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Revisiting the scientific nature of multiverse theories

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Abstract

Some scientists or philosophers argue that multiverse theories are unfalsifiable and thus not scientific. However, some advocates of multiverse theories have recently argued that although the multiverse is not observable, multiverse theories are indeed falsifiable in principle. Therefore, they share similar features with a conventional scientific theory. On the other hand, the proposals of an epistemic shift and nonempirical theory assessment have possibly revived the discussions of the scientific nature of multiverse theories. In this article, I revisit the falsifiable arguments made by the advocates of multiverse theories and show that these arguments do not justify arguing the scientific nature of such theories. Moreover, even if we accept the proposals of the epistemic shift and the nonempirical theory assessment, I argue that multiverse theories still cannot pass or satisfy the required assessments based on the new theoretical virtues and the nonempirical arguments.

Keywords: Multiverse; Falsifiability; Nonempirical theory; Epistemic shift; Fine-tuning

1. Introduction

The existence of a multiverse is an intriguing topic that has attracted much attention from both academia and the general public. Simply speaking, the ensemble of 'parallel' universes is described as a multiverse (Carr, 2007, 1). Although the idea of a multiverse has been discussed for a long time (Rubenstein, 2014), it remains a hot topic in science and philosophy. The scientific multiverse theories mainly originate from the latest developments from cosmology, string theory and quantum mechanics. Generally, different multiverse theories predict different intrinsic properties for the universes. The major variations include the number of universes and the universe generation mechanisms.

Recently, scientist Sean Carroll has posted an article on the physics research archival platform (arXiv) arguing that "multiverse theories are utterly conventionally scientific, even if evaluating them can be difficult in practice" (Carroll, 2018, 1).[1] Here, "multiverse theories are conventionally scientific" means that multiverse theories are "perfectly ordinary science, so the ways in which we evaluate the multiverse as a scientific hypothesis are precisely the ways in which hypotheses have always been judged" (Carroll, 2019, 301), like traditional normal scientific theories. Based on three arguments, he claims that multiverse theories should be treated as normal scientific theories that could be tested or conceived to be tested.

He defends multiverse theories because there are many scientists and philosophers who believe that the existence of a multiverse is unfalsifiable and thus not scientific. For example, scientist George Ellis says, "I do not believe the existence of those other universes has been proved – or ever could be" (Ellis, 2011). The comments of philosopher Richard Swinburne on the multiverse hypothesis (many-world interpretation) are as follows (Swinburne, 1998, 178):

"The postulation of the actual existence of an infinite number of worlds, between them exhausting all the logical possibilities, many of them consisting of an infinite quantity of matter – energy behaving in accord with simple laws over infinite time, which are not caused by anything else, which do not causally affect each other, but which between them exhaust the logical space without any one being qualitatively identical to any other, is to postulate complexity and non-prearranged coincidence of infinite dimensions beyond rational belief".

As stated by Karl Popper, whether a hypothesis or a theory is scientific depends on its falsifiability (Popper, 1959). Although it is in fact now a minority position among philosophers of science, many recent discussions concerning the multiverse hypothesis, especially among scientists, focus on its falsifiability. Since the speed of light is finite, the total volume of the observable universe is also finite. However, the actual volume of our universe is much larger than the volume of the observable universe; therefore, a part of the volume of our universe is unobservable. If there exist a large number of universes besides our own universe, it is impossible for us to observe them. Since we cannot observe other universes even if they exist, the multiverse hypothesis seems impossible to verify or falsify.

To defend multiverse theories as normal conventional scientific theories, Sean Carroll presents three arguments for their scientific nature. These arguments can generally reflect why some scientists believe that multiverse theories are intrinsically scientific. Moreover, on the philosophical side, the proposal of an epistemic shift argues that multiverse theories could remain safely within the border of science (Kragh, 2014). This shift provides a justification that multiverse theories could be scientific even without any empirical testability. On the other hand, the nonempirical theory assessment proposed by Richard Dawid can be applied to support nonempirical theories such as string theory and multiverse theories. These philosophical arguments have revived discussions on the alleged scientific nature of multiverse theories. In this article, I will first review and discuss those three arguments made by Sean Carroll. Then, I will discuss whether the proposal of an epistemic

[1] The quote appears in the abstract of the article. However, the article published in the book does not have the abstract. It only appears in the article published in arXiv:1801.05016.

shift and the assessment of nonempirical theory can justify the scientific nature of multiverse theories.

2. Carroll's arguments

2.1 The problem of predictions and falsifiability

Sean Carroll argues that although a multiverse is not observable, this does not mean that it is not falsifiable. He defines five levels or categories of falsifiability, from the least to the most, as follows (Carroll, 2019, 304).

1. There is no conceivable empirical test, in principle or in practice or in our imagination, which could return a result that is incompatible with the theory.
2. There exist tests which are imaginable; however, it is impossible for us to ever perform them.
3. Tests exist that can be performed within the laws of physics but are hopelessly impractical.
4. There exist tests that can be performed; however, these would only cover a certain subset of the parameter space for the theory.
5. There exist doable, definitive tests that could falsify the theory.

According to Sean Carroll, Popper's view on unfalsifiable theories belongs to category 1, similar to the theories of Freud, Adler, and Marx. The multiverse hypothesis belongs to category 2 (Carroll, 2019, 304). He further states that some specific multiverse models are in category 4 (Carroll, 2019, 305).

First, whether the theories of Freud and Marx belong to category 1 is controversial. In fact, Popper wrote that the early formulations of Marx's theory made testable predictions. However, when these predictions were falsified, the advocates "reinterpreted both the theory and the evidence in order to make them agree" (Popper, 1965, 37). Thus, there are conceivable tests for Marx's theory. However, the theory could be modified or reinterpreted such that it is difficult to falsify. A theory could be easily changed if it does not have enough empirical content to constrain itself intrinsically. Therefore, in this case, the degree of falsifiability or testability depends on the amount of empirical content but not on whether there exists any conceivable test. Such a modification is regarded as a conventionalist approach (Popper, 1959). Some studies even argue that cosmologists are using a conventionalist approach to defend the standard cosmological model (Merritt, 2017; Chan, 2019a).

Strictly speaking, multiverse theories also encounter such problems. There is no widely accepted empirical content for multiverse theories. For example, we do not know the actual number of universes for the most popular multiverse theory based on string theory. Some studies claim 10^{500} (Hawking and Mlodinow, 2010, 118), while others claim $10^{10^{10^7}}$ (Linde and Vanchurin, 2010). Many scientists, such as Stephen Hawking, invoke multiverse theories to explain the fine-tuning problem of our universe. However, if there exist only 10^{500} universes, it is not sufficient to account for the fine-tuning problem because, according to the calculations by Roger Penrose, the probability of all the necessary conditions sufficient to allow the formation of planets coming together for life evolution by chance is just $10^{-10^{123}}$ (Penrose, 1990, 343-344). If the number of universes is $10^{10^{10^{7}}}$, then it is probably sufficient. Due to the uncertainty of empirical content, the multiverse theories easily change and accommodate the observed data.

Second, Sean Carroll argues that the theories in category 1 are clearly not scientific in any practical sense, while those in category 5 are (Carroll, 2019, 304). He believes that, although there is no clear line to demarcate between scientific and nonscientific theories, there exists a line between categories 1 and 2 rather than between categories 4 and 5. He argues that lumping categories 1-4 together is metaphysical, while lumping categories 2-5 together is epistemological because the theories in categories 2-4 state something about the world, whereas those in category 1 do not (Carroll, 2019, 304). Therefore, a clear distinction exists between categories 1 and 2. Another argument made by Sean Carroll to draw a line between categories 1 and 2 rather than 4 and 5 is that some specific multiverse models are actually in category 4 (Carroll, 2019, 305). Therefore, the theories in categories 2-4 share a similar nature.

It is strange to argue that the theories in category 1 do not state anything about the world. As mentioned by Sean Carroll, Freud's theory and Marx's theory belong to this category. Nevertheless, these theories state something about our world in the sociological domain or the psychological domain, although they might not be falsifiable. On the other hand, what do multiverse theories tell us about our world? Multiverse theories would tell us that our world consists of many universes. That may be the only thing, and it may not imply any specific observable consequence in our observed universe.

Furthermore, many hypotheses can only be falsified if joined together with auxiliary hypotheses. In particular, there are many versions of multiverse theories, which depend on completely different auxiliary hypotheses or prior assumptions. Max Tegmark suggests that multiverse theories can form a four-level hierarchy, allowing progressively greater diversity (Tegmark, 2007, 99). Different levels of multiverse theories contain different features and assumptions. For example, level-two multiverse theories assume that different universes have the same fundamental equations of physics, while level-four multiverse theories assume that different universes have different fundamental equations of physics (Tegmark, 2007, 101). Therefore, strictly speaking, it is very difficult for us to apply the five levels or categories of falsifiability suggested by Carroll to assess the general multiverse theories. We may only be able to assess them one by one if the theories have clear and well-defined content. In other words, the first argument made by Carroll is somewhat oversimplified.

2.2 Abduction and Bayesian inference

The second argument made by Sean Carroll is that the investigations of multiverse theory follow the abduction approach or Bayesian inference, which is commonly used in normal conventional science (Carroll, 2019, 306). This approach is occasionally called inference to the best explanation (IBE). The best explanation is to infer "from the premise that a given hypothesis would provide a 'better' explanation for the evidence than would any other hypothesis, to the conclusion that the given hypothesis is true" (Harman, 1965, 89). Some philosophers have suggested several explanatory virtues (e.g., simplicity, degree of testability, informativeness) to qualitatively evaluate which explanation is the best fit for current observations (Kuhn, 1977, 321-322; Lipton, 1991, 59; Dawes, 2009, 112). On the other hand, some philosophers apply the Bayes theorem to quantitatively compare the likelihoods or posterior probabilities of different hypotheses. The hypothesis that has the largest likelihood or posterior probability would be regarded as the best explanation (Swinburne, 1973, 1; Carroll, 2019, 307). Sean Carroll mainly follows the latter approach (Bayesianism) to evaluate scientific theories (Carroll, 2019, 307).

Sean Carroll argues that "[r]ather than simply pointing out that the multiverse cannot be directly observed (at least for some parameter values) and therefore can't be falsified and therefore isn't science, we should ask whether a multiverse scenario might provide the best explanation for the data we do observe, and the face of new data – just as we do for any other scientific theory" (Carroll, 2019, 307). He further points out that the discovery of the extremely small value of the cosmological constant is evidence to evaluate the multiverse hypothesis (Carroll, 2019, 308-309). Based on the Bayesian inference, the small cosmological constant is treated as evidence for giving increased credence to the multiverse hypothesis. Therefore, Sean Carroll believes that "physicists have been greatly influenced by the realisation that a multiverse need not be simply posited as a logical possibility, but is actually a prediction of theories that are attractive for entirely different reasons: inflation and string theory" (Carroll, 2019, 310). Based on the argument that "an ability to account for the data is always the overwhelmingly important quality a scientific theory must have" (Carroll, 2019, 310), multiverse theories should be somewhat regarded as normal conventional scientific theories.

It is true that many scientific theories can be assessed by Bayesian inference or IBE. However, this does not imply that any theory that could be assessed by Bayesian inference or IBE must be scientific in nature. Bayesian inference is a traditional scientific tool to evaluate hypotheses or theories. Nevertheless, a hypothesis or theory being assessable by Bayesian inference does not entail that it is scientific. For example, many philosophers are using Bayesian inference to study the existence of God. Some studies based on the fine-tuning phenomena in our universe or special characters in life claim that God exists (Swinburne, 1998). In fact, in addition to the scenarios or possibilities listed by Sean Carroll (Carroll, 2019, 308), some suggest that the extremely small value of the cosmological constant could be explained by the design of God (Collins, 2007). These studies basically follow the method of Bayesian inference. Generally, many theories in different disciplines and areas can be assessed by this scientific tool. It should be noted that the evaluation process is somewhat scientific, while the theories undergoing such an assessment may not be scientific. Moreover, note that the above discussions oppose the criterion suggested by Sean Carroll only, but not arguing that the theory of God should be included in scientific investigation.

Apart from the above problem, some other difficulties could be encountered while using Bayesian inference to assess multiverse theories. In the framework of Bayesian IBE, we need to compare the posterior probability of one theory to that of another competing theory. The posterior probabilities significantly depend on the prior probabilities, which could lead to very different results. Therefore, Sean Carroll points out that "[t]he role of priors is crucial" (Carroll, 2019, 307), depending on several criteria suggested by Kuhn. However, it is very difficult to assign any objective values to the prior probability of multiverse

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theories. Since there is no widely accepted empirical content for multiverse theories (e.g., the total number of universes, sizes of the universes, interaction between the universes, etc.), the prior probabilities of multiverse theories are difficult to evaluate. In the views of likelihoodism, one may have some subjective degree of confidence in each of the competing theories, but someone else may have a different degree of confidence (Sober 2019, 21). As a result, there are almost no objective priors for multiverse hypotheses. Generally, if one can calculate the likelihood of data given a hypothesis, then the hypothesis can be regarded as falsifiable. However, as there are very few constraints for multiverse theories, one can arbitrarily add many assumptions or auxiliary hypotheses in these theories so that the likelihoods of multiverse theories are very high.

Furthermore, although the small cosmological constant problem could be a piece of evidence to support multiverse theories, there is counterevidence that disfavours multiverse theories. For example, the probabilistic predictions of multiverse theories state that the observed value of the primordial quantum fluctuation parameter Q of our universe should lie near the edge of the anthropic region (Garriga and Vilenkin, 2006). However, the observed value is not close to either edge of the anthropic region. This problem is now known as the Q-catastrophe. Should we regard this as falsifying evidence for multiverse theories? Note that it is just a probabilistic prediction. We can always argue that it is still possible for multiverse theories to be true. However, if the probabilistic prediction is not strong enough to falsify multiverse theories, why should we consider that the small cosmological constant problem could be evidence to support multiverse theories?

2.3 The unavoidable unobservable

The third argument made by Sean Carroll is that the multiverse theory is the only choice to account for certain observational data. He states that “[t]he best reason for classifying the multiverse as a straightforwardly scientific theory is that we don’t have any choice” (Carroll, 2019, 311). He further points out the following two criteria for this argument (Carroll, 2019, 311).

1. It (i.e., the multiverse theory) might be true.
2. Whether or not it is true affects how we understand what we observe.

He again considers the previous example – the unexpected small value of the cosmological constant. He opines that “one cannot spend equal amounts of research effort contemplating every possible idea, as the number of ideas is extremely large” (Carroll, 2019, 311). In such a case, the existence of a multiverse is an “inescapable consideration” (Carroll, 2019, 311) because the multiverse theory can naturally explain why the observed value of the cosmological constant is so small. Therefore, he says that “the only unscientific move would be to reject one or the other hypotheses a priori on the basis of an invented methodological principle” (Carroll, 2019, 311). In other words, the existence of a multiverse should be considered by default and can be regarded as a straightforward scientific theory.

It is true that we should consider any possible solution that can account for observations. However, this does not mean that the multiverse theory is scientific even if it is possible to

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account for the cosmological constant problem. We should certainly not neglect multiverse theories. However, this is not a reason we should classify multiverse theories straightforwardly as scientific theories. The two criteria suggested by Sean Carroll are not directly related to the criteria of a scientific theory. A theory that can explain any natural phenomenon is not necessarily regarded as a scientific theory. For example, as mentioned above, the God hypothesis or the design hypothesis can also be used to account for the cosmological constant problem. The God hypothesis basically satisfies the two criteria: 'it might be true' and 'whether or not it is true affects how we understand what we observe'. Therefore, we should not neglect the possibility of the existence of God. Following Sean Carroll's argument, rejecting the consideration of the God hypothesis is an unscientific move. However, it seems that such an argument has not been able to persuade scientists to consider the God hypothesis.

Certainly, based on Carroll's argument, we can allow that certain versions of the design hypothesis indeed are scientific because we do not have a rigorous definition of science. However, the two criteria suggested are too easy to satisfy. This would allow a huge number of similar theories to be regarded as scientific, such as the Intelligent Design hypothesis or astrological theories, which would greatly challenge our common understanding of science. It seems that Carroll's third argument could be used to justify just about any hypothesis as scientific.

Second, we do not know how many universes there are or whether the number of universes is large enough to explain the small value of the cosmological constant. In fact, multiverse theories can also account for a large value of the cosmological constant. They can give numerous solutions and values for the cosmological constant. As noted by Karl Popper, a theory that explains everything, explains nothing. If multiverse theories can account for almost every value of the cosmological constant, should we still regard them as scientific theories for consideration? Antony Flew said that "[a] true scientific explanation […] is like a single well-aimed bullet. The idea of a multiverse replaces the rationally ordered real world with an infinitely complex charade and makes the whole idea of "explanation" meaningless" (Flew, 2007, 119). Therefore, Carroll's third argument is problematic.

3. Epistemic Shift

As mentioned above, most of the major discussions and attention have focussed on the falsifiability or testability of multiverse theories, especially among scientists. Nevertheless, some philosophers have proposed challenging the standard falsifiability criterion. The idea of a multiverse has initiated the question "do we need to change the definition of science?" (Matthews, 2008). Such a proposal in the philosophy of science is called an 'epistemic shift' (Kragh, 2014). An epistemic shift refers to "suggestions that traditional criteria of evaluation of scientific theories (or of theories claimed to be scientific) are no longer adequate and should therefore be replaced by new criteria that better fit the problems under investigation" (Kragh, 2014). In other words, this approach suggests a potential need for a kind of 'paradigm shift' in the definition of science to embrace the scientific research of multiverse theories.

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In view of this suggestion, scientist Susskind claims that "[g]ood scientific methodology […] is conditioned by, and determined by, the science itself and the scientists who create the science" (Susskind, 2006, pp.193-195). Therefore, he believes that scientists can define science as what they do. However, this presupposes that all scientists have almost the same ideas of what constitutes science (Kragh, 2014). Even though some cosmologists and physicists are working on multiverse theories, we should not decide whether a particular theory discussed by them is in fact scientific. Kragh argues that nearly all physicists agree that "testability is an epistemic value of crucial importance" and "a theory which is cut off from confrontation with empirical data just does not belong to the realm of science" (Kragh, 2014). Therefore, it is still a consensus of scientists that testability is a necessary epistemic standard for a scientific theory. The need for any epistemic shift is absolutely doubtful, and it is problematic to propose an epistemic shift in the criteria for what should pass as science.

Some scientists argue that the meaning of confirmation of testing should include mathematical consistency (Susskind, 2006, pp.193-195). Many cosmologists and physicists are building theoretical models with inner harmony and simplicity. These aspects can be viewed as good theoretical virtues to claim for good scientific theories. However, as Kragh (2014) points out, "Popper never held that falsifiability is a sufficient condition for a theory being scientific, only that it is a necessary condition". Therefore, although some multiverse theories, such as string theory, contain internal consistency or mathematical elegancy, they cannot be regarded as scientific theories unless they have a certain degree of falsifiability. Containing other theoretical virtues does not help.

Although the need for an epistemic shift is controversial, we can step back and sympathetically assume that there is a need to have an epistemic shift. Then, we examine whether multiverse theories could be justified as scientific based on the new theoretical virtues after the epistemic shift as suggested by some scientists. Kuhn (1977, pp.320-339) has suggested 5 standard criteria for evaluating the adequacy of a theory: (1) accuracy, (2) consistency, (3) broadness of scope, (4) simplicity, and (5) fruitfulness. These criteria are commonly used by scientists, and they can be used as the theoretical virtues to judge whether a theory is scientific under an epistemic shift. The first criterion, accuracy, refers to the agreement between the consequences deducible from a theory and the observational results. Since it is related to the testability or falsifiability of a theory, we will skip this criterion and consider the other four criteria serving as possible theoretical virtues for judgement after the epistemic shift. We will discuss whether multiverse theories could be justified as scientific based on these new virtues.

3.1 Epistemic shift of theoretical virtues

First, one of the most supportive arguments for multiverse theories is their consistency. Generally, the existence of a multiverse is consistent with the fine-tuning phenomena observed in our universe and string theory in theoretical physics. However, such consistency is at a very low level – generally and conceptually consistent. In many specific domains, inconsistency can be found in multiverse theories. For example, the value of Q (primordial fluctuation) observed in our universe is inconsistent with the principle of living dangerously based on general multiverse theories (i.e., the Q-catastrophe) (Barnes, 2012). Gil and Alfonseca (2014) perform a computer simulation and discover that the physical

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laws of our universe should show a certain time dependence if we follow the most general type of multiverse theories. However, this is not true for our cosmological theories and principles. Therefore, these findings at least show some external inconsistency with the current accepted principles for multiverse theories. Moreover, multiverse theories may also have internal inconsistency. Due to no widely accepted empirical content, there can be various versions and different levels of multiverse theories. Different versions or levels of multiverses could be inconsistent with the others. For example, for the most general type of multiverse, Don Page says that "different mathematical structures can be contradictory, and contradictory ones cannot co-exist. For example, one structure could assert that spacetime exists somewhere and another that it does not exist at all" (Page, 2007, 424). Therefore, multiverse theories are still problematic in their internal and external consistency.

The broad scope of a theory means that it should be able to extend far beyond the current formalism. As mentioned above, there is no widely accepted empirical content for the multiverse theories. The number of universes is uncertain. Whether the fundamental constants in different universes are different is also unknown. We also do not know how a multiverse would be generated. Therefore, we do not know what we could extend from the current formalism. We cannot extrapolate a theory based on its unknown or vague properties.

Popper believes that a simpler theory should be more falsifiable (Popper, 1959, 140). However, if we do not connect simplicity with falsifiability, there are some other ways to define simplicity. Sober (1975) suggests that a simple theory requires less additional information to be able to answer the questions. If we follow Sober's suggestion, we need to know what questions we are answering for the multiverse theories. Most of the advocates of a multiverse (e.g., Stephen Hawking) believe that a multiverse can explain the fine-tuning phenomena of our universe and why we are living. If there are many universes and each has a particular set of fundamental constants, it would be more likely to have a universe (e.g., our universe) that has anthropic fundamental constants. Therefore, a multiverse could be a simple idea that can address the problem of fine-tuning. Based on this idea, we need a tremendous number of universes so that there would be at least one anthropic universe. However, we do not know theoretically how many universes we need or the critical number of universes needed. We also do not know whether different universes would have different fundamental constants. Therefore, much additional information is needed. In fact, as Johansson and Matsubara (2011) argue, assuming the real existence of a multiverse reduces the explanatory value because now we have more assumptions in explanans. The general idea of a multiverse might be simple, but the available multiverse theories required to address the fine-tuning problem are far from simple.

The fruitfulness of a theory refers to its fecundity, which means that the theory can give rise to new research findings. Generally, multiverse theories are related to string theory and the chaotic inflation theory. Therefore, working on multiverse theories might possibly benefit the research on string theory and the chaotic inflation theory. However, both string theory and the chaotic inflation theory also suffer from the problem of testability. To date, no new testable predictions have been made for string theory (Johansson and Matsubara, 2011). For the chaotic inflation theory, although it is extrapolated from known and tested

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physics, that extrapolation is unverified and indeed unverifiable (Carr and Ellis, 2008). Therefore, the potential benefits from multiverse theories are purely theoretical but difficult to verify. This suggests that the fruitfulness of multiverse theories is very limited.

In short, even if we allow the epistemic shift from falsifiability to either of the other four criteria, multiverse theories fail to pass the tests and are difficult to justify as good scientific theories.

3.2 Epistemological anarchism

In addition to the theoretical virtues discussed above, we also consider the epistemological anarchism proposed by Feyerabend as the possible target of an epistemic shift. Feyerabend suggests that “[s]cience is an essentially anarchic enterprise: theoretical anarchism is more humanitarian and more likely to encourage progress than its law-and-order alternatives” (Feyerabend, 1988, 9). He emphasises progress rather than following a fixed set of rules. Based on the history of science, he suggests that “[t]he demand to admit only those theories which are consistent with the available and accepted facts […] leaves us without any theory” (Feyerabend, 1988, 51). Hence, we have to tolerate any anomalies arising from the theories proposed. These anomalies might be reconciled in the future.

If we follow this line of argument, do we need to tolerate multiverse theories even if they cannot be falsified now? It is logically possible that some future evidence might be able to support some specific models of multiverse theories. For example, it has been suggested that the void existing in front of the cosmic microwave background cold spot in our universe could be explained by some possible scenarios of multiverse theories (Vaas, 2010). Nevertheless, Feyerabend thinks that we should not merely tolerate the anomalies or contradiction but also ‘seek it out’ (Feyerabend, 1988, 54). We need to criticise the anomalies and find a way to escape from the anomalies based on the theories proposed. According to Feyerabend, the major goal of introducing theories is to facilitate scientific advancement, and the key to scientific advancement is to multiply interpretations by introducing new theories (Staley, 2014, 96). Therefore, the ultimate goal of following epistemological anarchism is to achieve scientific advancement.

To a certain extent, multiverse theories can provide a new interpretation or explanation to answer a few problems in cosmology, such as the fine-tuning problem and the small value of the cosmological constant. However, it is doubtful that multiverse theories can make any real scientific advancement. In some versions of multiverse theories, they suggest that all that can happen happens. In other words, these versions can explain everything. If a theory can explain everything, it does not lead to any scientific advancement. Johansson and Matsubara (2011) suggest “a multiverse, consisting of an enormous set of universes, each characterised by a unique combination of values of those constants […] fits rather well with Lakatos’ description of a degenerative phase in which empirical findings drive the theoretical development, although in this case the empirical results were known in advance”. For many other general types of multiverse theories, there is too little or even no empirical content that can facilitate any real scientific advancement. Therefore, it seems that multiverse theories are passively driven by empirical findings or theoretical constructions rather than actively leading to any new scientific advancement.

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4. Nonempirical theory assessment

Recently, Dawid (2013) argues that a considerable degree of trust in an empirically unconfirmed theory could be generated based on 'nonempirical theory confirmation'. His account of nonempirical theory assessment is to complement traditional theory assessments and support string theory as a good scientific theory. If a theory does not have any empirical support, nonempirical theory assessment can be used as an assessment tool to evaluate the degree of confirmation of that theory. He has proposed three nonempirical evidences for the assessment (Dawid, 2013): 1. No alternative argument (NAA); 2. Unexpected explanatory coherence argument (UEA); and 3. Meta-inductive argument (MIA).

The NAA argues that if scientists have problems finding alternatives for a considerable time, it must be because there are few alternatives available to find. Therefore, we can gain confidence in the solution already in hand (Dawid, 2019, 114). The UEA argues that if a theory was developed to solve a specific problem, but it also provides explanations with respect to a range of problems whose solution was not the initial aim of developing the theory, we can gain confidence in the theory developed (Dawid, 2019, 114). The MIA argues that if a theory in the research field that satisfies a given set of conditions has shown a tendency to be viable in the past, we can gain confidence in the theory (Dawid, 2019, 114). These arguments can provide an assessment to justify a good nonempirical scientific theory.

Dawid's nonempirical theory assessment has been criticised by many philosophers. For example, Chall (2018) argues that the three nonempirical arguments suggested by Dawid are all problematic. In particular, he argues that the MIA is idle because its role in underwriting the future predictive success of a theory is subsumed by the normal accounting of its predecessor's predictions in theory growth (Chall, 2018). Moreover, Rovelli (2019, 121) argues that "[t]he very existence of reliable theories is what makes science valuable to society. Losing this from sight is not understanding why science matters". Therefore, "nonempirical evidence is emphatically insufficient to increase the confidence of a theory to the point where we can consider it established – that is, to move it from 'maybe' to 'reliable'" (Rovelli, 2019, 121-122). Although the validity of the nonempirical theory assessment is controversial, we still apply these arguments to see whether multiverse theories can satisfy the nonempirical assessment.

4.1 No alternatives argument (NAA)

One of the major goals for introducing the idea of a multiverse is to account for the fine-tuning phenomena in our universe. As discussed in Section 2.3, Carroll states that we have no choice other than a multiverse to solve the problem (Carroll, 2019, 311). Although Carroll does not mean that multiverse is the only alternative for the fine-tuning phenomena, it seems that we lack any alternatives currently and that the NAA can be used to support multiverse theories. However, this claim has jumped too fast to arrive at the conclusion. In fact, some constants in our universe can be explained by theories without a multiverse. For example, why our universe is so flat has been a mystery for a long time. This is known as the flatness problem in cosmology. The flatness of our universe is governed by the total energy density. Surprisingly, the total energy density of our universe is almost exactly equal to the critical density for a flat universe. Later, the theory of inflation can satisfactorily explain the fine-tuning of the total energy density. Although cosmological inflation has yet to be confirmed, many cosmologists currently support this proposal, and this theory can now be seen in many standard textbooks. Moreover, the latest measurement of W boson indicates that the Standard Model in particle physics is not complete (CDF Collaboration, 2022). Additionally, we have no idea what constitutes dark matter and dark energy. We know very little about particle physics, which is one of the keys to understanding the fine-tuning phenomena. Therefore, it is too fast for us to conclude that no alternatives other than multiverse theories are available for the fine-tuning problem. Additionally, the empirical content is too small for us to judge whether multiverse theories can satisfactorily account for the fine-tuning problem (e.g., the required number of universes).

4.2 Unexpected explanatory coherence argument (UEA)

The scientific idea of a multiverse is mainly initiated and derived from cosmological fine-tuning and the landscape version of string theory. Generally, multiverse theories have no impact on string theory or other theories. Nevertheless, multiverse theories may have some implications for the origin of our universe. For instance, Aguirre (2006) suggests that multiverse theories can provide a seed of universe generation. This can avoid the singularity problem of our universe described by the Borde-Guth-Vilenkin (BGV) theorem (Borde, Guth and Vilenkin, 2003). Therefore, it seems that multiverse theories can unexpectedly provide a solution to another cosmological problem.

Note that when a theory provides a solution to another problem, it may also simultaneously create additional challenges or difficulties in other areas. If we accept that there is a 'multiverse generator', we must assume that such generation must be infinitely long in time. Otherwise, it would have a beginning and cannot escape from the space-time singularity problem. However, this would imply that there may be infinitely many objects in the multiverse (Kragh, 2014), which might create some philosophical problems (Chan, 2019b). We also need to address the philosophical or metaphysical nature of the absolute origin of the 'multiverse generator' (Kragh, 2014). These problems can outweigh the positive impact of the multiverse theories so that the UEA becomes a negative support overall. Moreover, since there is no empirical content of the universe generation (e.g., rate of generation), it is difficult to use the UEA to support multiverse theories even if we do not consider the negative impact.

4.3 Meta-inductive argument (MIA)

As mentioned above, multiverse theories are generally related to string theory and the chaotic inflation theory. We can gain some confidence in multiverse theories if there is any success in string theory or the chaotic inflation theory. However, as discussed in Section 3.1, string theory and the chaotic inflation theory also suffer from the problem of testability.

Moreover, one of the major supporting framework of string theory, supersymmetry theory, is disfavoured by collider experiments (Autermann, 2016). Although the experimental results do not support supersymmetry theory only (i.e. the results have no direct implications for string theory), this yields a negative impact for string theory. Therefore, the MIA does not help with multiverse theories.

In summary, even if Dawid's nonempirical assessment is valid, the three arguments involved do not help multiverse theories gain credence. This calls the scientific nature of multiverse theories into question.

5. Conclusion

Sean Carroll has presented three different arguments to stress that "multiverse theories are utterly conventionally scientific, even if evaluating them can be difficult in practice" (Carroll, 2018, 1). Based on the above discussion, it seems that none of the arguments can satisfactorily show that multiverse theories are conventionally scientific. Here, I do not intend to prove that multiverse theories are entirely unscientific. I only intend to point out that the arguments made by Sean Carroll do not justify that multiverse theories are conventionally scientific.

Whether multiverse theories are scientific is controversial. It is true that multiverse theories involve and rely on some scientific tools, such as mathematical formulations, geometry, and physical concepts. In addition, as mentioned by Sean Carroll, some specific models of a multiverse are indeed falsifiable by indirect observations (Carroll, 2019, 305). Additionally, even if multiverse theories are not testable now, they may become testable in the future. However, the current empirical content for multiverse theories is too little, and it is not quite possible for us to observe or verify the existence of a multiverse directly. It is also very difficult or nearly impossible for us to verify or falsify multiverse theories by conventional scientific methods (e.g., experiments and direct detections). Note that observing an entity directly is not the crucial factor for falsifiability. For example, we cannot observe black holes or dark matter directly via electromagnetic waves. Nevertheless, there are various techniques or experimental methods to confirm or disconfirm black holes or dark matter (e.g., direct detection experiments of dark matter search and X-ray emission around black holes). For multiverse theories, we do not have such detection techniques because it is not certain whether different universes within a multiverse could interact with each other. Therefore, it is highly dubious to either confirm or disconfirm multiverse theories at a certain confidence level (e.g., the 5-sigma confirmation is a general consensus in the scientific community). Multiverse theories are highly model dependent, so the systematic uncertainties are too large to reach any possible conclusion.

In fact, for a scientific theory, it is by far not enough to be falsifiable. However, in assessing the scientific nature of multiverse theories, most of the scientists are focussing pretty much on the falsifiability criterion. Apart from falsifiability, I evaluate multiverse theories particularly by considering a possible epistemic shift of virtue from falsifiability to other theoretical virtues or epistemological anarchism, suggested by some philosophers. They have been considered as good criteria for assessing the scientific nature of a non-empirical theory. However, based on my arguments, none of them can satisfactorily show that multiverse theories contain an important scientific nature. Finally, I show that multiverse theories cannot pass the nonempirical theory assessment suggested by Dawid. Therefore, these arguments significantly challenge the standard scientific nature of multiverse theories.

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