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EMPIRICALLY EQUIVALENT THEORIES AND THEORY CHOICE

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Abstract

Empirical equivalence is necessary for the evolution of science. However, the problem of the underdetermination of scientific theory by data has plagued scientific realism at least since its inception by the French philosopher Pierre Duhem in his 1906 *Aim and Structure of Physical Theory*. Allegedly, empirically equivalent theories lead to underdetermination. Contrastive underdetermination holds that, for any theory we can construct, there will be another of equal explanatory power that can account for the any given body of data. All forms, however, conclude that scientists have no rational way of deciding between two or more competing theories. There are many schools of thought that seek to undermine scientific realism, although a close look at the problem of empirical equivalence might reveal that the onus is on them.

C.S. Peirce argued for an intersubjective truth predicate. We can choose between two or more competing theories given sufficient time, and the convergence of the opinions of scientific investigators. If we see the progress of science abductively, we also minimize problems with correspondence and theory choice. Non-empirical virtues allow for an inference to the best explanation. In turn, empirical equivalence, rather than a problem, is descriptively a cornerstone of scientific discovery on this view. Although there are objections to transient (temporal) solutions, the additional non-empirical virtue of the research community rendering intersubjective verisimilitude should be considered and has been in the philosophical literature for years.

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Introduction

Time itself bears with it the dissolution of many problems. Abduction is a form of logic that utilizes an inference to the best explanation to discern which is the best out of a set of empirically equivalent theories. Philosophers often associate classifications of scientific methodology with grand, macrocosmic "isms" of some sort (e.g., "structural empiricism", "instrumentalism", "verificationism"). Realist views have suffered attacks in various forms. In our post-Kuhnian era, seemingly most philosophers do not plainly state that they consider our best running scientific theories to be literally true representations of reality in a strict correspondence sense. The great Scottish philosopher David Hume in his *A Treatise of Human Nature* written 1739-40 argued we could have little if any knowledge beyond the senses, which, in themselves, could be doubted.

Later, Sir Karl Popper urged that there ought to be a requirement that scientific theories pass new and severe tests, otherwise they should not be considered scientific.[1] But, relatedly, we might ask, what exactly are scientific theories and what are they meant to describe? Historically, W.V.O. Quine is perhaps one of the most widely respected philosophers who has ever written on these particular subjects. He writes:

> Part of our concern here has been with the question what a theory's commitments to objects consist in (§ 49), and of course this second-order question is about words. But what is noteworthy is that we have talked more of words than of objects even when most concerned to decide what there really is: what objects to admit on our own account. This would not have happened if and insofar as we had lingered over the question whether in particular there are wombats, or whether there are unicorns. Discourse about non-linguistic objects would have been an excellent medium in which to debate those issues. But when the debate shifts to whether there are

[1] Karl Popper, *Conjectures and Refutations*. (London: Routledge, 1963).

> points, -270- miles, numbers, attributes, propositions, facts, or classes, it takes on an in some sense philosophical cast, and straightway we find ourselves talking of words almost to the exclusion of the non-linguistic objects under debate. Carnap has long held that the questions of philosophy, when real at all, are questions of language; and the present observation would seem to illustrate his point. He holds that the philosophical questions of what there is are questions of how we may most conveniently fashion our "linguistic framework," and not, as in the case of the wombat or unicorn, questions about extralinguistic reality. He holds that those philosophical questions are only apparently about sorts of objects, and are really pragmatic questions of language policy.[2]

Quine's description directs our attention towards semantic considerations as well as concrete concerns with description, reality and their relationship. Aristotle is attributed with the project of attempting to codify the entirety of the observable world into kinds, laws, and forces. Shortly after the renaissance (roughly14th-17th C.E.) in Europe,[3] the enlightenment period brought with it the further development of the Western hemisphere's intellect with the burgeoning new sciences. Hume, following a lineage dating back to the ancient pre-Socratics, noted during the enlightenment that one cannot get past the senses in order to posit the existence of a substratum.[4] Of course, with this view, one must look upon posited unseen laws, forces, and objects with scepticism. We, even as seasoned scientific investigators, cannot *know*. The Aristotelian dream of knowing all there is to know about the world now seemed to be in jeopardy.

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[2] W,V.O. Quine, *Word and Object* (USA: MIT Press, 1960), 291.

[3] Although he couches it differently, Karl Popper further contextualizes this nicely: The great movement of liberation which started in the Renaissance and led through the many [. . .] free societies in which the English-speaking peoples are privileged to live, this movement was inspired throughout by an unparalleled epistemological optimism: by a most optimistic view of man's power to discern truth and to acquire knowledge. *Conjectures and Refutations* (London: Routledge, 1963).

[4] "That there is nothing in any object, consider'd in itself, which can afford us a reason for drawing a conclusion beyond it; and, that even after the observation of the frequent or constant conjunction of objects, we have no reason to draw any inference concerning any inference concerning aby inference beyond those of which we have had experience." Hume's *A Treatise of Human Nature* Selby-Bigge (e.d.) (Oxford: Clarendon Press, 1888), 152.

Following in this vein is underdetermination, the view that scientific investigators will never have enough data to prove their theories to be ultimately true (*certain* in a strict deductive sense). An inference to the best explanation can assuage one aspect of the problem of under-determination, that of empirical equivalence. This form of logical inference moves from many "conclusions" toward the single most corroborated one endorsed by active researchers in the field, and is in fact a part of the internal logic of the progress of science. In contemporary non-correspondence speak, the best theory that has warranted assertibility is the one that wins out among competitors and is the educated opinion that has the most verisimilitude, and vice versa. The scope of this thesis will be to show that the logical method of abduction, and the non-empirical values of time indexicality, and research community, are key factors that can dissolve the problem of empirical equivalence of competing theories and the purportedly related problems of underdetermination of theories by data that may ensue.

Before embarking on our Peircean solution to these problems in the philosophy of science, we will look closely at the different forms of underdetermination anti-realists commonly employ. Contrastive underdetermination has recently been the most openly debated. According to it, theories have indefinitely many empirically equivalent rivals. The argument continues that we actually do not know out of a set of (possibly infinite) alternatives, which is the correct theory. This will result, the argument runs, in a Humean-style global scepticism, which denies we can have any knowledge of an existing reality apart from our senses at all—if that.

Larry Laudan claimed that all underdetermination is transient, and this is our pivotal move. One of the most contemporary positions on underdetermination fully recognizes the importance of this dimension; forms of contrastive underdetermination point out that at any given time *T*, there is another theory of equal explanatory power that is sufficient to have all the data conform to it. He

furthermore states with Jarrett Leplin that as science progresses more technology arises. This will be used to delineate the running theories into those that pass crucial tests and those that do not. One will succeed in the long run and on the whole over rivals. Time and the convergent intersubjective verisimilitude of learned opinions are important here. According to many philosophers, empirical equivalence is not a problem. Non-empirical virtues will be a deciding factor in theory choice. There seems to be conflicting accounts and these virtues seem hard to formalize and standardize. Two factors I will mention quite often throughout my argument for an abductive view of scientific discovery are the Kuhnian research community and, of course, time itself.

The first step in our argument is to indeed follow Leplin and Laudan in asserting that all cases of underdetermination are cases of transient determination in their assessment of the problem of empirical equivalence. The *Stanford Encyclopedia of Philosophy* astutely tells us that "the phrase was first coined by Larry Sklar (1975, 1981). He has called 'transient' underdetermination, that is, theories which are not empirically equivalent but are equally (or at least reasonably) well confirmed by all the evidence we happen to have in hand at the moment, so long as this transient predicament is also recurrent."[5] Underdetermination ensues on this view. The focus should be what breaks the equivalence. If we agree that all underdetermination is transient and build in a temporal signifier into our abductive view of science, we should have a solid answer to the anti-realist in respect to all three accounts of underdetermination.

[5]Stanford, Kyle, "Underdetermination of Scientific Theory", *The Stanford Encyclopedia of Philosophy* (Winter 2021 Edition), Edward N. Zalta (ed.), (2021). Retrieved from <https://plato.stanford.edu/archives/win2021/entries/scientific-underdetermination/>.

Chapter 1: Materials and Methods

How shall we proceed? Underdetermination of scientific theory supposedly undermines scientific rationality. It can foster global scepticism. However, an enquirer new to the philosophy of science might ask exactly what all this means. In order to explain something in sufficient detail, we need the raw materials in order to cover it in some depth. Were this a *bona fide* scientific experiment itself, the material would consist of the entire history of science, and the method would be a socio-historical one akin to those used by Feyerabend, Lakatos, or Kuhn (dubbed "historicist"), with a later commentary on the logical method of abduction as descriptive of science in the same vein as Popper's hypothetico-deductivist (H-D) account. What we will gain from this is a topological view of the subject before delving more deeply into it.

We will mirror the sociologists of scientific knowledge, without engaging in the normative implications. Philosophers of the history of science such as Kuhn or Feyerabend are highly critical of the privileged epistemological place for science it has hitherto enjoyed. The impact of the views of these sociologists of science have been tremendous, the 1962 *Structure of Scientific Revolutions* earning a glowing forward by Ian Hacking.[6] However, like Popper and Carnap, we will take a more optimistic view of the aims and objectives of science. Imre Lakatos actually summarizes the first half of our endeavor when he writes: "the history of science has been and should be a history of competing research programmes (or, if you wish 'paradigms'), but it has not been and must not

[6] Ian Hacking, "Introductory Essay," in *The Structure of Scientific Revolutions,* 4th ed. (Chicago: University of Chicago Press, 2012), vii-xivi.

become a succession of periods of normal science."[7] The sooner competition starts, the better it is for scientific progress in the physical sciences as a whole. Theoretical pluralism is better than 'theoretical monism'."[8] Culling the entire history of science for items such as research programmes and/or paradigms shifts (even under different names, loosely) has been the mainstay of many philosophers of science since the discipline's beginning. That there are instances wherein science has been undermined since the inception of the history and philosophy of science has been pointed out often in the literature.[9]

Pierre Duhem noticed the recurrent phenomenon known later as holistic underdetermination as early as 1906 in his *Aim and Structure of physical theory.* Antedating the Copernican revolution, and now furthering into string theory, we have had philosophers delving into the depths of not only the logic of discovery, but also the possible socio-historical forces that could impact theory choice. There are still realists safeguarding the view that scientific terms refer to unobservable objects. The debate about realism contextualizes empirical equivalence and provides an excellent chance to see both historicism and contrastive underdetermination as far as argumentation. We will see more in terms of anti-realism in connection with empirical equivalence, and how it plays out in the current literature.

Hilary Putnam, Stathis Psillos, Leplin, J.J.C. Smart, and Peter Lipton are noteworthy names when it comes to the various voices that have spoken in favor of realism. Putnam points out that without the thesis of realism, the success of science would be a miracle.[10] Kuhn, Lakatos, and Paul

[7] Lakatos quoted in Shelby Hunt, *Reason, Truth and Objectivity* (London: M.E. Sharpe, 2003), 153.
[8] Imre Lakatos, *The Methodology of Scientific Research Programs* (New York: Cambridge University Press, 1989), 75.
[9] Although the pessimistic meta-induction was articulated more recently by Larry Laudan. See "A Confutation of Convergent Realism," *Philosophy of Science*, Vol. 48, No. 1 (1980): 19-49.
[10] Hilary Putnam, "What is Mathematical Truth?" *Mathematics, Matter and Method* (New York: Cambridge University Press, 1975), 60-78.

Feyerabend, are in opposition to this view and were excellent historicists, but they were spearheading a movement which had political aims. Feyerabend was completely disdainful of how rugged science was with older religious and cultural institutions.[11] Throughout the history of the Western hemisphere, and since its inception, science has enjoyed a privileged epistemic status (I daresay "epistemic superiority" over other belief systems).[12] With Duhem's *Aim and Structure*, and perhaps dating back to Hume's treatise, it has been shown that one can rationally withhold voluntary epistemic consent. In addition, it is important to note, especially when discussing Quine's view, this particular debate also involves different conceptions of truth, e.g., coherence, pragmatic, and correspondence.

1.1 The Historicist Approach

Some impressive names that have changed the intellectual temperament of the Western mind are associated with the history of science: Copernicus, Tycho Brahe, Kepler and Galileo, Euclid, Aristarchus, Archimedes, Copernicus, Kepler, Galileo, Descartes, Newton, Maxwell, and Einstein. When one delves into this topic, one notices recurring counterinstances to established physical theories, anomalies. The most astute observers of this historical phenomenon would be the sociologists of scientific knowledge. They are also known to have contextualized scientific discoveries in their respective ages. They would note, for example, that it would be nearly

[11] Feyerabend's most notable work is *Against Method* (London: New Left Books, 1975). In it, he writes: "the point of view underlying this book is not the result of a well-planned train of thought but of arguments prompted by accidental encounters. anger at the wanton destruction of cultural achievements from which some intellectuals interfere with the lives of people, and contempt for the treachy phrases they use to embellish their misdeeds was still the motive force behind my work." 252.

[12] Although Laudan points out there have been counterexamples even though a theory may have enjoyed epistemic success. See "A Confutation of Convergent Realism," *Philosophy of Science* Vol .41, No.1 (Chicago: The University of Chicago Press, 1981), 19-49.

impossible to have the Heisenberg uncertainty principle floating around somewhere in a vacuum during the age of Newtonian physics, for example. This contextualization allowed them to perform more of a culturally informed in-depth analysis. The phlogiston theory of combustion, given the extent of knowledge at the time, may not have seemed as absurd to us as it does today, with our contemporary knowledge of chemistry. It has been a project of many philosophers of science to develop some sort of an evolutionary guide to explain how science developed. Many in contrast to the normatively slanted stance of the sociologists of scientific knowledge, prefer a straight-ahead methodological account, e.g. Popper's hypothetic-deductive (H-D), or Karl Hempel's inductive-statistical (I-S) model as descriptive of the movements of science. Lakatos writes:

> Some historians look for the discovery of hard facts, inductive generalizations, others for bold theories and crucial negative experiments, yet others for great simplifications, or for progressive and degenerating problem shifts; all of them have some theoretical 'bias '. This bias, of course, may be obscured by an eclectic variation of theories or by theoretical confusion: but neither eclecticism nor confusion amounts to an atheoretical outlook.[13]

Since we will be using his terminology, it may be most expedient to focus on Thomas Kuhn as the major figurehead in the sociology of scientific knowledge movement (SSK). The part of philosophy of science which I would like to consider would be his theory of scientific discovery as set out in his *The Structure of Scientific Revolutions*. His view is that science develops through periods of normal science which are characterized by the dominance of a paradigm. These are turn interrupted by occasional revolutions during which the old paradigm is replaced by a new one.

[13] Imre Lakatos, *The Methodology of Research Programmes* (New York: Cambridge, University Pres, 1973), 120.

Kuhn gives three main examples of scientific revolutions. These are the Copernican Revolution, the Chemical Revolution, and the Einsteinian Revolution. His notion of normal versus revolutionary science shows how two equivalent theories comes into play.[14] He also pointed out prescience, which was a concentration of opinions rather than things, while in stark contrast revolutionary science happened during a paradigm shift. We will find later that verisimilitude and empirical equivalence seem both to undermine the sociologist's sceptical aims. What is important is that realism and historical methods are both highlighted here.

It might be asked why these concerns are important to a discussion of empirical equivalence at all. The answer is twofold: historical methods are rampant within the philosophy of science, and they boldly illustrate the importance of the research community. Pointing out changes within a branch of science draws our attention to how scientists adopt new theories. The change from Newtonian physics to the general theory of relativity is a paradigm change according Kuhn's view, and this is the state of affairs is that is to be differentiated from "normal science". He writes, and this will be important to our assessment of Leplin and Laudan's view, that normal science extends "those facts which the paradigm displays as particularly revealing, by increasing the extent of the match between the facts and the paradigms predictions, and be further articulation of the paradigm itself."[15] Paradigm shifts happen from within physics and this demonstrates the abductive structure of the historical movement of science, on our view. When an equivalence arises, one theory wins out. According to Karl Popper's logic of scientific discovery, equivalence means plausible rivals in the running have not yet been sufficiently falsified in favor of a superior theory; on Quine's virtue-based account of theory change, the reigning theory must possess desirable non-empirical

[14]See Thomas Kuhn, *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press, 2012).
[15] *Ibid*., 24.

virtues in order for it to be considered a rational choice.[16] Rivals cannot be completely epistemically disregarded otherwise.[17]

Other historical instances of theory choice such the displacement of the phlogiston theory of combustion by the oxygen theory which paved the way for modern chemistry show without a doubt that there may be empirically equivalent theories running at the same time. C.S. Peirce argued that this was the case.

> Consider the multitude of theories that might have been suggested. A physicist comes across some new phenomenon in his laboratory. How does he know but/that/ conjunction of the planets have something with the time of year ago chanced to pronounce some word of mystical power, or hypotheses might be made of which one only is true; and yet after two or three or at the very most a dozen guesses, the physicist hits pretty nearly on the correct hypothesis.[18]

According to Peirce, we do not know out of a set of empirically equivalent theories which is ultimately true in a strict deductive or correspondence sense, although we can know upon which educated opinion scientific researchers converge upon at time t_2. After more testing and investigation, the research community may choose another opinion, at time t_3.[19] This is the view I shall champion. Imagine, if you will, that there is a body of observable data or "instances of a phenomenon" if you like, and the researchers' findings in the lab. Out of the set of all the possible theories to account for the data $\{a,b,c. . . z\}$ one researcher hits upon the correct theory, i, say.

[16] W.V.O. Quine, "Two Dogmas of Empiricism" in *From a Logical Point of View.* Cambridge: Harvard University Press, 1980.

[17] André Kukla, "Does Every Theory Have Empirically Equivalent Rivals?" *Erkenntnis*, Vol. 44, No. 2, (1996): 155.

[18] C.S. Peirce, "The Nature of Meaning" *The Essential Peirce, Volume 2.* (Indianapolis: Indiana University Press, 1998, 217.

[19] Karl Popper wrote the truth-content but not the falsity-content of t_2 exceeds that of t_1, b. the falsity-content of t_1, but not its truth-content, exceeds that of t_2. In *Conjectures and Refutations*. (London: Routledge, 1963), 229.

Others working in the field corroborate those results, and also conclude i is the best theory to account for the given body of data. The epistemic rivals are then to be disregarded. Popper points out that at this stage, *h*, the previous running theory in the set, was displaced by i.[20] There is a phasing in of the new theory as it is adopted by the greater community. There will be more tests and experiments conducted. In the case of the oxygen theory, phlogiston did not last after Lavosier discovered the previously obscure oxygen hypothesis, which was passed down. He began testing it. In addition, there were anomalies associated with the alchemical theory preceding it. As a result of this we have modern chemistry.

Cases of underdetermination are as antagonistic toward scientific realism as the sociology of scientific knowledge movement. If anti-realists can undermine theories with cases of under-determination, allegedly the problem that occurs here is global skepticism. Those interested in preserving the aims, objectives, and values of scientific inquiry may find this thesis philosophically interesting. The general idea was that science had a privileged epistemic status. Sociologists of scientific knowledge cast doubt on science breaking out of the situation of being a socially constrained activity.

1.2 Realism

What actually is at stake here in these discussions? One very expedient and easy answer would be realism itself, or our common sense understanding of the world (science often seen as an extension of common sense). There are four varieties: direct, naïve, scientific, and structural.

[20] Popper argues for a Darwinist account of theory choice in his *Conjectures and Refutations*: *The Growth of Scientific Knowledge* (London: Routledge, 1963).

Realism (at least "naïve realism") preserves more of our mundane, lay ideas about science—that it is exacting, it refers to entities we can't see with the naked eye, it is objective. Scientific realism has been the straw man for arguments of underdetermination, typically. It might be pertinent to get more of a clear idea of what the idea entails, before diving headfirst into the argument.

The realist view stereotypically holds that non-empirical entities of a theory correctly correspond to features of the world, so that beliefs from the theory's unobservables motivated by the content of the theory get justified by its empirical success. "In short, the realist states that theories are empirically successful because they are (partially, approximately) true, and that the terms in empirically successful theories that denote unobservable entities have an objective reference in the world."[21] Philosophers are quick to delineate between observational, instrumental, and predictive success of theories. Confirmation of scientific theories is also an important concept in that it requires new information in order to verify that the theory has this desirable, coherent relationship.

There are debates as to the ontological and epistemic status of non-observable entities postulated by scientific theories (especially in physics), although the idea is that since the observable phenomena behave in certain ways, researchers can postulate the existence of forces and laws of nature at work. In some way, realists maintain, very generally speaking these items refer to reality in some correspondent sense. To say dark matter exists near Alpha Centari at time t_2 means that indeed there is dark matter near Alpha Centari at time t_2.[22] Psillos breaks scientific

[21] Pablo Acuna, "Charting the Landscape of Interpretation, Theory Rivalry, and Underdetermination in Quantum Mechanics," *Synthese* 198, (2021): 1733.

[22] What I seek here is merely a putatively agreeable riff on the Tarskian schema-T version is truth. A full-blown discussion on truth theory is beyond the scope of this thesis.

realism down a little more precisely into three types. The overall gist of what he intends to convey is apparent:

> The metaphysical stance asserts that the world has a definite and mind independent structure . . . The sematic stance takes scientific theories at face-value, seeing them as truth-conditioned descriptions of their intended domain, both observable and indescribable. Hence, they are capable of being true or false. Theoretical assertions are not reducible to claims about the behavior of observables, nor are they merely instrumental devices for establishing connections between observables. The theoretical terms figuring into the theories have putative factual reference. So, if scientific theories are true, unobservable entities they posit populate the world . . . The epistemic stance regards matures and successfully scientific theories as well-confirmed and approximately true of the world. So, the entities posited by them, or at any rate, entities very similar to those pointed, do inhabit the world.[23]

This account is often cited, and we see how it dovetails nicely with some of the general assertions we made about our lay understanding of science as well. Psillos is just one strong voice in favor of realism, Peter Lipton and Hilary Putnam are others that come to mind as far as noteworthy proponents of scientific realism. The sociology of scientific knowledge only used socio-historical and ethical views to call into question the objective nature of science.[24] In addition to this, anti-realists contend with the notion that the history of science furnishes the realist with a huge point in its favor,—science works! Although it has its critics, the no-miracles argument stands as a challenge to anti-realists. Putnam writes:

[23]Stathis Psillos, *Scientific Realism: How Science Tracks Truth* (London: Routledge, 1999), 18.
[24]E.g. Paul Feyerabend, *Against Method* (London: New Left Books, 1975).

> The positive argument for realism is that it is the only philosophy that does not make the success of a theory a miracle. That terms in mature science typically refer . . . is that the theories accepted in mature science are typically approximately true that the same terms can refer to the same things even when it occurs in different theories-these statements are viewed by the scientific realist not as necessary truths but as part of the only scientific explanation of the success of science and hence as part of any adequate scientific description of science and its relation to its objects."[25]

Putnam flip-flopped when it came to his theory of truth. At one time he endorsed a pragmatic realism which was partly reliant on James' theory, and even warranted assertibility was entertained during his career.[26] In "The Meaning of Reference" (1973) and "The Meaning of Meaning" (1975) he launches his Twin Earth argument for scientific realism. After an examination of some possible alternatives to a more correspondence-type view he comes to the conclusion that "meaning just ain't in the head".[27] It is important to note that most scientific realists are also committed to the premise that mature scientific theories allow us to predict and control our environment. If the theories were not at least approximately true, there would be no technological success arising from them. J.J.C. Smart's "cosmic coincidence" adds further context to our understanding of realism:

> If the phenomenalist about theoretical entities is correct, we must believe in a cosmic coincidence. That is, if this is so, statements about electrons, etc., are of only instrumental value: they simply enable us to predict phenomena on the level of galvanometers and cloud chambers. They do nothing to remove the surprising character of the phenomena . . . on the other hand, if we interpret a theory in a realistic way, then we have no need for such a cosmic coincidence: it is not surprising the

[25] See Maria Baghramian, "From Realism back to Realism: Putnam's Long Journey," *Philosophical Topics* Vol. 36, No.1 (2008): 17-35.
[26] *Ibid.*
[27] Putnam, Hilary. "Meaning and Reference" *The Journal of Philosophy.* Vol.17, No.19 (1973): 701- 704.

> galvanometers and cloud chambers behave in the sort of way they do, for if there really are electrons, etc., this is just what we should expect. A lot of surprising facts no longer seem surprising.[28]

The realism/anti-realism debate can be couched in terms of scepticism and undetermination. The logical form of inference known as induction which was originally thought to be used in the creation of general laws from individual observed instances is logically invalid according to the strict demands of deductive logic. Sir Francis Bacon promoted simple enumerative induction as descriptive of science.[29] Multi-valued logics, a deductive solution, statistical inference, and warranted assertibility have all been attempted as more accurate accounts pertaining to scientific discovery. Karl Popper writes:

> Hume, I felt, was perfectly right in pointing out that induction cannot be logically justified. He held that there can be no valid logical arguments allowing us to establish "that I do not think that, if we accept the suggestion that 'in agreement with reality" and "true" are Thus a "good" or "valid" rule of inference is useful because no counterexample can be found.[30]

The problem of induction is a huge topic. From it, Hume concludes the following: ". . .That there is nothing in any object, consider'd in itself, which can afford us a reason for drawing a conclusion beyond it; and, that even after the observation of the frequent or constant conjunction of objects, we have no reason to draw any inference concerning any inference concerning aby inference beyond those of which we have had experience."[31] We will touch more

[28] J.J.C. Smart, *Philosophy and Scientific Realism* (London: Routledge 1963), 30.
[29] Please see Francis Bacon, *Novum Organum* (New York: Collier and Son, 1902).
[30] Karl Popper, *Conjectures and Refutations* (London: Routledge, 1963), 55.
[31] David Hume, *A Treatise of Human Nature*, Selby-Bigge (ed.), (Oxford: Clarendon Press, 1888), 152.

upon the technical niceties of his argument in more detail later, when we go Bacon's original proposed inductive methodology to found science at the outset of the Enlightenment as well. Let us now turn toward an issue brought up by Bas C. van Frassen, and André Kukla.

1.3 Unconceived Alternatives

Unconceived alternatives to a theory were raised against scientific realism with algorithms of equivalence as a form of contrastive underdetermination. According to Richard Boyd, the thesis of underdetermination can be reformulated to it applies across the board, not to individual cases of empirical equivalence. He writes" "the thesis of empirical equivalence can simply be reformulated so that it applies not to individual theories, but to "total sciences" i.e., the conjunction of all our acceptable scientific theories."[32] Empirical equivalence leads to a devastating form of underdetermination. Algorithmic theories can be created from any other which is an issue brought about to argue just these points. There are many objections here. Would they be semantically equivalent, merely observationally equivalent, or instrumentally equivalent? Numerical identity here would be out of the question. T' on some level $\neq$, T yet empirical equivalence obtains. Furthermore:

> A hypothesis. . . is not to be required as probably true because it accounts for all the known phenomena since this is a condition sometimes fulfilled tolerably well by two conflicting

[32] Richard Boyd, "The Current Status of Scientific Realism" in Leplin (ed.), *Scientific Realism* (Berkely: University of California Press), 50.

> hypotheses. . . while there are probably a thousand more which are equally possible but which, for the want of anything analogous in our experience, our minds are unfitted to conceive.[33]

One answer to the concerns about the various nuances contrastive underdetermination can take whilst in van Fraassen's hands would be abduction. Abduction allows more than one theory to co-exist at one time. At one point, Peirce called this method "retroduction"–a completely backward version of deduction; if concomitances, or past conjunctions, in some way, suggest three major possible reasons e.g. for the blood on Jones' shirt, we may begin there. [34] When it comes to theories, the one that wins out "in the long run and the whole" is the one to be adopted.[35] A scientifically plausible unconceived alternative (SPUA) might be conceivable but why does it not need to be *conceived* in order to pose a threat to the reigning theory much less scientific realism as a whole? It really can't even be thought of as in the running. Here, abduction does not seem to have the same problems that other forms of inference might have when it comes to extra-logical factors that may conceived of as hurdles. If the SPUA seems to be out of place or *ad hoc*, it simply shouldn't be adopted. Lipton's general remarks point out that the use of inference to the best explanation offers the user many non-empirical virtues in order to narrow down theory choice.[36]

There are various forms of anti-realism out there which seek to displace any hegemony science may have had epistemically and take stabs at its claim to epistemological supremacy. The realism versus anti-realism debate, which is explicated clearly in Bas C. van Fraassen's *The Scientific Image* (1980), points out crucial differences between empiricism and realism in order to argue the

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[33] Kyle Stanford, "Underdetermination of Scientific Theory" in *The Stanford Encyclopedia of Philosophy* (2021), Retrieved from <https://plato.stanford.edu/archives/win2021/entries/scientific-underdetermination/>.

[34] Bruce Thomson, *Retroduction*, 2019. Retrieved from <https://www2.palomar.edu/users/bthompson/Introduction%20to%20Fallacies.htm/>.

[35] Charles Peirce, "How to Make Our Ideas Clear," in *Popular Science Monthly* 12, (1878): 297.

[36] Peter Lipton, *Inference to the Best Explanation* 2nd ed., (London: Routledge, 2004).

view that our best running theories are only epistemically adequate. Empiricism, when taken to its greatest logical conclusion, seemingly cannot make a privileged claim to truth. Therefore, strictly speaking, we should withhold epistemic consent when it comes to even our best and most rigorously tested scientific theories about the world. "Is science rational?" an interlocutor might ask. Acceptance of a theory only means that it is empirically adequate on Van Fraassen's account in *The Scientific Image*—constructive empiricism as a doctrine holds that the goal of a scientific theory is to give an accurate account only about observable aspects of the world. This view is a nod toward contrastive underdetermination, although it is important to look at all three types. The following argument from Kyle Stanford seems to sound the death-knell for arguments from contrastive underdetermination. He writes:

> Empirical equivalents are no essential part of the case for a significant problem of contrastive underdetermination. Our efforts to confirm scientific theories are no less threatened by what Larry Sklar (1975, 1981) has called "transient" under-determination, that is, theories which are *not* empirically equivalent but are equally (or at least reasonably) well confirmed by all the evidence we happen to have in hand at the moment.[37]

We will see later on that non-empirical virtues and unconceived alternatives become crucially important when discussing the contemporary problem complex of the issue of empirically equivalent theories. This is pretty much the core of Laudan, Leplin, and Kukla's debate. Unconceived alternatives lead us into underdetermination, and the anti-realist argument continues that this state of affairs will bring us into global scepticism. We have no rational way to choose

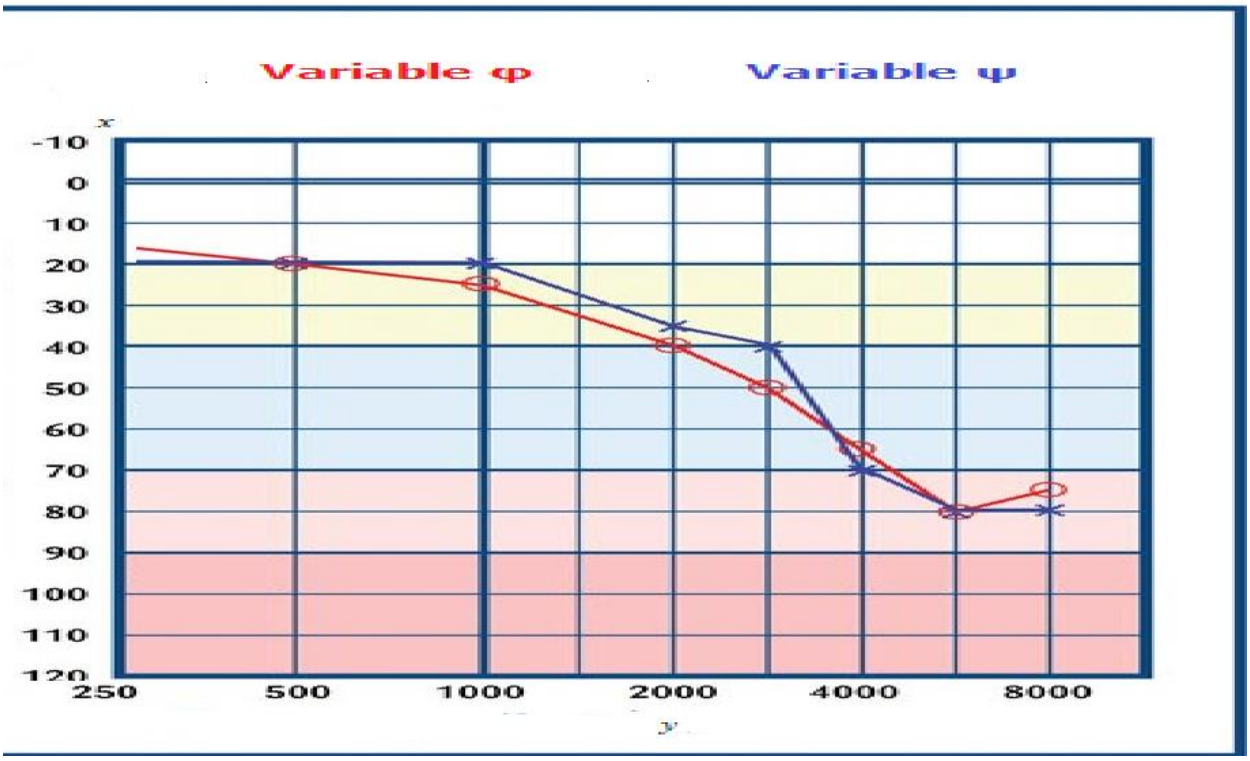
[37]Stanford, Kyle, "Underdetermination of Scientific Theory," *The Stanford Encyclopedia of Philosophy* , (2021) Edward N. Zalta (ed.). Retrieved from <https://plato.stanford.edu/archives/win2021/entries/scientific-underdetermination/>.

theories. Peirce did not see the coexistence of equivalent theories to have any negative bearing on the epistemic status of science. Pedro Acuña has continued this line and offered a suggestion that empirical equivalence is not a problem.[38] Larry Laudan and Jarrett Leplin argue that all forms of underdetermination are transient. Theirs is an important shift toward inference to the best explanation as playing a role in our descriptive view of science. Historically, we have seen the problem of underdeterminism as described by Duhem turn into an issue of empirical equivalence and non-empirical virtues.

Chapter 2: Tables and Graphs

The more technical aspects of underdetermination are fascinating. Empirical equivalence is thoroughly contextualized within the philosophy of science like a knot. The issue of empirically equivalent theories exists within layers and sub-problems. Tables, graphs and illustrations have always aided in every discipline. The philosophy of science is no different. Historically, the Duhem-Quine thesis serves as a defining case of holistic underdeterminism. Fortunately, it is remarkably easy to understand when portrayed visually. We can get more of a handle on how to divide macroscopic problems from the more technical ones closer to the center of our debate. Specifically, underdetermination of theory by evidence involves a pre-existing set of data when it comes to the explication of this thesis. Consider the following graph. The theories, represented by lines, are predictively equivalent where they touch.

[38] Pablo Acuña, *Predictively Equivalent Theories: What's the Problem?* (2021). Retrieved from <https://www.youtube.com/watch?v=WlPPJtH9h-k/>.



The visual representation above illustrates a case of underdetermination according to the Duhem-Quine thesis. We have the following data set, choosing any referent you like for the lines representing variables φ and ψ. The values presented do not represent any factual state affairs, we are merely illustrating a relation between two theories that could obtain given a similar yet inexact body of evidence. At the points where the lines touch, we say they are empirically equivalent. Given that a researcher does not have access to any other information, there might a confusion as to the more accurate theory.

The problem of unconceived alternatives purports to show that there may be many theories at any time for a single data set. Furthermore, some have conjectured that there may be *infinitely* many alternatives that may be suitable explanations for a single case of an observable

phenomenon, and they could be rendered very plausible. Kyle Stanford has argued that historically speaking it is likely that we will always have alternatives.[39]

This brings to mind the pessimistic meta-induction. If phlogiston, for example, remained a reigning champion in terms of a "scientific" account whilst there were more accurate accounts of combustion out there, we could hardly trust our most popular theories. Why should we consent to the alleged epistemic superiority of science at all? We must keep in mind that even Duhem had a concept of *good sense*, when choosing a theory, however.[40] Even with his underdetermin-istic outlook, we now have a decent guide for further discussion and analysis of what good theory choice should and could consist of, i.e., non-empirical virtues to aid in theory choice (by Quine, notably). Clark Glymour writes "comments such as these pave the way for discussions on non-empirical virtues used in theory choice. Which ones to adopt, which ones are descriptive, and which prescriptive."[41] We will find this to be the last step toward a new, fully-developed philosophy of science.

[39] Samuel Rumkorff, "Difficulties with the Problem of Unconceived Alternatives," *Philosophy of Science*, Vol.68, No.5 (2011): 876.

[40] See Pierre Duhem, *Aim and Structure of Physical Theory*, (Princeton: Princeton University Press, 1954), 37-39.

[41] Clark Glymour argues that some of the non-empirical virtues we take for granted leave us with the measurement problem in quantum mechanics in his 1970 "Theoretical Realism and Theoretical Equivalence," *PSA Proceedings of the Bicentennial Meeting of the Philosophy of Science Association*, 275-288.

Table 1

Variable φ

x	y
20	500
40	2000
50	3000
80	6000

Table 2

Variable ψ

x	y
20	500
40	3000
80	6000
80	8000

φ ∩ ψ

x	y
20	500
60	3900
80	5000

Table 3

2.1 The Duhem-Quine Thesis

We finally get to the meat of the problem dealing with one of the most notorious mani-festations of the underdetermination of scientific theory by evidence known in the philosophy of science. Above we see three data sets that correspond to graph 1. Duhem pointed out that there are what he calls "auxiliary assumptions" in the background when a scientist chooses a theory.[42] In the case wherein a researcher in the lab tests a theory, he does not just test the single hypothesis intended for verification or falsification, he tests a whole bundle of background assumptions. The single hypothesis can never be tested in isolation. If the test comes out negative, the scientist does not know what, exactly, in the scientist's web of beliefs, is being falsified.

In a biological experiment involving cells, there are a number of assumptions about the microscope used, for example. As the sociologists of scientific knowledge were quick to point out,

[42] Pierre Duhem, *The Aim and Structure of Physical Theory* (Princeton, New Jersey: Princeton University Press, 1982).

cultural biases may inhabit theory choice as well. If there are cases of underdetermination in conjunction with the processes of choosing between two or more competing theories, it looks to be the case that scientific methodology as we know it can be neither entirely objective nor rational. It simply involves some kind of theory choice, and that is all that can be said about it, if some of these sentiments are right.

Holistic underdetermination, unlike other forms of underdetermination, directly challenges potential grand overarching schemes of belief that scientists might personally bring to the table when making theory choices. In this respect, these concerns are not unlike the SSK's. Pablo Acuña writes:

> The Duhem-Quine thesis implies that it is always logically possible to save H by arranging the set of auxiliary assumptions A and replacing it by A', so that the outcome of the experiment could be accommodated. In that case, we could always have a case of empirical equivalence between H and H'. For any data set there are an infinite number of ways one could describe the relation. underdetermination of theory by evidence. An analysis of this graph reveals that under-determination holds due to the equality of theories at the given data points. They intersect given that the observed consequences of each theory are the same. We may properly call them empirically equivalent.[43]

If we accept holistic underdetermination, it is possible to rearrange the auxiliaries in order for the reigning theory to remain preferred above its rivals despite falsifying evidence. Some argue that the underdetermination thesis and empirical equivalence are incompatible. However, what the

[43]Pablo Acuña and Dennis Deiks, Underdetermination of Theory Choice," *European Journal for the Philosophy of Science* 4, (2014): 13.

Duhem-Quine thesis also seems to suggest is that investigators with their auxiliary assumptions may never rest fully satisfied with one single theory, which may put a pessimistic aura around science itself as a whole. Although we will see that this is not mutually exclusive of evolutionary views of science, some philosophers have had their worries. Henri Poincaré summarizes some of the concerns philosophers have had deftly when he writes:

> The ephemeral nature of scientific theories takes by surprise the man of the world. Their brief period of prosperity ended, he sees them abandoned one after the other; he sees ruins piled upon ruins; he predicts that the theories in fashion today will in a short time succumb in their turn, and he concludes that they are absolutely in vain. This is what he calls the bankruptcy of science.[44]

Holistic underdetermination, the Duhem-Quine thesis, and empirical equivalence can all be historically demonstrated by paradigm shifts made in astronomy, which provides textbook examples. If there are anomalies in the way we think stars should move, (e.g., in a circular fashion, rather than ellipses) then any belief may change in our web of beliefs to keep this idea that the planets move in circular orbits according to Quine's account. Laudan and Leplin point out that competition between Ptolemy and Copernicus, the equivalence between Einstein and H.A. Lorentz, as well as the disjunction between Newtonian and relativity theory all demonstrate the tension between rival theories in this regard.[45] John Earman concurs with this line of thought when he writes: "at least two genuine cosmological theories have serious non-skeptical, and non-

[44] Quoted in Worrall's "Philosophy of Science, Classic Debates, Standard Problems, Future Prospects," Retrieved from John Wiley & Sons, Incorporated, (2002), 31. Retrieved from <http://johnworrall.org/wp-content/uploads/2019/12/2002a-Philosophy-Of-Science-Classic-Debates-Standard-Problems-Future-Prospects.pdf.>.

[45] Larrry Laudan and Jarrett Leplin, "Empirical Equivalence and Underdetermination," *Journal of Philosophy*, Vol.88, No.9 459.

parasitic empirical equivalents [. . .] the first essentially replaces the gravitational field in Newtonian Mechanics with a curvature in spacetime itself, while the second recognizes that Einstein's general theory of relativity permits cosmological models."[46] Quine succinctly put the final nail in the coffin when it came to the thesis of holistic underdetermination in his 1951 "Two Dogmas of Empiricism". He summarizes his own position as follows:

> Any statement can be held true come what may, if we make drastic enough adjustment elsewhere in the system. Even a statement very close to the periphery can be held true in the face of recalcitrant experience by pleading hallucination or by amending certain statements of the kind called logical. Conversely, by the same token, no statement is immune to revision. Revision even of the logical law of the excluded middle has been proposed as a means of simplifying quantum mechanics; and what difference is there in principle between such a shift and the shift whereby Kepler superseded Ptolemy, or Einstein Newton, or Darwin Aristotle?[47]

What gives the Duhem-Quine thesis much of its bite is Quine's adoption of the coherence theory. A coherence theory of truth will specify that our beliefs don't need to correspond to a substratum of facts in order to be considered true. What is important is that they hang together coherently in a web of beliefs. Correspondence theorists, in contrast, believe that justified true beliefs *do* correspond to a substratum of facts.[48] Quine argues that worries about under-determination are an aspect of the more general question of the reliability of our inductive methods

[46]Quoted in Kyle Stanford, "Underdetermination of Scientific Theory", *The Stanford Encyclopedia of Philosophy* (2021), Edward N. Zalta (ed.). Retrieved from <https://plato.stanford.edu/archives/win2021/entries/scientific-underdetermination/>.

[47]W.V.O. Quine, "Two Dogmas of Empiricism" in *From a Logical Point of View: 9 Logico-Philosophical Essays,* 2nd ed. (London: Harvard University Press, 1980), 43.

[48]Kyle Stanford, "Underdetermination of Scientific Theory," *The Stanford Encyclopedia of Philosophy* Edwrd N. Zalta (ed.), (2021). Retrieved from <https://www. https://plato.stanford.edu/entries/scientific-underdetermination/>.

for determining beliefs. Although concerns about verificationism and operationalism are a little outside of the scope of this thesis, it is important to note that he makes a departure from logical positivism which, generally speaking, was beholden to the correspondence theory of truth.[49] It might be important to note that coherence *prima facia* may allow for social concerns to creep into a researcher's theory decision-making process, unfortunately. An assumption that participants in the realism/anti-realism debate are also proponents of coherentism may be a matter worth exploring as well.

When it comes to our graph, the general idea is that the less data they are given, the more scientists have to guess. The antecedent idea is that they are *not* given enough data to choose the right theory at the outset of these scenarios. As we see, if all we had were the following set of data points {20,500; 60,3900; 80,5000}, then we would be led back to our initial problem, a theory choice between $(\varphi \vee \psi)$ wherein $\varphi \neq \psi$. Kyle Stanford offers us an excellent example of underdetermination: ". . .if all I know is that you spent $10 on apples and oranges and that apples cost $1 while oranges cost $2, then I know that you did not buy six oranges, but I do not know whether you bought one orange and eight apples, two oranges and six apples, and so on . . ."[50] We do not have enough information in front of us, so we cannot provide a decisive answer as to how many apples and how many oranges were bought. Since there are possible rival explanations, the situation becomes more complex.

The problem of empirically equivalent theories and the ensuing underdetermination of scientific theory by data can be expressed by means of a simple argument. One of the more

[49] Alfred Ayer, *Language Truth and Logic*, (New York: Dover Publications, 1952).

[50] Kyle Stanford, "Underdetermination of Scientific Theory," *The Stanford Encyclopedia of Philosophy* (2021), Edward N. Zalta (ed.). Retrieved from https://plato.stanford.edu/archives/win2021/entries/scientific-underdetermination/.

dynamic voices on the subject we have already seen is Pablo Acuña. He writes of contrastive underdetermination that:

> The first premise states that for any theory *T* that entails the class of observational consequences O there is another theory *T′* whose class of observational consequences is also O. The second premise is that entailment of evidence is the only epistemically justified criterion for the confirmation of theories. From these two premises . . . Notice that the universal scope of the first premise implies that the problem holds for science as a whole, in the sense that all theories are affected by empirical equivalence.[51]

From the graph, we can see that without the proper data set (limited only to table 3), there is a chance we could confute the two lines since they overlap; φ and ψ may have indeed been observationally equivalent at time t_1. If two theories have the same set of observational consequences and there is no way of choosing between them, we have a case of under-determination. There is not enough data to choose. Is this a *bona fide* problem for which we need to find a solution?

Attacks on realism manifest themselves in the literature in many forms. Anti-realists often endorse Hume's response to Bacon's simple enumerative inductive method of inference. The Duhem-Quine thesis suggests that crucial experiments taken with the auxiliaries fail to show the main theory is falsified, and scientists cannot conclusively confirm it, either. Philosophers maintain that underdetermination has been historically recurrent and this may lead to more

[51] Pablo Acuna, "Another Look at Empirical Equivalence and Underdetermination of Theory Choice" in *European Journal for Philosophy of Science* (2014): 153-180.

macroscopic concerns such as the pessimistic meta-induction.[52] To expound on this problem, Kyle Stanford has pointed out that unconceivable alternatives may be a problem because we have seen paradigm shifts in the past.[53] Scepticism about science resulting from the problem of empirically equivalent theories seems to signify there isn't a stable truth or falsity of the matter. Hence, the argument runs, the methods used to create theories are irrational. We cannot show that theories will continue to make correct predictions.

2.2 Underdetermination

Now that we have a handle on the Duhem-Quine thesis, it may be expedient to go into the more in-depth technical aspects of the underdetermination of scientific theory by data. As with many items in philosophy, underdetermination can be broken down into major branches of underdetermination. They all have their own respective angles: contrastive, holistic, and transient. Also, there are "strong and weak versions of underdetermination, which would be sceptical as opposed to social via different avenues based on the anti-realist's position."[54]

To summarize: holistic underdetermination is one of the more well-known in the classical literature in the philosophy of science due to the Duhem-Quine thesis. Accepting a theory entails that there are auxiliary assumptions in use when makes an epistemic choice of a single theory over others. Transient underdetermination of theory by data, on the other hand, involves time

[52] Larry Laudan pointed out that since science is riddled with instances where underdetermination has occurred, we may be reassured that this is a reason to avoid a realist view. See "A Confutation of Convergent Realism" *Philosophy of Science.* Vol .41 No.1 Chicago: University of Chicago Press (1981): 19-49.

[53] Samuel Ruhmkorff, "Difficulties for the Problem of Unconceived Alternatives," *Philosophy of Science*, Vol. 78, No. 5 (2011): 876.

[54] Pablo Acuña, *Predictively Equivalent Theories: What's the Problem?* (2021) Retrieved from <https://www.youtube.com/watch?v=WlPPJtH9h-kJohn/>.

indexicality. Theories represented by φ and ψ may entail the same observational consequences at t_1, but later, one will win out. At this point, it might be argued that the two theories are merely "empirically adequate" or merely "instrumentally equivalent". They describe observable phenomena, or seem to have the same amount of predictive success in certain contexts. They *save* the phenomena. This frames van Fraassen's argument for constructive empiricism in *The Scientific Image*.[55] According to the contrastive underdetermination thesis, which has seen a lot of play in the current literature, for any theory *T* we can construct another theory *T′* which has the same observational consequences.

Underdetermination, empirical equivalence, and the coherence theory render a sceptical outcome in terms of rational theory choice. Contrastive underdetermination must hold that all of the combinations of the apples and oranges scenario are inexhaustible. In this debate, much consideration is given to the idea that merely at a certain time there may be insufficient data to determine what beliefs we should hold in response to a theory. There is no rational basis for epistemic consent, the argument runs, if either transient or contrastive forms of underdetermination are binding. With Quine's web of beliefs, we can change the auxiliaries around to accommodate an hypothesis in the face of disconfirming evidence, as well. This leaves scientists in a precarious position. "Depending on precisely what is being asserted about the character, the availability, and (most importantly) the rational defensibility of the various competing hypotheses or ways of revising our beliefs that the evidence supposedly leaves us free."[56] The textbook

[55] Bas C. van Fraassen, *The Scientific Image*. (Oxford: Clarendon Press, 1980).

[56] Kyle Stanford, "Underdetermination of Scientific Theory" *The Stanford Encyclopedia of Philosophy* (2021). Retrieved from <https://plato.stanford.edu/archives/win2021/entries/scientific-underdetermination/>.

example cited by the *Stanford Encyclopedia of Philosophy* furnishes us with an excellent concrete example of this predicament.

The more macroscopic question tying in underdetermination would be whether or not we are able to rationally differentiate between our lines on the graph we illustrated earlier if the values presented on table 3 were the only ones available a time t_1? Since variables φ and ψ were color-coded we would see only one purple line on the graph (stretch the imagination a bit, if you will). A problem of this type may be the case with all instances of underdetermination of scientific theory by data. All these considerations leave us with questions. Is there an extra empirical "catch" in which we can maintain the privileged epistemological supremacy of science? Is there a deductive way in which to support the basic tenets of scientific methodology?[57] It is these concerns that supposedly can lead to a global scepticism on the level of Hume or Descartes.[58] Quinean coherence avoids the question, although correspondence theorists are still out there, with their arguments. Humean scepticism cannot gain a foothold if a substratum of facts is unnecessary for our predicate to be correctly applicable, however.

Notoriously, global scepticism is hard on some of the forms of reasoning most human beings take for granted, especially those based on sense impressions. David Hume's observation that induction was invalid changed the ways in which philosophers thought about science, logic, and epistemology. Science is usually considered an inductive enterprise. Popperians, being deductivists, are the notable exception. Bacon advocated a method of simple enumerative induction which moved ahead toward a conclusion via a series of observation-statements,

[57] Karl Popper, *Conjectures and Refutations: The Growth of Scientific Knowledge* (London: Routledge, 1963).

[58] W.V.O. Quine, "Two Dogmas of Empiricism," *From a Logical Point of View* (Cambridge: Massachusetts, Harvard University Press, 1996), 43.

ultimately with critical tests administered at the end. He was writing at the beginning of the enlightenment period, the *Novum Organum* written in 1620. In a more contemporary context, inductive inference is putatively much more sophisticated with the introduction of Bayesian reasoning, a multivalued statistically based form of inference.[59] Despite where one stands as to a solution, a thorough grasp of the problem of induction is crucial to an understanding of the nuances involved with the empirical equivalence of scientific theories.

André Kukla, John Earman. Larry Laudan, Jarrett Leplin, and Kyle Stanford have an interesting debate going on in the realm of empirical equivalence. The interesting thing about this lively contemporary debate is that many of the major parties are arguing in favor of completely different things. Kukla's issue always points to contrastive underdetermination. He utilizes scientifically plausible unconceived alternative theories (SPUAs), and the use of algorithms (he claims there a four) showing there will always be empirically equivalent theories in his essay entitled "Does Every Theory Have Empirically Equivalent Rivals?"[60] Larry Laudan insists that in this form, the thesis is simply bereft of interesting or important consequences for epistemology" Critics here unanimously seem to show insurmountable problems with Kukla's overall *point*. There is a shift here in the literature towards the issue of transient under-determination. This is the view that two theories are observationally equivalent only temporarily, we are limited by the data set we have available at the time. It does not seem that algorithms have much going for them in terms of anything remotely descriptive.

[59] For more on this see Howson and Urbach, *Scientific Reasoning: The Bayesian Approach* (Chicago: Open Court, 2006).

[60] André Kukla, "Does Every Theory Have Empirically Equivalent Rivals? " *Erkenntinis* (1975-) Vol. 444, No.2 (1996): 137-166.

There is much to be gained by a deeper analysis of this argumentation. In Kukla's defense, he does maintain the alternatives must be plausible.[61] His algorithms do shed much light on a conceivable anti-realist rescue of contrastive underdetermination. Larry Laudan and Leplin suggests the major takeaway is that contrastive underdetermination put in this form is harmless. In "Demystifying Underdetermination" they suggest that the significance of such underdetermination has been greatly exaggerated and has nothing to do with how theories are actually confirmed.[62]

In the end, it may be a matter of dispute whether global skepticism could arise due to the various forms of underdetermination philosophers have talked about: contrastive, transient, and/or holistic. There may be a tacit slippery slope here as well. Some attempted solutions seem to have had a strong philosophic resonance. "Bas C. van Fraassen's constructive empiricism holds that the aim of science is not to find true theories at all, only those that are empirically adequate."[63] It is important to keep in mind that transient underdetermination will become a major player in terms of the overall thrust of our abductive/IBE view, and it ties in snugly with Laudan and Leplin's major argumentative contention that all cases of underdetermination are transient. Pablo Acuña summarizes Leplin and Laudan's position. "The upshot is that if two theories make the same predictions now, it does not follow that they are empirically equivalence, for further development of science could break the equivalence and, *a fortiori*, the empirical underdetermination of the choice to be made."[64]

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[61] *Ibid.*

[62] Larry Laudan, "Demystifying Underdetermination," C. Wade Savage (ed.), *Scientific Theories* (Minneapolis: University of Minnesota Press, 1990), 267-97.

[63] Kyle Stanford, "Underdetermination of Scientific Theory," *The Stanford Encyclopedia of Philosophy* (Winter 2021 Edition), Edward N. Zalta (ed.). Retrieved from <https://plato.stanford.edu/archives/win2021/entries/scientific-underdetermination/>.

[64] Pablo Acuña, *Predictively Equivalent Theories: What's the Problem?* (2021). Retrieved from <https://www.youtube.com/watch?v=WlPPJtH9h-kJohn/>.

The idea here is that given sufficient time, the best theory will win out. Laudan and Leplin relied upon the technological advancements in the laboratory. Empirical equivalences only involve a certain limited timeframe, say between t_2-t_3. At time t_4, the theory with the most explanatory power will be chosen. It will have the most predictive power. They conclude "the thesis of underdetermination, at least in so far as it is founded on presumptions about the possibility of empirical equivalence for theories [. . .] stands refuted."[65] For now, it is important to note the time indexicality involved with their solution to ultimately all of the forms of underdetermination. Holistic and contrastive underdetermination have been covered in some depth up until this point, and the importance of transient underdetermination will be made clearer later. Let us now turn to the major issue facing us in this thesis.

2.3 Empirically Equivalent Theories

Quine argued that "two theory formulations are underdetermined if they are empirically equivalent but logically incompatible."[66] According to Kukla, any new data can confirm empirically equivalent yet contradictory theories. This is tied to the paradoxes of confirmation, attributed Carl Hempel.[67] On this view, no one theory can be shown to be true or even likely to be true, only that it is one of a set of theories that is confirmed by the evidence. John Stuart Mill

[65]Larry Laudan and Jarrett Leplin, "Empirical Equivalence and Underdetermination," *The Journal of Philosophy*, Vol. 88, No.9 (1991): 466.

[66]W.V.O. Quine. "Two Dogmas of Empiricism," in *From a Logical Point of View* (Cambridge, Massachusetts: Harvard University Press, 1996).

[67]Carl Hempel, *Aspects of Scientific Explanation and Other Essays in the Philosophy of Science* (London: Collier-Macmillan Limited, 1965).

articulated a different version of the concern with impressive clarity in *A System of Logic*, where he writes:

> Most thinkers of any degree of sobriety allow, that an hypothesis...is not to be received as probably true because it accounts for all the known phenomena, since this is a condition sometimes fulfilled tolerably well by two conflicting hypotheses...while there are probably a thousand more which are equally possible, but which, for want of anything analogous in our experience, our minds are unfitted to conceive. are taken as perfectly natural, and nobody seems to see any harm in them. We know from Aristotle that "of two contradictory statements, both cannot be true, and both cannot be false. But what about two competing scientific theories?[68]

The problem of empirical equivalence can be phrased in formal logic as follows:

$(\forall T)(\forall p)(\exists T')(T \vdash p) \leftrightarrow (T' \vdash p)$; $(\forall T)(\forall p)(\exists T')(T \vdash Prob(p) = n) \leftrightarrow (T' \vdash Prob(p) = n)$[69]

Formalized, we can see that the logic is sound enough. Empirical equivalence boils down to a problem of induction in the hands of Kukla and other anti-realists. According to this reasoning, our set of observation statements is not exhaustive enough to make a sound inductive inference. In a set of theories that are all equally confirmed, unless one takes non-empirical virtues as being decisive, we arrive at this conclusion. Anti-realists in the past have suggested that contrastive and holistic underdetermination sound the deathknell for scientific realism in its many forms and derivatives. Leplin and Laudan's argument that there is a way out of an empirical tie concentrated on the fact that science does not halt at a stalemate. Popper along with other philosophers argue that further testing can bring out crucial differences in verisimilitude. He writes:

[68]John Mill, *A System of Logic* (New York: Harper and Brothers, 1900), 328.

[69]Pablo Acuña, *Predictively Equivalent Theories: What's the Problem?* (2021). Retrieved from <https://www.youtube.com/watch?v=WlPPJtH9h-kJohn/>.

> . . . There is no doubt whatever that we can say, and often want to say, of a theory t 2 that it corresponds better to the facts, or that as far as we know it seems to correspond better to the facts, than another theory t 1. I shall give here a somewhat unsystematic list of six types of case in which we should be inclined to say of a theory t 1 that it is superseded by t 2 in the sense that t 2 seems--as far as we know--to correspond better to the facts than t 1, in some sense or other. 1. t 2 makes more precise assertions than t 1, and these more precise assertions stand up to more precise tests. 2. t 2 takes account of, and explains, more facts than t 1 (which will include for example the above case that, other things being equal, t 2 's assertions are more precise). 3. t2 describes, or explains, the facts in more detail than t1. 4. t2 has passed tests which t 1 has failed to pass. 5. t2 has suggested new experimental tests, not considered before t 2 was designed (and not suggested by t 1, and perhaps not even applicable to t 1); and t2 has passed these tests. 6. t 2 has unified or connected various hitherto unrelated problems. If we reflect upon this list, then we can see that the contents of the theories t1, and t2 play an important role in it. (It will be remembered that the logical content of a statement or a theory a is the class of all statements which follow logically from a, while I have defined the empirical content of a as the class of all basic statements which contradict each other. For in our list of six cases, the empirical content of theory t 2 exceeds that of theory.[70]

Myself and like-minded philosophers are of the opinion that science is never a completed process. Science begins and metamorphosizes in those very terms of empirical equivalence. It holds part of the key as to why abduction used with inference to the best explanation assuages worries that there is a necessary extant case of underdetermination in every case of empirical equivalence. On the other hand, it might be that on some accounts that a case of abduction (and arguably of scientific discovery) only obtains if empirical equivalence is present. Karl Popper, as we shall later see, believed in a sort of survival of the fittest theories. Empirical equivalence is *beneficial* on this view. It is only through the Popperian Darwinist progression that our reigning theories will remain cutting-edge and the best, descriptively speaking. In order to clarify what is

[70] Karl Popper, *Conjectures and Refutations* (London: Routledge, 1963), 228.

going on here in terms of the discrepancies involved with theory choice in the hard sciences, abduction or inference to the best explanation can be used. The history and philosophy of science is rife with examples of abduction or IBE.

In the literature, ampliant virtues are mentioned in the debate as a deciseive factor in the case of two or more empirically equivalent theorires. If we do not have a sufficient enough number of observation-statements in order to break a tie, we have a case wherein an equivalence may arise and we need some form of legitimate criterion in order to progress. At time *T* the aether theory versus Einstein's theory of special relativity was a draw, for example. What Laudan and Leplin are going to say is that when combined logic with the ampliative principles of science and good reasoning we can choose among alternative theories. A major criticism of Laudan is that he cannot account for Quine’s web of beliefs and his ampliant virtues can be called into question. Non-empirical virtues as a means to break a tie when an empirical equivalence arises has been debated. Seemingly, until this point there has been no standardization of tie-breaking virtues.

Chapter 3: Discussion

Larry Laudan argues that "one of a number of empirically equivalent theories may be uniquely preferable on evidentially probative grounds."[71] We might want to take a step back here and ask what makes a theory worthy of being called a theory? Quine's answer to the rival problem was indeed non-empirical virtues (testability, simplicity, etc.). In response to the unconceivability thesis we may wonder whether or not unconceived "theories" are theories *at all*.[72] Kukla has argued that there are four algorithms from which we can derive SPUAs, but the main idea is that for any theory *T*, another can be constructed to account for all the data in the data set. The wish here is for a reliant criterion (or criteria) that we can look upon in order to choose the epistemically superior theory without the worry of rivals. These problems are undermined if we see the empirical equivalence of *bona fide* theories in the running as a part of science.

André Kukla maintains that algorithms can be concocted to start new theories off an original theory *T*. This is another way of formulating the problem of unconceived alternatives which is a contrastive form of underdetermination of scientific theories by data. There might be equivalent observational consequences of a hitherto unconceived alternative. They have to be plausible, apparently, although the other virtues have been up for debate in the current literature . . .Outside of attempting an outright solution, philosophers have either tried to sidestep or dissolve the problem.[73] The problem of unconceived alternatives exists on an assumption that there is indeed a problem to be found. Laudan and Leplin are the staunchest voices against this thesis and have

[71]Larry Laudan and Jarrett Leplin, "Empirical Equivalence and Underdetermination," *The Journal of Philosophy* Vol. 88, No. 9 (1991): 450.

[72] See, e.g. Lawrence Sklar, "Do Unborn Hypotheses Have Rights?" *Pacific Philosophical Quarterly* 62 (1981): 17-29.

[73] Pablo Acuña, *Predictively Equivalent Theories: What's the Problem?* (2021). Retrieved from <https://www.youtube.com/watch?v=WlPPJtH9h-kJohn//>.

pointed out that the empirical equivalence of two theories does not mean that a choice between them underdetermined.[74]

There is a vagueness on Kukla's part. How plausible does a SPUA have to be? A theory needs to be well-formulated and tested, until then it is a mere hypothesis. What exactly is meant by "unconceived"? Other than that, *prima facia*, the logic seems unsound: since a bucket might spring a leak, I might as well not build it, although it is in my power to easily do so, say. The weatherman, who is always right predicts a drought, however. Those who don't like being left high and dry might find the reasoning behind contrastive underdetermination suspect. In other words, should science and technology somehow be placed on hold since something unconceived might come along? Kukla antecedently disregards the scope, methods, and aims of science with these kinds of irksome yet seemingly pointless minutiae. The argument from unconceived theories is suspect, to say the least.

3.1 State of the Debate

We come now to the most contemporary part of our thesis, here. One of the important issues we came into contact with was over ampliant auxiliary assumptions, initially brought to light by Duhem, with his holistic version of the underdetermination thesis. The meat of the con-temporary debate is the contention that for any theory *T*, there can be another empirically equivalent theory *T′* that could be constructed of equal explanatory power to fit the data via an algorithm. Here

[74] E.g. Laudan, "Empirical Equivalence and Underdetermination," *The Journal of Philosophy* Vol. 88, No.9 (1991): 466.

there may be a confusion between verification and confirmation on Kukla's part. Underdetermination is allegedly the result of these considerations, nevertheless.

Laudan and Leplin argue that this state of affairs could lead to a global Humean "anti-scientific" scepticism, and conclude that transient underdetermination is actually the only issue since empirical equivalences do not last.[75] Technological advances in the laboratory allow scientific researchers better testing, and hence they can better determine which theories have more explanatory power over their rivals which are also in the running, and which ones cannot pass crucial tests. So, as time moves forward in a linear fashion, scientific researchers hone in on better theoretical views of the phenomenal world. Those theories with less explanatory power are discarded along the way.

Kuka's additional considerations to the problem of underdetermination of scientific theory by data remains in dispute. Empirical equivalence can be instantiated in different ways on his account, holistically by accommodating auxiliary hypotheses according to the Duhem-Quine thesis by the regular practice of science, and by concrete artificial examples. Laudan and Leplin argue that there is no instrumentalist argument for underdetermination. If there is an equivalence and the predictive success of T and T' are equivalent on an instrumentalist account, it does not mean that they are theoretically the same. This is yet another blow to Kukla's underdetermi-nation thesis. Laudan and Leplin also claim there is no guarantee of the possibility of empirically equivalent theories. This looks to be a major blow to Kukla's unconceivability argument.[76]

[75]Larry Laudan and Jarrett Leplin, "Empirical Equivalence and Underdetermination," *Journal of Philosophy*, Vol.88, No.9 (1991), 449-472.
[76] *Ibid*., 449.

Inference to the best explanation is mentioned often throughout the current literature. It would seem there must be a procedure that would be adequate enough so scientists never miss out on the best explanation for the phenomena in question.[77] According to Peirce's original account, although we do not know which is ultimately true in a set of rivals at time t_1, we can know upon which theory those who investigate converge upon at time t_2. Given time, the research community may converge upon yet another theory. Peirce himself clarifies:

> In sciences in which men come to agreement, when a theory has been broached, it is considered to be on probation until this agreement has been reached. After it is reached, the question of certainty becomes an idle one, because there is no one left who doubts it. We individually cannot reason-ably hope to attain the ultimate philosophy which we pursue; we can only seek it, therefore, for the community of philosophers.[78]

Until it is tested, it is a mere hypothesis. Inference to the best explanation does not seem to have the same problems that other forms of inference have when it comes to extra-logical factors. The objections to IBE are many, however. The major issue is that anti-realists believe there needs to be a detailed, thorough, and exhaustive account of all the non-empirical and ampliant "auxiliaries" in play during the decision-making process. Others generally claim it is simply wanting of correspondence or is similar to induction, generally. Raised against any kind of comprehensible account of scientific discovery at all, the pessimistic meta-induction, which contemporary anti-realists still cite.

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[77] For a proposal along these lines, see Lipton, , *Inference to the Best Explanation* 2nd ed. (London: Cambridge, 2004).
[78] See Charles Peirce, *The Essential Writings Volume 1*. (Bloomington: Indiana University Press), 29.

They maintain that if it is the case that our scientific theories were false in the past, we have no reason to believe they will be true in the future. E.g., it would be a farce to continue to use Tycho Brahe's view of the movement of celestial bodies today. He got a few things right, but believed that the Sun orbited the Earth. From such theoretical shortcomings, it is argued that we are heading for global scepticism. Hume maintained that any conclusions based on empirical observation or inductive reasoning are faulty. Even after the observation of the frequent or constant conjunction of objects, we have no reason to draw any inference concerning any object beyond those of which we have had immediate experience. The meta-induction does not take into account pragmatic and predictive success of theories, however, and there may indeed be non-empirical values that are currently in use although they are underplayed in the philosophy of science.

Many current debates foreshadow inference to the best explanation as being very viable in terms of an account of scientific methodology. IBE is attributed to Peirce. The temporary empirical equivalence between quantum theories implied that there was a choice to be made between them, and at some future point one will win out due to predictive success. The von Neumann, Bohm, and Heisenberg interpretations all have of their own theoretical spin on what makes the quantum universe tick, although these interpretations match the same set of baffling data. Quine stressed that the predictability and success of theories have something to do with pragmatic interpretation, and this is perhaps an overlooked point. He writes in "Two Dogmas of Empiricism":

> Carnap, Lewis and others take a pragmatic stand on the question of choosing between language forms, scientific frameworks; but their pragmatism leaves off at the imaginary boundary between the analytical and the synthetic. In repudiating such a boundary I espouse a more through pragmatism. Each man is given a barrage of sensory stimulation; and the consideration which guide

> him in warping his scientific heritage to fit his continuing sensory promptings are, where rational, pragmatic."[79]

Quine here nods to the distinction between pragmatism and direct realism. Warranted assertibity is another option where one wants to shy away from an alleged straight-ahead truth-fact relation between theory and reality. Theories that have concepts such as verisimilitude or are multi-valued do not have the sceptical issues that can usually be tied to correspondence theories of truth. The strange relationship between theory, reality, and pragmatic interpretation will have some bearing on our conclusion. Even outdated theories seem to have some use, and perhaps may give us a clue as to whether we can actually gain access to the Kantian *Ding an sich.*[80]

These theories, though in the main incorrect, may nevertheless dovetail nicely with the unobservable factual substratum according to certain accounts of scientific realism. Lawrence Sklar writes:

> It is certainly reasonable to think of an older theory, once it has been replaced by a successor that is more empirically or conceptually adequate than it was or that has greater generality than it did, as living on in science in only such a domain- limited and approximative fashion. No doubt such a view of the present status of Newtonian mechanics in a world governed by relativistic and quantum theories does much justice to what scientists really think of as the remaining "truth" that the Newtonian theory can be said to possess.[81]

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[79] W.V.O. Quine, *From a Logical Point of View: 9 Logico-Philosophical Essays,* 2nd (ed). (London: Harvard University Press, 1980), 46.

[80] See Immanuel Kant, *Prolegomena to Any Future Metaphysics*, (Indianapolis: Hackett Classics, 1977).

[81] Lawrence Sklar, *Theory and Truth, Philosophical Critique Within Foundational Science* (Oxford: Oxford University Press, 2000), 105.

For example, kinesiology is a branch of medicine reliant upon Newtonian mechanics. If there was a problem there—if it were merely a neat little mathematical exercise and some *ad hoc* yarn spun by Dr. Newton himself, kinesiologists relying upon body mechanics for their trade would be in trouble. There would be no point in using it, and it simply wouldn't work. The pessimistic meta-induction itself is undermined on this head. Underdetermination of scientific theory by the evidence does not sufficiently account for the actual processes behind scientific reason at use.

Despite Kukla's argumentation, putatively it looks as if SPUAs are philosophically uninteresting, have too many non-empirical virtues to contend with, and represent something non-descriptive of science, despite the alleged plausibility of the unconceived alternatives. Laudan and Leplin have pointed out (a) problems with Kukla's instrumentalist account of empirical equivalence in which theoretically there is no problem, (b) they have shown that a choice between two empirically equivalent theories does not imply evidential underdeterminsim, (c) and they also showed that there is no general guarantee of the possibility of equivalent theories.[82]

It is important to remember that the debates about SPUAs lead us into concerns about contrastive underdetermination. According to van Fraassens's constructive empiricism, our theories cannot be better or worse supported by any possible evidence. Contrastive underdetermination as described by his account has been shown to be persuasive and potent. A possible theory can undermine an original theory *T*, so there can always be a theory constructed of empirical equivalence, allegedly. Generally, those who cite the problem of the empirical equivalence of scientific theories argue that there is no rational way of deciding between two or

[82] John Worrall "Who's afraid of Underdetermination?" (2017). Retrieved from <https://nanopdf.com/download/ppt-5afa6fb4ef95d_pdf>.

more competing theories. Taking Laudan and Leplin's line that all underdetermination is reducible to transient underdetermination is a way to dissolve these types of problems.

3.2 Popper and Falsificationsim

One way to battle scepticism has been put forward by Karl Popper. "Conjectures [are] boldly put forward for trial, to be eliminated if they clash with observations."[83] It is undisputedly true at the time of this writing that Sir Karl Popper's philosophy of science and his "rationalist" view of scientific method both continue to be a hotbed of debate and discussion. We will focus on three of his concepts that will dovetail nicely with our thesis: verisimilitude, corroboration, and fallibilism. Popper's method can be called either "hypothetico-deductivism", or "falsification-ism". The more apt title to choose would be "falsificationism" here with its specific connotations because it hones in precisely on our intent towards an evolutionary explanation of scientific discovery. According to this view, scientists continually test theories in the laboratory in order to falsify them. If there is a peripheral theory that has not undergone this process, even if it is correspondently true, it does not seem reasonable to give epistemic consent to it. Popper claimed that a theory is corroborated by the supporting evidence by failed rivals and in surviving severe tests. He also believed he conclusively solved the problem of induction. He writes:

> *Only the falsity of the theory can be inferred from empirical evidence, and this inference is a purely deductive one*. Hume showed that it is not possible to infer a theory from observation statements;

[83]Popper summarized in Imre Lakatos, "The Role of Crucial Experiments in Science," *Studies in the History and Philosophy of Science*, Vol. 4, No. 4 (1974): 309-325.

> but this does not affect the possibility of refuting a theory by observation statements. The full appreciation of this possibility makes the relation between theories and observations perfectly clear. This solves the problem of the alleged clash between the principles (a), (b), and (c), and with it Hume's problem of induction [his emphasis].[84]

Corroboration is the concept that replaces confirmation in Popper's philosophy of science. Scientific investigators look back to see what theories have survived various tests. We will see that corroboration dovetails nicely with the idea that there can exist empirically equivalent theories. Laudan, Leplin and Pablo Acuña are just a few that argued that there isn't a problem. The process of corroboration seems to foretell of this. Lakatos notes:

> It is true that a certain type of proliferation of rival theories is allowed to play an accidental heuristic role in falsification. In many cases falsification heuristically 'depends on [the condition] that sufficiently many and sufficiently different theories are offered' (Popper [1940]). For instance, we may have a theory *T* which is apparently unrefuted. But it may happen that a new theory *T′* inconsistent with *T*, is proposed which equally fits the available facts: the differences are smaller than the range of observational error. In such cases the inconsistency prods us into improving our 'experimental techniques', and thus refining the 'empirical basis' so that either *T* or *T′* (or, incidentally, both) can be falsified."[85]

Bayesian philosophers, and others, have argued against Popperian falsificationism since its inception. There are some noteworthy names against his conception of scientific discovery, more generally speaking, they include "Salmon (1967, 1981), Jeffrey (1975), Howson (1984a), and

[84]Karl Popper, *Conjectures and Refutations: The Growth of Scientific Knowledge* (London, Routledge, 1963): 55.
[85] Imre Lakatos, *The Methodology of Research Programmes* (New York: Cambridge, University Press, 1973): 37.

Howson and Urbach (1989)."[86] Putatively, Popper's proposed solution to the problem of induction is a failure. However, other forms of hypothetico-deductivism (H-D) are out there, and falsificationism is surely anything but dead. Imre Lakatos is a huge challenging voice to Popperian falsificationism, which he categorizes as "methodological", claiming there are actually four varieties, many of which have unique shortcomings. These are: naïve, methodological, naturalistic, and sophisticated methodological. In the end, no matter how corroborated a theory becomes on his account, we still can't claim unity, absolute truth.

The idea that science is a continuing never-ending process rings true when it comes to a major premise of our argument. Popper's totally deductive falsificationism is cited often in the literature as not being an exhaustive historical account, due to the universal generalizations used in the first premise of a deductive syllogism, although many see the reasoning clearly enough. The idea here is to prove a theory wrong. theories are weeded out through this method if they have explanatory shortcomings in the face of falsifying evidence.

Verisimilitude in Popper's hands in and of itself acknowledges the severity and validity of Hume's problem. *Verisimilitude* means "truth-like", although Imre Lakatos adds the following:

> "Verisimilitude" has two distinct meanings which must not be conflated. First, it may be used to mean intuitive truthlikeness of the theory; in this sense, in my view, all scientific theories created by the human mind are equally verisimilar and 'occult'. Secondly, it may be used to mean a quasi-measure-theoretical difference between the true and false consequences of a theory which we can never know but certainly may guess. It was Popper who used 'verisimilitude' as a technical term to denote this sort of difference. But his claim that this explication corresponds closely to the original

[86] Brendan Shea, "Karl Popper: "Philosophy of Science," *Internet Encyclopedia of Philosophy* (2002), Retrieved from <https://iep.utm.edu/pop-sci/#SH2d/>.

> meaning is mistaken and misleading. In the original Popperian usage' verisimilitude' could mean either intuitive truthlikeness or a naive proto-version of Popper's empirical truthlikeness. Popper gives interesting quotations for the latter. . .[87]

To paraphrase: the technical sense in which the word is used means the difference between the falsity and truth content of a theory. A philosophy that espouses this alternative to a hard truth predicate usually acknowledges that scientific theories cannot get at a direct correspond-ence relation to reality, even though this may allegedly be what the hard-minded scientific types are really after—truth with a capital T. "Karl Popper was the first philosopher to take the logical problem of truthlikeness seriously enough to make an assay on it. This is not surprising, since Popper was also the first prominent realist to embrace a very radical fallibilism about science while also trumpeting the epistemic superiority of the enterprise."[88]

Underdetermination gets its bite from, mainly, inductive scepticism of the Humean variety. Logicians of the Aristotelian persuasion find the syllogistic model of logical inference to be impeccably truth-preserving. Deductive reasoning starts with a universal generalization and then applies it to a particular instance in order to reach logical conclusions. The subject-predicate cupola that is the conclusion necessarily obtains in a sound argument.

P1. Socrates is a Man

P2. All Men are Mortal

[87]*The Methodology of Research Programmes* (New York: Cambridge University Press, 1973): 101.

[88]Graham Oddie, "Truthlikeness" *The Stanford Encyclopedia of Philosopjy* (Winter 2016 Edition), Edward N. Zalta (ed.), Retrieved from <https://plato.stanford.edu/archives/win2016/entries/truthlikeness/>.

∴ Socrates is Mortal

Popper admitted that prominent thinkers like Issaac Newton held that inductive methods were utterly scientific. About this use of induction in the history of science, he writes:

> Newton himself asserted that he had wrested its functional principles from experience by induction. In other words, Newton asserted that the truth of his theory could be logically derived from the truth of certain observation-statements. Although he did not describe these observation statements precisely it is nevertheless clear that he must have been referring to Kepler's laws, the laws of the elliptic motions of the planets. And we can still find prominent physicists who maintain that Kepler's laws can be derived inductively from observation-statements, and that Newton's principles can in turn be derived, entirely or almost entirely, from Kepler's laws.[89]

We do know that it is used frequently—purportedly, but what exactly are the mechanics of it? Sir Francis Bacon's bold pronouncement in his 1640 *Novum Organum* was to found new knowledge, deduction only dealt with what was already known to exist. The promise he made in this text was to release philosophy from the grasp deduction had held since the time of Aristotle.

> As we pretend not to found a sect, so do we neither offer nor promise particular effects; which may occasion some to object to us, that since we so often speak of effects, and consider everything in its relation to that end, we ought also to give some earnest of producing them. Our course and method, however (as we have often said, and again repeat), is such as not to deduce effects from effects, nor

[89] Karl Popper, *Conjectures and Refutations* (London: Routledge, 1963), 251.

> experiments from experiments (as the empirics do), but in our capacity of legitimate interpreters of nature, to deduce causes and axioms from effects and experiments, and new effects and experiments from those causes and axioms.[90]

Bacon was highly critical of what he called the "Aristotelian syllogism" in that it rendered no new information. Thought was restricted by geometrical thinking that passed from the Greeks and then on to the scholastic philosophers of the medieval ages. He argued that his inductive method would be the model for new forms of knowledge that would benefit mankind, to distinguish it from this dogmatically accepted method. Importantly, for our purposes here, inductive reasoning in contrast to deduction induces broad generalizations from specific observation statements in order to work toward universal generalizations. The logical method of simple enumerative induction he promoted in the *Novum Organum* can be illustrated as follows:

Observation Statement #1: "Raven 1 is black."
Observation Statement #2: "Raven 2 is black."
Observation Statement #3: "Raven 3 is black."
.
.
.
.
Observation Statement *n*: "Raven *x* is black."
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[90] Francis Bacon, *Novum Organum* (New York: Collier and Son, 1902), 43.

∴ All ravens are black.

. . .Every raven I have observed is black; therefore, I conclude all ravens are black. The process outlined above illustrates how simple enumerative induction works. This is not the entirety of the story, since, as David Hume pointed out, we can never be conclusively certain of universal generalization derived. We cannot be certain that the subject-predicate cupola obtains in all possible worlds. He believes we assume that there is a principle on which we can base these generalizations upon. "If reason determin'd us, it would proceed upon that principle that instances, of which we have had no experience, must resemble those, of which we have had experience, and that the course of nature continues always uniformly the same.*'*"[91] The principle of the uniformity of nature must be present if such reasoning is to be considered valid. Hume continued "there can be no demonstrative arguments to prove that those instances of which we have had no experience, must resemble those, of which I have had experience."[92] There may indeed be an albino raven out there who escaped our powers of observation during the enumeration process.

Bayesians are some of the most vociferous in terms of holding Popper to be mistaken on a few fronts, although personally I like his terminology in that it is more apt than simply saying "theory *x* is true". In addition, there are interlinking concepts with his system that can give us a more detailed account. Importantly, Popper's vision suffers a huge setback, here. Bayesian reasoning is the most finely-tuned inductive reasoning philosophers have concocted to date. These statistical methods, which are extremely popular, do not use the binary values of T or F. It is based on numerical values ranging from 0 to 1 indicate probability. Bayes' theorem, concocted by Reverend

[91]David Hume, *A Treatise of Human Nature*, Selby-Bigge (ed.), (Oxford: Clarendon Press, 1888), 152.
[92] *Ibid.*

Thomas Bayes and delivered to the Royal Society of England in 1763, utilizes a reiterative formula to account for new data received, and hence escapes the problem of deduction nicely. The Bayesian probabilist looks toward new data as evidence for a hypothesis *h*.[93]

Popper held that this testing process never ceases. The whole of science is a series of conjectures and refutations. The first premise had to be a bold conjecture, although it could be falsified by any inductive counterinstance. Our best theories render the most information about observable phenomena, although they are easier to falsify. The demarcation problem which supposedly results from the abandonment of inductive inference, is connected to this, and separates science from pseudoscientific views that in contrast cannot be falsified.

Popper was writing at a time when philosophers were interested in confirmation rather than corroboration as a hallmark of true, probable, or truthlike theories.[94] This is the idea that new evidence may support a theory, and there was some debate about some of the more nuanced versions of this. Notably, Carl Hempel of the Vienna Circle pointed out the paradoxes of confirmation, which were quite devastating.[95] Popper, adopting falsification, cannot have a confirmational view, his will be falsificationist. Under the performance of critical tests, we can place more confidence in one theory over another depending on outcomes. Jarrett Leplin points out there are problems here in that philosophers believe Duhem pointed out that the falsifying observation-statements will be inductive, and will have to be based, as such, partially upon auxiliary assumptions. Popper's retort was that the observation does not need to be so based.[96]

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[93]Colin Howson and Peter Urbach, *Scientific Reasoning the Bayesian Approach* 3rd ed. (Chicago: Open Court, 2006).

[94]Nelson Goodman writes: "confirmation of a hypothesis by an instance depends rather heavily upon features of the hypothesis other than its syntactical form. That a given piece of copper conducts electricity invites the credibility of statements stating that other pieces of copper conduct electricity, and this confirms the hypothesis that all copper conducts electricity. *Fact, Fiction, Forecast* (Cambridge, Massachusetts: Harvard University Press, 1979), 53.

[95] Carl Hempel, *Aspects of Scientific Explanation and Other Essays in the Philosophy of Science*. (London: Collier-Macmillan Limited, 1965).

[96] Jarrett Leplin, *A Novel Defense of Scientific Realism* (New York: Oxford University Press, 1997).

Verisimilitudinarity does not designate a truth-predicate in terms of the old binary deductive system, although we are talking about scientific inquiry specifically. In our case. the concept would apply to our best running theory. Furthermore, the finished predicate we have been working on throughout this thesis would be based partially on Popper's ideas but would also include the virtue of intersubjectivity. The predicate would not be correspondent, nor would it need to be for science to remain a rational discipline.

A fallibilistic view of science is an end result of the state of affairs that maintains when we acknowledge that our theories might not latch on to reality perfectly. "By 'fallibilism' I mean here the view, or the acceptance of the fact, that we may err, and that the quest for certainty (or even the quest for high probability) is a mistaken quest."[97] Fallibilism suggests that science is a human endeavor, which means that scientific investigators might not get it right all of the time. Historically, this is shown in cases like the phlogiston theory of combustion, or Kepler's theory of planetary orbits. Philosophers with a dim view toward deductive reasoning antecedently might have a problem here with Popper's overall theory.

3.3 Non-empirical Virtues

Through a rational process, we can arrive at the single theory that best fits our data set. Theories are often looked at as needing to fulfill certain criteria in order to be considered cogent candidates. Many cited non-empirical virtues abound. A list would run something like the following: testability, empirical accuracy, simplicity, unification, consistency, coherence. Putnam points out others, he mentions "plausibility, simplicity, conservativism, operational utility, inner beauty and

[97] Karl Popper, *The Open Society and Its Enemies*. Princeton, Princeton University Press, (2020): 491.

elegance."[98] Quine cites a number of empirical virtues a theory ought to have as well, so it seems like a strict standardization is still to be desired. Finally, psychologists have started to investigate the role of theoretical virtues ". . .testability, empirical accuracy, plausibility, simplicity, uniformity, consistency, coherence, fertility.[99] As we see here, there isn't much of an agreement. Therefore, they are not well-established and cannot be used to derive sound criteria for assessment. It may be that philosophers have not been looking in the right direction or haven't been positivistic enough to assert the non-empirical virtues that ought to be used ubiquitously.

Non-empirical virtues ensure that we have theories that are relevant and can rightly be considered by a rational agent to be warrantably assertible. The research community itself as a non-empirical virtue has not yet been exploited as a *bona fide* "scientific virtue" to my knowledge, although it has been spoken about in the philosophy of science to great extent. If we assume that the scientific investigators are educated in their field(s) and are actively working with the main theories under consideration, it would be virtuous to turn to them for their opinions. Right?

What these admittedly rhetorical considerations show us is simply that science itself possesses tools that may eventually lead out of an allegedly underdeterminating impasse. Empirically equivalent theories may not have the same explanatory power until there are sufficient tests administered. Tycho Brahe's theory of celestial movements simply did not stand up to the virtues of explanatory power that its successor had. There were anomalies in the heavens that had to be addressed on his account. As more astronomers looked to the sky in order to discern the actual movements, alternative hypotheses were formulated.

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[98]Maria Baghramian, "From Realism back to Realism: Putnam's Long Journey," *Philosophical Topics* Vol. 36, No.1 (2008): 23.

[99]Samuel Schindler, "Theoretical Virtues in Science," *Oxford Bibliographies*. Retrieved from <https://www.oxfordbibliographies.com/view/document/obo-9780195396577/obo-9780195396577-0409.xml>.

In order to be considered mature theories, these hypotheses needed non-empirical virtues, as well as have the degree of cogency to pass severe, possibly falsifying, tests. I believe what this tells us something that can be cashed out in terms of Peirce's theory of truth. "Antirealists of an empiricist stripe go on to argue that we should confine ourselves to believing what theories tell us about observable phenomena and suspend judgement about the unobservable world."[100] Fallibility may be key. In the interim, non-empirical virtues as a rule of thumb should be considered as having some merit.

I agree with this angle, arguing that a time index should play a significant role in quantifying observation-statements, at least those that are considered in the running. This non-empirical virtue will narrow down the set of theory choices and give us a stronger predicate. The research community as a non-empirical value could serve as well, providing an intersubjective truth predicate which avoids Quiniean objections against correspondence, as well as provide a check against utter subjectivity (as well as the bad lot objection), despite whether or not a correspondence would obtain.[101]

Pragmatic, epistemic, ontological and metaphysical criteria are usually invoked in order to defend one interpretation or another. These non-empirical factors, though subject to controversy, are not arbitrary. This means that, evidential underdetermination notwithstanding, a rationally supported choice between theories can be made. What we want by focusing in on time and research community would be the breakdown of the evidential tie, despite empirical equivalence. This way to break underdetermination was endorsed by Quine at the end of "Two Dogmas" and draws our attention to the fact that theories are not chosen arbitrarily. When first formulated, both theories

[100]James Ladyman. "Science, Metaphysics and Structural Realism," *Philosophica* Vol. 67, No. 1 (2001): 57-76.
[101] Bas C. van Fraassen in *The Scientific Image* (Oxford: Clarendon Press, 1980).

are consistent with the rest of accepted knowledge. "Assume now that later development of science is such that a new theory N—which is incompatible with T' but consistent with T—gets evidentially accepted. The empirical evidence in favor of N is then evidence against T', whereas T remains as confirmed as before the introduction of N."[102]

The appeal to non-empirical virtues should not mean that they are merely compliant properties. According to the stipulation of anti-realist arguments, empirically equivalent hypotheses are equally believable, antecedently. Therefore, belief in any theory must not be arbitrary and unfounded.[103] If we take certain virtues not only as merely prescriptive and/or descriptive, but as rules of thumb, we have a way to cope with the pessimistic meta-induction. Pablo Acuña and Dennis Deiks mention "scientific common sense" to defeat Descartes' evil genius,[104] Some believe the entailment of the evidence is the only thing that is epistemically relevant for the confirmation of a theory.[105] If we were to take a virtue-based approach to theory choice as prescriptive, there would be more to the story.

The notion of a possible intersubjective truth predicate was pioneered by C.S. Peirce, although Lakatos maintains that "the main contemporary proponents of the ideal of 'truth by consensus' are Polanyi and Kuhn."[106] Importantly, there is an historical background to the idea that time and research community could be used as non-empirical virtues for theory choice. The idea of non-empirical success means that the theory conforms to certain standards *qua* a mature scientific

[102] Boyd quoted in Pablo Acuña & Dennis Dieks, "Another Look at Empirical Equivalence and Underdetermination of Theory Choice," in *European Journal for the Philosophy of Science* 4 (2014): 153–180.

[103] *Cf.* André Kukla, *Studies in Scientific Realism* (New York: Oxford University Press, 1998).

[104] Pablo Acuña & Dennis Dieks, "Another Look at Empirical Equivalence and Underdetermination of Theory Choice," in *European Journal for the Philosophy of Science* 4 (2014): 153–180.

[105] Pablo Acuña & Dennis Dieks, "Another Look at Empirical Equivalence and Underdetermination of Theory Choice," in *European Journal for the Philosophy of Science* 4 (2014): 153–180.

[106] Imre Lakatos, *The Methodology of Scientific Research Programs* (New York: Cambridge, University Press, 1989).

theory. Ideally, what we want is for a theory throughout its career to not have anomalies that call it into question. We would then be warranted in holding it in high epistemic esteem. There needs to be a sort of structural correspondence that holds between the theory and observable phenomena as Acuña pointed out.

The idea of non-empirical virtues to guide in theory choice, from the coherence theory of Quine to the realism of Hilary Putnam, have been mentioned often as rules of thumb, at the very least. That there is an intersubjective component involved with research communities is beyond dispute. There is no room for a solipsistic subjectivism here. That time breaks ties of empirical equivalence has also been shown by historical examples, and was discussed favorably by Karl Popper. For now, let us call this the "optimistic meta-induction" for empirically equivalent theories.

3.4 The Transient Conclusion

Transient underdetermination is the view that there are empirically equivalent rivals to all or most scientific theories that face this kind of underdetermination only temporarily. They are all well-confirmed by the evidence simultaneously. Since we don't have all the answers, and it might be the case we never will, scientific theories at least at one time during their careers will have empirically equivalent rivals, if the optimistic meta-induction is right. These rivals will be plausible, cogent, coherent theories that are well confirmed by the evidence we have at the moment."[107] At a future time during investigation, the decidability between rivals will obtain.

On Leplin and Laudan's account, this will take place due to technological advancements in the laboratory. This is also a matter of the optimistic meta-induction. To include simply a time indexical would be less cumbersome and could serve as a quantifier in a formal sentence. In

[107]Kyle Stanford, "Underdetermination of Scientific Theory," *The Stanford Encyclopedia of Philosophy* (2021). Retrieved from <https://plato.stanford.edu/archives/win2021/entries/scientific-underdetermination/>.

addition, this handy phraseology might make broad generalizations of the history of science more fine-tuned. Another consideration would be the possibility that in all cases technology might not be the deciding factor in all cases. A very general example would be the following: the Einsteinian theory of relativity superseded the Newtonian view of physics not by a more powerful telescope or the invention of a Leyden jar, say, but by a handful of observations and some mathematical skill. The truth is that which is fated to be true by all those who investigate, sayeth the great Peirce.[108]

Laudan and Leplin will claim that two theories will not always remain empirically equivalent. They may seem to make the same prediction right now but might someday make different ones. How are they equivalent? One objection they forward is to the effect that instrumental and theoretical equivalence are different, and on some accounts this is not considered. Another objection is that the problem of empirical equivalence is irrelevant given an historical perspective of science. If we can take all cases of empirical equivalence to be transient, along with the argument against instrumentalist views, Laudan and Leplin have a possible solution to the problem of empirical equivalence. Also there is a separate argument against the idea that is leads to underdetermination. There is a further contention that underdetermination and empirical equivalence are congruent. These two authors maintain they are not. Other concepts involved with the transient solution are important to note.

Predictive success does not mean conformity with the data. Instrumentalists have been criticized on this point many times. The transient solution we have devised works against underdetermination in respect to these problems on a broad scale. In the case of holistic under-

[108]Charles Peirce, "How to Make Our Ideas Clear," in *Popular Science Monthly* 12, (1878): 297.

determination, abduction in conjunction with the non-empirical values connected to the rational process of inference to the best explanation could be used against global scepticism that anti-realists argue obtains. The brain in the vat should be rendered moot, according to scientific common sense along with non-empirical virtues. The first step in an abductive argument is anti-Humean as well.

There would be non-empirical criteria which would be utilized in order to determine which theory an investigator ought to discard in the face of falsifying evidence when it came to empirical equivalence, during an inference to the best explanation and the utilization of crucial tests. Are sceptical scenarios scientifically plausible? Must we focus on Descartes' evil demon? Attention might be required toward elimination of these more macroscopic problems. With contrastive underdetermination, abduction might furnish us with further reasons for staying with our time indexed observation-statements that indicate the explanatory success of a theory, along with the informed investigative opinion of the research community. One correspondent and empirically equivalent hypothesis might be true yet uncorroborated and unnoticed by the research community at large, while the confirmed one temporarily that has survived more tests will continue to be the chosen one according verisimilar and warranted assertibility accounts. In short, there is no problem, and descriptively this is closer to how science moves forward.

Fallibilism in Popper's sense takes into account that scientific theories are always doubtable, and we can never know the ultimate truth value of theoretical content. According to this view, theories may perhaps fit the data perfectly, but another can arise to take its place. Larry Sklar, who coined the term, wrote: "sometimes it is claimed that our theory choice is determined by an

additional factor"[109] The notion of transience points our attention to the temporary dynamic of scientific theories. The von Nuemann interpretation of quantum physics may be the most plausible at time t_1, although the active research community may later prefer the Bohm interpretation at time t_2. We attribute a *t*-modifier to signify time. So, at time t_3, researchers are warranted in asserting the Bohm interpretation as the best quantum theory for the data at time t_3. at time t_1' it might not have been the theory they would have wanted to assert due to explanatory shortcomings in the face of anomalies, or insufficient testing, etcetera. I believe this temporal indexical ought to be further developed within the philosophy of science, and that it could be used to quantify statements in this respect "True at time t_2" is not, ultimately, what I have in mind, although "*x* is warranted in asserting ψ at time t_3" might be more palatable due to the current philosophical climate.

Our main idea that science is a process, and that it never ceases, starts with our adoption of Popper and Peirce, we will view it ultimately as humankind's strand of evolutionary intellectual advancement that seeks understanding of their environment. Perhaps more modestly, if we can safely assume that science progresses in any manner at all, research and testing simply do not discontinue. As Kuhn points out, there is always "normal science". We may assume that the necessary information to break a tie in a case of empirical equivalence will arise. We see here why a temporally construed analysis of anomalies is important. Research does not stop after a paradigm shift. Scientists work under a paradigm, developing technologies from it and so on. This leads us straight into abduction/IBE.

[109]Larry Sklar, "Do Unborn Hypotheses Have Rights?" *Pacific Philosophical Quarterly*, 62 (1981), 23.

To conclude this section, the problem of global scepticism here stemming from the problem of the equivalence of predictive theories may in part be a confusion as to which non-empirical virtues to choose. The sceptic's argument states that there are no rational grounds to choose one theory out of a set of rivals. This is a threat to scientific realism. With a fallibilistic view including verisimilitude or warranted assertibility, we sidestep issues related to this. With the right criteria met in addition to a mature theory's success in the lab, we may be warranted in asserting that ψ is more truth-like than its rival. My approach assumes that universal and unique criteria can be both formalized and standardized for mature scientific theories under serious consideration.

Chapter 4: Case Study

We have spoken at length about non-empirical virtues, empirical equivalence, under-determination, inference to the best explanation, historicism and paradigm changes. The next step is to show how my responses to these items take effect. The following concrete example is a widely known standard in the literature surrounding debates about empirical equivalence and is well-known within the philosophy of science in general. I here speak of the discovery of oxygen, which was following on the coat tails of the notorious phlogiston theory of combustion, which was utterly abandoned due to its shortcomings of explanation. This episode in the history of science shows how two theories can be equivalent for a time, and how a theory reigning for 150 years can be displaced and abandoned through testing.

Antoine Lavoisier was officially accredited in showing that a gas was required for combustion to occur. Although others preceded him, they did not have his stature in the field of chemistry. Originally known as "dephlogisticated air", this substance would later be christened "oxygen" by those attempting to isolate this gas, and more research in this direction opened the floodgates to what we now understand as modern chemistry. From this example, we will show both abductive and falsificationist principles at work.

4.1 Phlogiston Versus Oxygen Theory

The original ideas behind phlogiston were derived from alchemy, which was then focused on the project of turning lead into gold. According to the phlogiston theory, physical objects that are phlogisticated are flammable and they contain a substance called "phlogiston". This inherent substance, originally known as *phlóx* (*flame*) from the Greek φλόξ, was released when an object

burned. A candle, for example, releases phlogiston, and as the air is saturated with it in a bell jar, it gets to a level that the flame goes out. Quite simple. Burned items are then considered de-phlogisticated. The phlogiston theory was also used to explain the calcination of metals. Theorists such as J.J. Bechler, Georg Ernst Stahl, and J.H. Pott promoted the theory. On a side note, it is interesting to see the technology in the lab develop in accordance with new findings, as Laudan and Leplin earlier pointed out in respect to transient underdetermination, during the evolution of early chemistry.

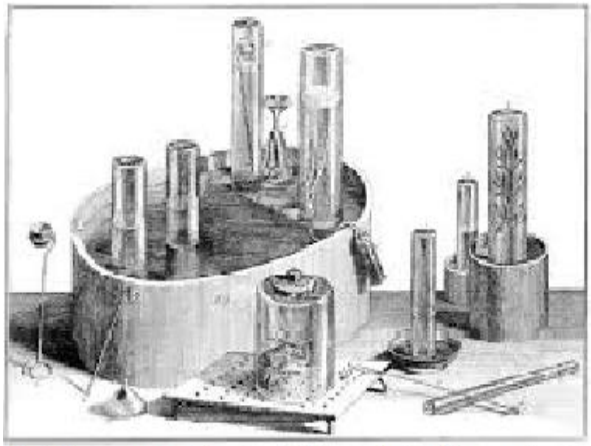

Fig. 1 Equipment used by Joseph Preistly during his experiments with air and other gases. Jospeh Preistly, *Experiments and Observations on Different Kinds of Air* (London: J. Johnson 1774-1786).

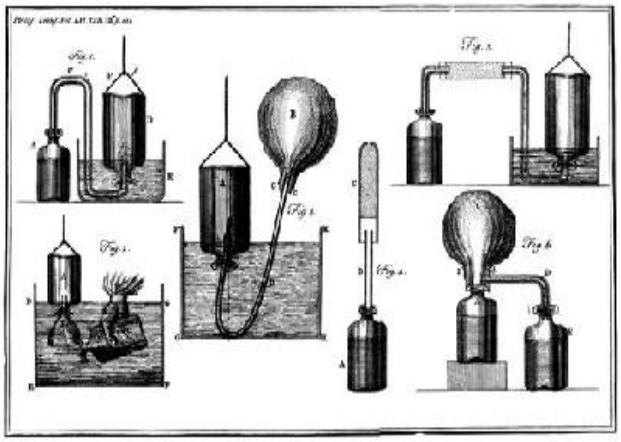

Fig. 2 Equipment for studies on atmospheric air, water, carbon dioxide, hydrogen. Henry Cavendish, *Three Papers, Containing Experiments on Factitious Air*, 56 (London, Royal Society, 1766): 141–184.

Officially, oxygen was officially discovered in about 1772 by a Swedish chemist named Carl Wilhelm Scheele, a pharmacist by trade working 40 miles outside of Stockholm, Sweden with Tobern Olof Bergman in his lab and an assistant.[110] He was the first to isolate the substance. He

[110]James and Virginia Marshall,"Rediscovery of the Elements: Carl Wilhelm Scheele," *The Hexagon*, Vol. 96, No.1 (2005). Retrieved from <https://digital.library.unt.edu/ark:/67531/metadc111204/m1/1/>.

discovered it by heating potassium nitrate, mercuric oxide, and many other substances. Scheele was sponsored by the renowned Bergman, who was also a Swedish chemist and mineralogist noted for his 1775 *Dissertation on Elective Attractions*, in which he published a widely respected table of elements.

There were many similar discoveries during this brief period in Europe, although a majority were attributed to Sir Henry Cavendish and Joseph Preistly. They discovered the process by which the ore of metal is heated to high temperatures in the absence of the thermal decomposit-ion of mercuric oxide, having isolated it. Lavosier later paved the way to a mature oxygen theory. The English chemists remained faithful to the phlogiston theory. Lavoisier eventually reinterpreted their results in terms of his new and developing oxygen theory. Cavendish's story is quite unique.

> Cavendish reached the reasonable (but erroneous) conclusion that inflammable air was a constituent of zinc, iron and tin and liberated by acids. He seems to have suspected that the 'air' might actually be pure phlogiston, the fiery matter which early modern chemists like Ernst Stahl (1660-1734) believed to exist in all combustible substances. However, he also considered the possibility that it was a more complex substance in which phlogiston played some part.[111]

Priestley published his findings before Scheele, in 1774, although his claim to original discovery is not as strong. Volume 1 of his of *Experiments and Observations on Different Kinds of Air* was only one out of eight volumes on the topic. In this work, he describes a gas known as O_2 in terms of dephlogisticated air. He met Lavoisier briefly in October of 1774, where they discussed the nature of the new gas.

[111] Mike Sutton, "Airs and Graces," *Chemistry World* (2010). Retrieved from <https://www.chemistryworld.com/features/airs-and-graces/3004484.article>.

Lavosier had always been leery of the phlogiston theory. Priestley, however, who lived until 1804, never officially gave it up. Scheele, Preistly and Cavendish were all credited with discovering the new gas separately. These were just a handful of investigators in the field who have converged on the one most warranted educated opinion on the matter. Lavoisier's new paradigm for chemistry was set out in his *Traité Elémentaire de Chimie* later in 1789. Despite the prior work, in terms of writings on classical chemistry, this was generally considered the first of its kind in the literature. Within a few years it was adopted by the majority of chemists in Europe.

Let us get into the technical details. According to the alchemical theory, carbon burns away and leaves little ash, hence it has a lot of phlogiston in it. Metals that were hard to burn but produced much ash were said to be low in phlogiston. When a metal is heated in air, in many cases it turns into a powder known as calx. Also, it was discovered that calx, when heated alone, produces a gas. Calx is usually found in ores of the metal, and the metal itself could often be obtained by heating calx with charcoal. These transformations were explained by postulating that calx + phlogiston = metal. When we heat a metal, phlogiston is given off, and the calx remains. Conversely, when we heat the calx with charcoal, since charcoal is very rich in phlogiston because it burns easily, the phlogiston from the charcoal combines with the calx to give the metal.

There were anomalies found within the phlogiston theory of combustion. What is observed in the combustion of sulfur and phosphorus may well take place in the case of substances that gain in weight by combustion and calcination. A metal changing to calx gains weight. This would mean that phlogiston has a negative weight. At the same time, there was an inference that calcination and carbonation occurs in combination with an active gas. It is in the air, and it was

combined in all cases of combustion. They noticed the new gases were sour or acid. With the oxygen theory, burning is explained as the combination of the substance with oxygen, while the calx is identified with the oxide of the metal.[112]

Within our framework sketched above, let us say that the dephlogisticated air and oxygen were both meant to denote the same thing. A description of this substance as dephlogisticated air could be epistemically disregarded after Lasovier's experiments. The experiments showed that the oxygen theory, considered at large to describe really a hypothetical substance, was later seen as having more explanatory power of observable phenomena when it came to more tests. It was epistemically superior to its rival, while phlogiston and its variant hypotheticals could not be redescribed by the new theory and was eliminated altogether.[113] The phlogiston theory of

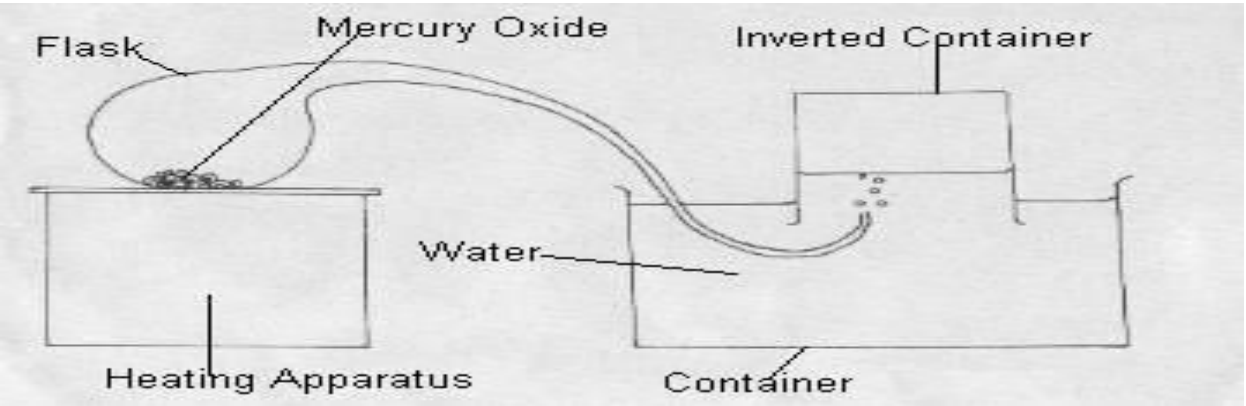

Fig. 3. Lavoisier's apparatus to study air. Houssian, *Lavoisier and the Discovery of Combustion* (Aberdeen University, 2001), Retrieved from http://www.chm.bris.ac.uk/webprojects2001/hossain/combustion.htm.

combustion was displaced completely, and the genesis of what we consider modern chemistry began. Bergman, Scheeler, Priestly, Cavendish, and definitely the great Lavoisier all converged

[112]Periscope Films, *The Discovery of Oxygen and Combustion*, E.J. Holmyard (ed.) (1946). Retrieved from <https://www.youtube.com/watch?v=HahAGmMewLU>.

[113]André Leplin, *A Novel Defense of Scientific Realism* (New York: Oxford University Press, 1997).

upon the same educated opinion through research that some gas in the air was responsible for the phenomena of calcination and combustion.

4.2 Abduction and IBE

Peirce believed that inquiries of a scientific nature proceeded according to the logical rules of abduction. Our argumentative move here is to accept a pragmatic outlook towards science, the optimistic meta-induction included. Concerns about Humean global scepticism should be laid to rest. Other writers generally have noticed the inappropriateness of these worries in the face of scientific rationality. Abduction or IBE are methods which allow for the antecedents to be conclusions, not unlike Karl Popper's hypothetico-deductivist model of inference. We can make educated guesses antecedently, and then, following Popper, commit to the falsificationist method, using the pattern of inference known as *modus tollens*.

Jaakko Hintikka claims that since abduction is "a hypothesis-forming operation" it is "the only way of introducing new hypothesis into inquiry."[114] Peter Lipton believed abduction is the only way we can account for how we come up with new theories. Elsewhere in the literature, Peirce talks about a process called "retroduction".[115] Retroduction uses concomitances in order to derive conclusions which are based upon past experiences. Concomitances take into account past experiences of constant conjunctions, counter to Hume's admonishments. We by no means see all of these myriad "conclusions" as correspondent, so we are taking into account a fallibilistic

[114]Cited in Mohammadian, "Abduction – the Context of Discovery + Underdetermination = Inference to the Best Explanation," *Synthese* (2021). Retrieved from <https://link.springer.com/article/10.1007/s11229-019-02337-z>.

[115]Charles Peirce. *Selected Writings Volume II* (1893-1913). (Indiana: Indiana University Press, 1998), 443-444.

outlook. Retroduction is ultimately a psychological phenomenon which is partially due to subjective past experiences and not based exclusively upon any factual state of affairs. This is used during hypotheses-formation.

Two factors came into play in Peirce's theory of truth as "that which is fated to be true by all those who investigate."[116] The hypothesis that has been verified through the process of the most rigorous testing and agreed upon by the majority of the research community should be considered superior to its rivals, most of which—borrowing from Popper—after times t_1, t_2, t_3. . . should be falsified. There may still be logical equivalences, although this is how science moves. It may be objected that while two mutually inconsistent theories cannot of course both be true, they may both be approximately true. The answer is that the research community will shift onto one theory after more testing and more falsifications occur, and so on. Of course, we are assuming objective methods, to avoid the admonishments of the SSK. The two major factors that come into play here are Peirce's doctrine of time, and the research community.

Peirce writes: "Cognitions … are of two kinds, the true and the untrue, or cognitions whose objects are real and those whose objects are unreal…. The real … is that which, sooner or later, information and reasoning would finally result in, and which is therefore independent of the vagaries of me and you. … This conception essentially involves the notion of a community, without definite limits, and capable of a definite increase of knowledge."[117] The educated opinions of investigators who are working in a field of research will converge upon a single answer to any given question. The most verisimilar opinion is fated to be converged upon. Peirce writes: "the

[116] Charles Peirce, "How to Make Our Ideas Clear," in *Popular Science Monthly* 12 (1878): 297.
[117] Bill Meachum, "The Pragmatism of C.S. Peirce," *Being Human in a Conscious Universe* (2014). Retrieved from <http://www.bmeacham.com/whatswhat/PDF/CSPeirce_20140721.pdf>.

opinion which is fated to be ultimately agreed to by all who investigate, is what we mean by the truth, and the object represented in this opinion is the real."[118] This means, given sufficient time, the investigators will find the answer they are looking for intersubjectively. Two things need to be required for this to ring true. Time, *T*, and the research community, *R*. "The object represented in the opinion is the real" suggests a form of scientific realism. At this point, Hume seems to raise his head, although we have borrowed both fallibilism and verisimilitude from Popper. Peirce writes in the "Fixation of Belief":

> The question of validity is purely one of fact and not of thinking. A being the facts stated in the premises and B being that concluded, the question is, whether these facts are really so related that if A were [the case] B would generally be [the case]. If so, the inference is valid; if not, not. It is not in the least the question whether, when the premises are accepted by the mind, we feel an impulse to accept the conclusion also…The true conclusion would remain true if we had no impulse to accept it; and the false one would remain false, though we could not resist the tendency to believe in it.[119]

To continue with our reasoning, Peirce's writing seems suspiciously suggestive of an objective factual substratum. However, let's briefly discuss the difference between abduction and IBE. Through abduction, we come up with some explanatory hypotheses for a given phenomenon and a ranking of these hypotheses which determines their pursuitworthiness according to non-empirical virtues such as cogency, operational utility, explanatory power, etcetera, during the actual inference. There is a difference between abduction and IBE on the grounds that the inference is where one is performing the actual adducement. One gets to the best explanation whilst making

[118]Charles Peirce, "How to Make Our Ideas Clear," in *Popular Science Monthly* 12, (1878): 297.
[119]Charles Peirce, "The Fixation of Belief," *Popular Science Monthly* 12, (1877): 1.

an abductive inference using concomitances, as Peirce would have it. Mohammed Mousa has written a recent paper on this debate, he says:

> Hintikka (1998) distinguishes between abduction and IBE on the ground that the latter is more akin to deduction. Minnameier (2004), however, claims that abduction is different from IBE, because the latter is similar to Peirce's concept of induction. Campos (2009), too, extensively discusses the fact that abduction has nothing to do with confirming (or disconfirming) evidence for a hypothesis—i.e., has nothing to do with induction—while IBE is similar to induction.**"**[120]

Peter Lipton gives us a detailed account of inference to the best explanation with his aptly entitled *Inference to the Best Explanation*.[121] Although there are debates about how IBE and abduction are related, let us stick with the answer that inference to the best explanation is the process used during abductive reasoning. *The Stanford Encyclopedia of Philosophy* uses the following example to illustrate the reasoning process: "We may have observed many gray elephants and no non-gray ones, and infer from this that all elephants are gray, because that would provide the best explanation for why you have observed so many gray elephants and no non-gray ones. This would be an instance of an abductive inference."[122]

Now that we have seen how these interlocking pieces connect, let us delve deeper into how they fit in with our overall thesis. Abductive reasoning in conjunction with the non-empirical virtues of time and the research community resolve the problem of empirical equivalence. Time itself is the important variable, it is quantifiable, and fits easily into a formal logical sentence more

[120]Mousa Mohammadian, "Abduction – the Context of Discovery + Underdetermination = Inference to the Best Explanation," *Synthese* (2021). Retrieved from <https://link.springer.com/article/10.1007/s11229-019-02337-z>.

[121] Peter Lipton, *Inference to the Best Explanation* 2nd ed. (London: Cambridge, 2004).

[122] Igor Douven, "Abduction," *The Stanford Encyclopedia of Philosophy* Edward N. Zalta (ed.), (2021). Retrieved from <https://plato.stanford.edu/archives/sum2021/entries/abduction/>.

economically than Laudan's cumbersome "*x* had technological advancement α to test ψ & φ at time t_2." We could easily make our view into a falsificationist practice. "At time t_2, theory *x* was proven false," would be the falsifying statement. As a mature theory, we would want *x* to have spent a sufficient amount of time in the lab, have had tests administered, as well as had captured the attention of the research community. Statements like these are lucid, simple, concise and objective. Furthermore, they clear the way for more viable alternative theories. Laudan and Leplin's "solution" is rather vague. IBE contends that antecedently we do not have the answers. It is as fallibilist as Popper's methodology, and the temporal signifier reflects that.

Abductive reasoning starts with hypotheses and seeks the most likely explanation. Peirce offers us reasons to think abduction could help with holistic underdetermination. If we start with many hypotheses, anomalies do not seem to be much of a problem, since there are alternatives on hand. It simply is a matter of evolution, on the explanatory side. The idea that science is malleable would be a part of accepting abduction/IBE as a preferred form of inference. Desired non-empirical virtues could also be used as a gauge of a theory's prescriptive esteem within the research community, whilst keeping verisimilitude and intersubjectivity as key concepts. IBE relies on these virtues in order to narrow down theory choice, and this gives us reason to accept the most verisimilar hypothesis as the best, while keeping our fallibilistic outlook.

This account is descriptive of the actual way in which science works throughout paradigm and research programme changes. The antecedent retroductive premises (untested hypotheses) in an abductive argument are fallible.[123] This is descriptive of science. Philosophers have tended to miss the point, and that is why I believe it ties into the very evolutionary nature of science as a whole.

[123] Bruce Thompson, "Retroduction," (2019). Retrieved from <https://www2.palomar.edu/users/bthompson/About%20this%20Site.html>.

Fallibilism is the reason why the displacement of the phlogiston theory isn't baffling. It simply is not. The theory did not live up to the predictive power that its rival, the oxygen theory, had in the face of critical tests and was thereby overtaken by it.

Perhaps Kukla's considerations have less bite than we imagined, if we take the set of all possible theories that can describe our data, there will always be alternatives, conceived or not. At one time theory φ and theory ψ may have been considered to have the same amount of empirical success, within the general greater scientific community. The state of affairs will remain wherein the reigning theory in the running will have rivals. Pierce argued that science moved by the admission of antecedent conclusions. In the "Fixation of Belief" they are called "opinions". Through rational methods of testing, experiment, and observation, the research community will hone in on the most verisimilar conclusion. "The one true opinion" we will gloss as the "most verisimilar theory", since Peirce maintains that abduction or inference to the best explanation does not contain an airtight truth predicate. As more philosophers of science look at non-empirical virtues, perhaps some standardization there will occur. "Thus, abduction can be developed further as a 'pure' form of inference, and this gives means for analyzing and organizing the search explicitly within the research community."[124]

Concomitances and retroduction do the work during the process of adducement. We can make educated guesses antecedently. E.g., $\{h_1, h_2, \ldots h_n\}$ are the candidate explanations for our data set. According to Quine, theories are empirically equivalent if they logical imply the same set of observation statements.[125] We use *modus tollens* reiteratively through critical tests to narrow down

[124]Maj-Britt Råholm. "Abductive Reasoning and the Formation of Scientific Knowledge Within Nursing Research," Retrieved from <https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1466-769X.2010.00457.x>.

[125]Robert Sinclair, "Willard van Orman Quine Philosophy of Science," *Internet Encyclopedia of Philosophy*, Retrieved 2021 from <https://iep.utm.edu/quine-sc/>.

our choices. The truth is "the opinion which is fated to be ultimately agreed to by all who investigate."[126]

Extra-logical considerations should be kept to a minimum, development as well as formalization here may be required. Peirce only mentions investigators and time. What is requisite in addition is an intersubjective predicate in order to keep our solution entirely Peircean. Previous work on tensed facts allows us to see how we could quantify over formal sentences with a temporal signifier. Conclusions provide the best explanations for their premises, in an inverted inferential pattern. Perscriptively speaking, good explanations fit well with impartial and objective background knowledge, although we would be operating with a fallibilistic view. If one out of our set of possible explanations is the best, we can infer that it is the most verisimilar due to the stringencies of corroboration if it meets our standards of cogency, plausibility and so on. We would be warranted in asserting it.

Peirce summarizes his point succinctly. "A hypothesis, then, has to be adopted, which is likely in itself, and renders the facts likely. This step of adopting a hypothesis as being suggested by the facts, is what I call abduction."[127] More than one explanation means that other possibilities are taken into account with this system.[128] Scientific inquiry *starts* with possibilities. Hans Reichenbach notes "the physicist who is looking for new discoveries must not be too critical in the initial stages."[129] The Darwinistic process is only beneficial if there is some competition out there.

[126] Charles Peirce, "How to Make Our Ideas Clear," in *Popular Science Monthly* 12, (1878): 297.

[127] Charles Peirce, "On the Logic of Drawing History from Ancient Documents". *The Essential Writings Volume* 1, (Bloomington: Indiana University Press, 1992), 95.

[128] Hyung Yul Kim *and Charles Pierce's Response to Cartesian Skepticism*, (2020). Retrieved from https://www.youtube.com/watch?v=JpLk7k_AUaQ.

[129] Hans Reichenbach, "Einstein: The Philosophical Significance of the Theory of Relativity" in Holton, Gerald, *Thematic Origins of Scientific Thought* (Cambridge, Massachusetts: Harvard University Press, 1973): 292.

Conclusion

In philosophy, "positivism' is a mighty word. "Logical positivism", "scientific positivism", and other words like these always stand out as signifiers of progress and growth . . .the furthering and betterment of mankind. It means playing our strongest suit—what we should put forward. "Scientific positivism" was a phrase coined by Auguste Comte;[130] he strongly endorsed our most rational belief system (to use a rough lay phrase). I urge a mini-positivism—an outlook taking abduction/IBE as our preferred method of logical inference in the sciences.

Quine mentions in "Two Dogmas of Empiricism" (1951) that science is an outgrowth of common sense, as opposed to scepticism, which takes a dim view of it. First, the realist states that the empirical success of a theory corresponds to a real, objective facet of the world in some way. Our optimistic meta-induction gets a boost from the idea that if a sceptical scenario does not have any explanatory power, and the ordinary view of what scientists observe in the lab does, then, if abduction is a valid method at all, we would have reason to keep our positivism about the matter. Our safety check against naiveté, if we need one, is that the fallibilism we are borrowing from Popper stipulates scientific theories are hypothetical and always corrigible in principle. They are truth-like, verisimilar.

Underdetermination we found to be a logical and non-normative attack on scientific realism. Philosophers who embrace these types of arguments are anti-realists, and are properly so-called. We delineated them from the sociologists of scientific knowledge who have pronounced social agendas. We claimed there were three types of underdetermination: holistic, contrastive and transient. Larry Laudan and Jarrett Leplin pointed out that all cases of underdetermination were

[130]Auguste Comte, *A General View of Positivism* (*Discours sur l'ensemble du positivisme*), (London: Routledge, 1908).

actually transient. All three are condensable down to the epistemic scenario of the data we have at a certain time, t_1. This directs our attention to the situation that may arise at t_1 when two or more theories T, $T'...T^n$ have the same observational status. The state of affairs that obtains is known as an empirically equivalent tie. Abduction/IBE is a logical form of inference that allows empirical equivalence. It lauds this aspect of scientific discovery because it allows a Darwinistic process of weeding out bad theories.

Rival hypotheses that have not yet become fully developed mature theories, have not undergone sufficient testing within the research community and are mere hypotheses. The educated opinion of researchers which is to be corroborated or converged upon during investigation will be more verisimilar and will be considered superior to its rivals. As we confirm a theory above its rivals, ties will be broken at times t_2-t_n. Popper's falsificationist methodology weeds out inferior hypotheses as they are tested. We are always reaching for the truth, and as Hume discovered with the problem of induction, investigators may never get to a correspondent substratum of facts directly.

Abductive reasoning in conjunction with the non-empirical values of time and the scientific research community resolve the problem of empirical equivalence of scientific theories. Time itself is an important variable, it is quantifiable, and fits easily into a formal logical sentence more economically than Laudan and Leplin's clumsy citation of technological progress (which may or may not harbor a number of tacit assumptions). We found we could easily make our view into a falsificationist practice. "At time t_2, theory *x* was proven false," would be the falsifying statement. It is clear, simple, concise and objective, and clears the way for more viable alternatives. IBE contends that antecedently we do not have the answers. A falsificationist methodology would help narrow down the empirically equivalent theories as new observations arose. It is beneficial to our

point that all cases of empirical equivalence are cases of transient underdetermination, and that "normal science" progresses in such a way that as time moves forward in a linear fashion more technology arises such that we can perform more sophisticated tests, and further the weeding out of theories, even though technology may not be as great of a concern as the precise quantification of the statements of science.

The beauty of Peirce's philosophy of science really doesn't even come to light until one deals with the situation of empirically equivalent theories. IBE normally uses standardized non-empirical virtues when a theory is adduced, although the addition of time and the research community provide excellent checks that a *bona fide* scientific investigation is underway. I argue that this stays close to Peirce's original formulation, and that it is beneficial to science that it proceeds by elimination.[131] If we add all these factors, and nix correspondence in the process, we have not only a way around the problem of empirical equivalence, but a way in which to see it as inextricably *linked* to science (abduction/IBE may be a way around the problem the problem of induction as well).

There may be a huge tension between Humean scepticism and our positivism about abduction/IBE. Western philosophy might do better to simply avoid the problem of induction. Peirce might say with us, *avoid uncertainty*.[132] Scientifically plausible unconceived alternatives are not actively in the running *per se*, and I think their mention within the debates about empirical

[131]One morning you enter the kitchen to find a plate and cup on the table, with breadcrumbs and a pat of butter on it, and surrounded by a jar of jam, a pack of sugar, and an empty carton of milk. You conclude that one of your house-mates got up at night to make him- or herself a midnight snack and was too tired to clear the table. This, you think, best explains the scene you are facing. To be sure, it might be that someone burgled the house and took the time to have a bite while on the job, or a house-mate might have arranged the things on the table without having a midnight snack but just to make you believe that someone had a midnight snack. But these hypotheses strike you as providing much more contrived explanations of the data than the one you infer to. Igor Duoven, "Abduction", *The Stanford Encyclopedia of Philosophy* (Summer 2021 Edition), Edward N. Zalta (ed.), URL = <https://plato.stanford.edu/archives/sum2021/entries/abduction/>.

[132] Charles Peirce, "How to Make Our Ideas Clear," in *Popular Science Monthly* 12, (1878).

equivalence and the progress of science amounts to basically a mental exercise. We are simply led back to our original concern of empirical equivalence. If one has worries, Popper's falsificationism warns us that we should choose the theory that has undergone and passed the most tests. Anything "unconceived" doesn't even seem testable.

If empirical equivalence is a phase in the development of science, the alleged problem here vanishes, in favor of a mere description. The oxygen theory of combustion had been around before its adoption and the succession over the phlogiston theory by Lavosier. A time index is adequate here because after time t_2 the oxygen theory overtook the phlogiston theory of combustion. At time t_1, being a mere hypothesis in Dr. Scheele's mind in a loaned laboratory outside of Stockholm Sweden, suddenly became the best running theory of combustion due to Lavoisier's continued experimentation. How did this transpire? Time and research community. After time t_2 the oxygen theory was the best theory around. At time t_1, a mere hypothesis. The research community increasingly saw the value in Lavoisier's published work. As more educated opinions converged upon Lavoisier's theory, it completely overtook the phlogiston theory, and he was subsequently inducted into the Royal Society of England.

Even armed with fallibilism, perhaps there is still some murk in these waters. The non-empirical virtues leave room for debate. Although for a pragmatist, we discovered descriptively that the need for a hard truth predicate is unnecessary due to the movement of science and the ways in which theories actually come into the fore. That there will always be empirical equivalents to our best running theories has seemed to be the case, meta-induction or no. Empirical equivalence is reminiscent of the problem of induction itself, and also a little bit like the problem of the criterion. When faced with problems like these, one is struck with a sophomoric glow of awe and wonder. Sextus Empiricus writes:

> Those who claim for themselves to judge the truth are bound to possess a criterion of truth. This criterion, then, either is without a judge's approval or has been approved. But if it is without approval, whence comes it that it is trustworthy? For no matter of dispute is to be trusted without judging. And, if it has been approved, that which approves it, in turn, either has been approved or has not been approved, and so on ad infinitum.[133]

How will we actually know when we get it right? Philosophy, perhaps like science itself, can get closer maybe to an answer, although we are not sure if we will ever reach that zero point.

[133] Sextus Empiricus, *Outlines of Pyrrhonsim* (Buffalo: New York: Prometheus Book, 1990).

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