible knowledge — the answers to live questions, once… asked — [is] not affected by [contingent factors]. The form of possible knowledge, the questions that in the course of research made sense, [is] affected.[32]

What does this mean in the case of quantum mechanics? Answering this question relies crucially upon what Hacking means by results, which remains ambiguous. Interestingly, Hacking appears to amalgamate 'results' and 'answers to scientific questions,' in that he treats the identification of a determinant for answers to scientific questions (the natural world) as evidence that scientific results are inevitable. But if we define Hacking's 'results' as 'answers to scientific questions' and apply this definition to the case of SQM and BQM, it does not yield a consistent account. For example, if we take the empirical claims of SQM and BQM, we might say that they produce the same results in that they make the same predictions. But

[28] The view that successful science necessarily progresses towards a universally accurate theoretical account of how the world is.
[29] Kinzel, K. (2015). 'State of the Field: Are the Results of Science Contingent or Inevitable?' *Studies in History and Philosophy of Science*. Vol. 52, p, 59.
[30] I do not take this 'scale of contingency' particularly seriously, since numerically ranking contingency/inevitability claims ignores the significant complexity of the positions that constitute the debate (see Martin 2013). I include it only to situate the supposed strength of Hacking and Weinberg's claims within the broader debate, so that the ramifications of my argument can be made clear.
[31] Hacking, I. (2000). 'How Inevitable are the Results of Successful Science?' *Philosophy of Science.* Vol. 67, p. S61.
[32] Ibid., p. S69-70.

when asking which physical processes *cause* these empirical results, SQM and BQM are in substantial disagreement. A claim to the effect that the natural world specifically determines these substantively contradictory descriptive claims seems difficult to defend, and so it seems that 'results' and 'answers to scientific questions' cannot be synonymous, at least in this case.

Attending to Hacking's form/content distinction may assist us here. This is partially elaborated when Hacking addresses Andrew Pickering's contingency thesis regarding a 'quarky' particle physics.[33] Hacking argues that Pickering's claim is not that quarks, the object, are contingent, but that "the *idea* of quarks... might be [contingent]."[34] "It was a highly contingent fact that human beings would ever form an idea of [quarks], but the existence of [quarks] is not contingent on any human thought or action."[35] Being informed by Hacking's entity realism, this perspective might be criticised on a number of fronts, but it provides some insight into how the form/content distinction functions for Hacking. Hacking acknowledges "that the 'forms' of scientific knowledge could have been different, yet still, we would be recognisably exploring the same aspects of nature."[36] On this basis, we can infer that since the 'ideas' of quarks might be different, and quarks are actual entities, Hacking understands that a non-quarky particle physics would be a different *form* of particle physics, but that the *content* of that physics would inevitably refer to quarks.[37]

How then does this clarify what Hacking means by 'results,' and hence how his account operates in relation to quantum mechanics? As noted, SQM and BQM substantively disagree about the physical processes that give rise to their empirical claims. But for Hacking, both are inevitably exploring the same aspects of nature — quantum systems. Their disagreement regarding physical processes makes SQM and BQM different *forms* of possible knowledge regarding quantum mechanics, in that they present different *ideas* about quantum systems. The descriptive claims of SQM and BQM therefore cannot be 'results' in Hacking's sense, since he associates results with inevitable content rather than contingent form.

Understanding this enables us to resolve the inconsistency that I indicated above. The descriptive claims of SQM and BQM, which are in substantive disagreement, are different forms of quantum mechanics. But we can understand their empirical claims, since SQM and BQM make the same predictions, to be the results of quantum mechanics: I propose that Hacking's 'results' ought to be interpreted in this fashion, as meaning empirical claims. So, for Hacking, it is the shared empirical claims of SQM and BQM that are inevitable. This then allows the SQM/BQM divergence to

[33] Pickering, A. (1984). *Constructing Quarks: A Sociological History of Particle Physics.*
[34] Hacking 2000, 'How Inevitable are the Results of Successful Science?,' p. S61, emphasis in original.
[35] Ibid., p. S62.
[36] Ibid., p. S71.
[37] Hacking does not actually suggest that a non-quarky particle physics is possible.

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serve as evidence for Hacking's inevitabilism. Would any investigation of quantum systems produce the same results? In that SQM and BQM produce the same empirical claims, and these are understood as the results that Hacking refers to, Hacking's affirmative answer seems reasonable.

With this understanding in place, we can now ask what implications Hacking's inevitabilism has for the contingency theses recounted above. Cushing's claim is that the choice between SQM and BQM might be contingent on social and psychological factors.[38] It is not obvious that Hacking's claim is in any way inconsistent with such a statement, provided that we interpret SQM and BQM as different scientific forms in Hacking's sense. Hacking specifically admits that forms might be contingent, while Cushing specifically excludes the formalism of quantum mechanics — through which the empirical claims of SQM and BQM are derived — from his contingency thesis. For Hacking empirical claims are inevitable, and through this, we can infer that Hacking allows that scientific ontologies can be contingent. If this is accepted then the upshot is that, at least in the case of quantum mechanics, Hacking's inevitability permits Cushing's contingency.

Because Soler does not limit her contingency thesis as Cushing does, her contingentism may appear less compatible with Hacking's inevitabilism. Soler frames her long-term contingency as universally applicable to scientific courses of events.[39] In contrast, Hacking holds that no matter how scientific results are formulated (e.g. as SQM or BQM) they cannot be "incompatible," since scientific content is determined by aspects of nature.[40] Hacking is therefore suggesting that any contingency is limited by the determined character of scientific results, and so contingency cannot be as radical as Soler's thesis suggests. But, as Hacking notes, determining the compatibility or incompatibility of diversely formulated scientific results is not straightforward.[41] When diffuse results produced under different standards or epistemic assumptions are called compatible, this is typically dependent upon 'translating' one set of results into alignment with the standards under which the other set of results was produced. But this process "does not leave everything the same."[42] This is because 'results' are typically entangled with broader theory. This becomes evident if we take what might seem to be a clear case of relative compatibility, SQM and BQM's shared results. If BQM's results are held to be *compatible* with SQM, this will be because SQM can account for BQM's results under SQM's ontology. But SQM's results can be compatible with BQM on the same basis. Compatibility of results in no way resolves the SQM/BQM dilemma. As such,

[38] Cushing 1994, *Quantum Mechanics: Historical Contingency and the Copenhagen Hegemony*, p. 100.
[39] Soler 2008, 'Revealing the Analytical Structure and Some Intrinsic Major Difficulties of the Contingentist/Inevitabilist Issue,' p. 232.
[40] Hacking 2000, 'How Inevitable are the Results of Successful Science?,' p. S71.
[41] Ibid p. S67.
[42] Ibid p. S67.

compatibility of results in itself does not tell us much about the aspects of nature that are determining these results. What Hacking's criterion of compatibility tells us is that since results inevitably refer to aspects of nature, they are likely to admit translation between standards. But it cannot tell us which standard is more accurate. It does nothing to tell us whether SQM or BQM is descriptively closer to actual quantum systems.

In short, if we amend Soler's argument so that long-term contingency can occur, but that empirical claims are inevitably determined by aspects of nature, then Hacking's inevitabilism tacitly permits Soler's contingency as well. Regarding SQM and BQM, the claim becomes that both may prove long-term viable alternatives, but that the results of either model will inevitably refer to actual quantum systems. This is a relatively minor amendment regarding *what can be contingent* on Soler's account. Empirical claims about the world will inevitably refer to the "natural world, indifferent to human beings."[43] But this does not then refute Soler's specific claim that SQM and BQM are potentially long-term viable alternatives, since they disagree *not* on their empirical claims (their results) but on their account of the physical processes that cause such, i.e. their ontologies. Although the empirical claims of SQM and BQM appear compatible in the sense that I have outlined, this does not itself nullify the substantive contingency that Soler postulates. As has already been shown, Hacking's inevitabilism permits contingency of ontology. Therefore, Hacking's inevitabilism also permits Soler's long-term contingentism.

As noted, Weinberg is a particularly strong inevitabilist. But although he claims that science follows the "pull of reality,"[44] one of my goals here is to show that Weinberg's arguments actually exclude definitive convergent realism. Weinberg writes:

> The achievements of science [are] permanent. What changes is our understanding of why theories are true, and also our understanding of the scope of their validity. For instance, at one time we thought that there was an exact symmetry in nature between left and right, but then it was discovered that this is only true in certain contexts and to a certain degree of approximation. But the theory… was not a simple mistake. Within its scope of validity, this symmetry has become a permanent part of science.

He continues:

> There is a 'hard' part of modern physical theories that usually consists of the equations themselves, together with some understandings about what the symbols mean operationally and about the sorts of phenomena to which they apply. Then there is a 'soft' part; it is the vision of reality that we use to explain to ourselves why the equation works. The soft part does change… but after our theories reach their

[43] Ibid., p. S70.
[44] Weinberg 2001a, *Facing Up: Science and Its Cultural Adversaries*, p. 103.

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> mature forms, their hard parts represent permanent accomplishments. I think that physical theories are like fixed points… Our starting points may be culturally determined, our paths may be affected by our personal philosophy, but the fixed point is there nonetheless. It is something toward which any physical theory moves.[45]

Weinberg clarifies that this 'hard' part of physical theories can be partially characterised by predictive capacity.[46] Elsewhere, Weinberg writes that the 'permanence' of these accomplishments is twofold. Firstly, a means of reliable prediction will always 'function,' will always produce the same predictions regardless of how these predictions are interpreted.[47] Secondly, assuming that research continues, the ability to reliably predict phenomena will always feature as something that ought to be explained, despite any theory change that might occur.[48] This seems plausible enough — a key goal of many scientific enterprises is to provide explanations of empirical data and consistencies.

How do Weinberg's arguments function in the case of SQM and BQM? It appears that the formalism of quantum mechanics — Schrödinger's equation, from which both SQM and BQM are derived — ought to be accounted a 'hard' part of quantum mechanics, since it is used to derive reliable predictions. Leaving aside operational factors, the other hard aspect of quantum mechanics is the understanding that this formalism applies to quantum behaviour. If 'soft' parts of physical theories are visions of reality that explain why equations work predictively, then the divergent ontologies of SQM and BQM fit nicely into this category. As I have previously noted, these ontologies constitute very different conceptions of the physical processes which produce the empirical claims of quantum mechanics. This is consistent with Weinberg's anticipation that the descriptive content of SQM is likely to change in response to problems with quantum cosmology.[49] Although this is framed fairly vaguely, and Weinberg never substantively addresses BQM, he allows that the descriptive claims of SQM are *impermanent* or changeable, and this indicates that they must be soft on his account.

There are some obvious parallels between Weinberg's soft and hard parts of physical theories, and Hacking's form and content distinction. In the case of SQM and BQM, what Weinberg allows as 'soft' directly aligns with what Hacking regards as the potentially contingent forms of quantum mechanics — both refer to the descriptive or ontological accounts that seek to make sense of the empirical claims of quantum mechanics in general. Regarding the 'hard' parts of quantum mechanics, and Hacking's content, there is a (minor) difference between the two. Weinberg

[45] Ibid., p. 126.
[46] Ibid., p. 125.
[47] Weinberg 2001a, *Facing Up: Science and Its Cultural Adversaries*, pp. 118, 199.
[48] Weinberg, S. (1994). *Dreams of a Final Theory: The Scientist's Search for the Ultimate Laws of Nature*, pp. 127-8.
[49] Ibid., p. 67.

emphasises mathematical devices, like Schrödinger's equation, that allow for reliable predictions. Hacking's argument emphasises actual empirical claims and predictions. But these views are readily reconcilable in this case, since a) the formalism is what allows for the empirical claims of quantum mechanics to be produced, and b) the empirical claims of quantum mechanics are what validate the formalism.

In this sense, Weinberg's inevitability argument as applied to SQM and BQM is actually fairly similar to Hacking's. The 'fixed point' of a physical theory of quantum mechanics is presumably related to the actual nature of quantum systems. Since Schrödinger's equation can make reliable predictions regarding quantum behaviour, it must refer to this fixed point. Therefore, if investigation into quantum behaviour occurs, it will — assuming success — inevitably strike upon this consistency of quantum systems, which makes reliable predictions possible through a formalism. All this occurs independently of how the physical processes that cause such are understood. Another minor difference is that Weinberg's account suggests that quantum formalism as a means of reliable prediction will inevitably feature as something to be explained by future theory. This seems plausible and does not directly contradict Hacking's claims. A more significant difference is that Weinberg's arguments suggest that successful scientific investigation into quantum behaviour will *inevitably produce increasingly accurate approximations* of quantum systems. Hacking only claims that scientific results will inevitably refer to actual quantum systems — not that this will result in more accurate accounts. Weinberg's argument is that, in the long-term, accounts of quantum systems will inevitably become increasingly accurate representations of actual quantum systems. The implication is that any contingency that does occur during scientific investigation is ultimately insignificant in the long-term.

But does Weinberg's long-term inevitabilism actually follow from his argument? I think it is fairly obvious that it does not. Let us see how much contingency remains possible under Weinberg's schema of inevitability. As with Hacking, it is not clear that Weinberg is in any substantive disagreement with Cushing. If we understand SQM and BQM's differences as a difference of 'soft' scientific parts, then Weinberg is willing to admit that these can be affected by social and psychological factors, at least temporarily. Cushing does not argue that the formalism of quantum mechanics — its 'hard' part — is contingent, but only that historical contingency has affected the unfolding history of quantum mechanics to date.

At face value, Weinberg's long-term inevitability claim *does* seem to come into significant conflict with Soler's views. Whilst Soler argues that alternative physical theories are possible in the long-term, Weinberg argues that scientific investigation leads inevitably to specific theoretical accounts. Soler argues that SQM and BQM could remain viable alternatives in the long run, whereas Weinberg's claim is that

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any differences will inevitably be resolved. But Weinberg's argument, essentially presupposing convergent realism, does not stand up to scrutiny on his own account. For Weinberg, it is *invariantly predictive mathematical structures* — that is, nomological structures — that are inevitable. As it currently stands, for Weinberg it is the shared formalism of SQM and BQM that is inevitable. It may be that investigation into quantum behaviour will inevitably lead to more accurate means of prediction in this sense. But it is evident that ontology — the soft 'vision of reality' by which we explain the predictions made through nomological structures — cannot be derived from such. Weinberg's "pull of reality"[50] appears, by his own account, to be capable of producing *only* soft ontologies that remain susceptible to change based on social and psychological factors. The substantive disagreements between SQM and BQM cannot be decisively resolved via the hard parts of quantum mechanics to which Weinberg appeals.

The upshot is that Weinberg's account permits most of Soler's long-term contingency, although this does require another amendment to Soler's argument. In light of Hacking's argument, I allowed that in the long-term SQM and BQM would find their results inevitably determined by aspects of nature, although I suggested that the implications of this inevitability are necessarily ambiguous. Now, I propose that we ought to amend Soler's argument so that the nomological structure of quantum mechanics might be inevitable. This might appear to be a major concession to the inevitabilist, but it proves otherwise. To plausibly suggest that the nomological structure of quantum mechanics is contingent would require proposing a counterfactual alternative, and in this case, an alternative is nearly inconceivable. Moreover, as has been shown, an inevitable nomological structure is not related to the evidence of contingency found in the case of SQM and BQM — it cannot lead to a reconciling or definitive quantum ontology. So, although Weinberg's arguments regarding the inevitability of the 'hard' parts of quantum mechanics appear plausible, this does not resolve the substantive disagreements between SQM and BQM which most strongly suggest contingency. Weinberg (who, recall, may be as boldly inevitabilist as it gets) thus permits both Cushing's historical contingency, and a slightly amended form of Soler's long-term contingency, while specifically allowing for radically contingent scientific ontologies.

4. Concluding Remarks

This paper has aimed to demonstrate that, at least in regard to quantum mechanics, the contingency/inevitability debate is more or less lacking in legitimate philosophical tension. This is largely the result of a failure of conceptual clarity, wherein participants do not specify the targets of their arguments. Once this clarity

[50] Weinberg 2001a, *Facing Up: Science and Its Cultural Adversaries*, p. 103.

is achieved, it becomes fairly clear that the nominally competing claims regarding SQM and BQM are mutually sustainable, in that contingentists and inevitabilists target different aspects of quantum mechanics generally. It is significant that under scrutiny it becomes clear that not even the strongest inevitabilist is willing to argue that scientific ontology regarding unobservables is definitively determined by epistemic factors. The significance of social and psychological determinants in forming scientific ontology appears to be generally, if on the part of inevitabilists characteristically tacitly, accepted. We might reconsider whether arguments permitting such a large degree of historical contingency are deserving of the label 'inevitabilism.'

Finally, note that although quantum mechanics provides an excellent setting for the discussion of contingency/inevitability regarding science, the scope of my claims is limited by my focus on SQM and BQM. If more reliable general claims regarding the debate are to be formed, my approach will need to be applied to a broader set of cases.

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