# CHAPTER 2: THE CHALLENGE OF UNDERDETERMINATION THESIS TO SCIENTIFIC REALISM FROM THE PERSPECTIVE OF THEORY CHOICE

## 2.1 Introduction

Scientific realism is a view that believes in the existence of a mind-independent unobservable entity and process that told by scientific theory. Unobservable entities and processes are postulated to be either too tiny or too far to be seen with naked eyes, such as DNAs, black holes, quarks, electrons, quantum fields and so on. These unobservable entities and processes are needed to provide a unified scientific framework that can consistently accounts for the reality. According to the semantic thesis of scientific realism, one can conclude that the unobservable entities populate the world along with the observables if the scientific theories are true (Psillos 2003, 60).

Unobservable entities are regarded real because they are posited to exert influence on the observable phenomena. Scientific realists assert that scientific theory can be formulated from the experimental results which derived from the observed phenomena. They hold that rational theory choice is possible with the assumption of a one-to-one correspondence of theory and evidential evidence. The correspondence between the theory and the reality is commonly held among realists (e.g., Boyd 1989; Chakravartty 2007; Ladyman and Ross 2007).

Antirealists who espouse underdetermination thesis present a challenge to scientific realists' account of rational theory choice. Underdetermination thesis maintains that

crucial experiment is impossible because theory is underdetermined by the evidence. Scientists are unable to rationally choose among rival theories which entail identical observational consequences. Antirealists claim that a choice of theory is always influenced by other non-truth factors such as simplicity, aesthetic standard, empirical adequacy, popular community view, and personal favoritism.

Scientific realists must exhibit that, given two or more sets of observed data, a crucial experiment is possible to arbitrate the favorable theory among the rivals. Failure to do so will result in a dubious one-to-one correspondence between theory and reality, which is the main maxim of scientific realists. Hence, scientific realists need to defend the possibility of theory choice in order to convincingly show the strict correspondence between theory and reality. However, antirealists' underdetermination thesis which denies the possibility of crucial experiment has presented a serious challenge to scientific realists' account of theory choice.

In this chapter, I will first provide an overview of the theories of truth (section 2.2). Then, I proceed to discuss the scientific realists' criterion of truth (section 2.3). This criterion contributes to the realists' understanding of theory choice. I then proceed to elaborate the versions of underdetermination thesis (section 2.4). Duhemian underdetermination thesis will be discussed at length (section 2.5) because this is the agreed standard version which receives defense and attack widely from antirealists and realists. I discuss the most naïve realist's attack on underdetermination thesis (section 2.6) which is now deemed impotent due to its misinterpretation of the observation statement.

In section 2.7, I illustrate how the different arguments towards unobservable entities and processes lead to the divergent stance of theory choice between scientific realists and antirealists. The issue of empirical equivalent evidence is discussed in section 2.8 where the philosophical role of quantum physics in the problem of theory choice is discussed at length. In addition, underdetermination in biological science is also discussed in this section to provide a perspective of non-physical science to the issue. Lastly, a concluding remark will be provided in section 2.9 for this chapter.

## 2.2 The Theories of Truth

Truth is the central theme of philosophy ever since the Ancient Greek philosophy. It was first discussed in epistemology, and recently in philosophy of language and philosophy of science in the twentieth-century. In philosophy of science, truth is an implicit assumption of scientific realists, pragmatists and relativists for each of their philosophical quest, although they do not come to an agreement about what truth is. Regardless a wide range of diverging accounts of truth, van Fraassen, an anti-realist, holds that it is common to perceive truth as a virtue which cannot be logically separated from the explanatory power of a theory (Fraassen 2002, 56). There are three major distinct theories of truth, which are correspondence, coherence, and pragmatist theory of truth. Glanzberg dubs them as the "neo-classical theories of truth" (Glanzberg 2006).

The correspondence theory of truth assumes the correspondence between a belief and a fact/reality. From the semantic point of view, the belief is a truth-bearer which expressed

as observational sentence that describes the external fact. A belief is true if there exists a fact as described. If there is no corresponding fact, the belief is false. This version of truth theory is popular among scientific realists. Since correspondence theory of truth presupposes the ontology of external fact, its proponents are likely being what Putnam calls “metaphysical realists” (Putnam 1990).

The main objection to the correspondence theory is that it is too obscure. The correspondence relation is impossible to be clearly defined, consequently results in a broad range of corresponding facts (David 2002).

To counterattack the objection, correspondence is always interpreted by scientific realists as an isomorphism between beliefs and facts (David 2002). It provides a structural identity between beliefs and facts at two levels. The first level of isomorphic relation is the semantic identity. Beliefs are construed as concepts or words about the facts (David 2002). The second level of isomorphic relation is the ontological identity. It claims that the semantic structure of observational sentences is identical to the ontological structure of the external facts (David 2002).

It is hard to reduce the observational statements to the external facts. Imagine an observational statement “the snow is white” and an external fact “the white snow exists”. According to the correspondence theory, the observational statement is true if and only if the external fact obtains. That is to say, the observational statement about the color of the snow is made on the basis of the fact that snow is white in color. However, even if the

observational statement and external fact are compatible, the question of how and why such a correspondence takes place is still remained elusive.

One of the popular accounts that has been much discussed is Wittgenstein's "picture theory" of meaning (Horwich 2009, 597). It is a pictorial configuration between elementary propositions and atomic facts. Picture theory asserts that

> … an elementary proposition is a configuration of primitive constituents, an atomic fact is a logical configuration of simple objects, an atomic fact corresponds to an elementary proposition (and makes it true) when their configurations are identical and when the primitive constituents in the proposition refer to the similarly placed objects in the fact, and the truth value of each complex proposition is entailed by the truth values of the elementary ones.
>
> (Horwich 2009, 597)

This account of correspondence theory is not without problem. The concept of atomic facts is vague and impossible to be specifically defined for all existing external facts. Besides, the distinction between atomic facts and compound facts in Wittgenstein's picture theory is yet another problem to tackle. Notably, the later Wittgenstein has admitted the difficulty in defending his early correspondence theory by switching to a pragmatist and antirealist stance.

The correspondence theory of truth is hard to defend because it, though may not be claimed explicitly by realists in their notion of truth, presupposes: (1) the existence of mind-independent reality; (2) the reality in which human resides is the only world; (3) other possible worlds (e.g. that of Leibnizian and Lewisian versions) do not exist because (4) there is one-to-one correspondence between theories and reality; (5) a true theory

always corresponds to reality; (6) the reality consists of observable and unobservable entities and processes. Although a realist may reject some of these presuppositions, an anti-realist may legitimately hold that these assumptions are innate to the realist notion of the correspondence truth. To defend the correspondence theory, scientific realists have to explain not only how a true theory always corresponds to reality without exception, but also to explain how to justify this correspondence relation. This task is particularly difficult in justifying the correspondence between theories and unobservable entities without inviting skepticism. However, scientific realists are unable to discard the presupposition of unobservable (eg., Black hole) because it is always used to explain the successful prediction of a theory (eg., detection of time-space bending around black hole).

Notwithstanding the objections, J.J. Smart has rightly pointed out that the rejection of the correspondence theory does not mean that there are no correspondences between reality and observational statement (Smart 1999, 109). The main predicament of correspondence theory lies in accounting the strict point-to-point correspondence between reality and proposition.

The coherence theory of truth is the rival of the correspondence theory. It requires semantic verifiability of a belief. The coherence theory is different from the correspondence theory in two respects. First, the relation between propositions and truth conditions is coherence in the coherence theory while correspondence in the correspondence theory (Young 2001). Second, the coherence theory holds that the truth conditions of propositions consist in other propositions (Young 2001). For the

proponents of the coherence theory, a belief is true if all of its propositions are coherent. A belief is false if there is any contradiction among the propositions. The coherence theory does not require the corresponding external facts in determining the truth. Neurath, a typical advocate of the coherence theory, holds that the truth of a statement is only judged by "seeing whether it coheres with other empirical statements" (Misak 2005, 88).

There are two major versions of the coherence theory. The first version requires consistency in the coherence relation among propositions (Young 2001). The second version requires logical entailment in the coherence relation (Young 2001). Both versions require a holistic verification among a web of interconnected propositions, which is too strong a requirement for establishing a true belief because such interconnected propositions may plausibly be infinitely many. Unlike the correspondence theory which states that the truth conditions of propositions are the objective reality, the coherence theory asserts that the truth conditions of propositions consist in other propositions (Young 2001). The main problem of coherentism is that one is delimited within a system of propositions when she is verifying the truth of her proposition. A coherentist has no way to claim that a particular proposition is true (i.e. an external fact) by making a recourse to the reality. Granted that we have a perfectly coherent propositions or coherent physical theories, there is no guarantee that they are perfectly matched with the reality. This holistic view of coherence theory invites troubles as there could exist several conflicting but coherent systems of belief (Horwich 2009, 598). Hence, coherence theory does not guarantee the correspondence-truth. Some critics of coherentism, Horwich for example, even argue that "truth predicate exists solely

for the sake of a certain logical need." (Horwich 1990, 2; cited in Field 1992, 321) However, it is also argued that increasing coherence of a belief is linked to progress towards truth because a true belief is always coherent (Kuukkanen 2007).

As a minimalist, Horwich argues against the traditional theories of truth, including the correspondence theory, coherence theory and some form of verificationism (Horwich 2004). According to Horwich's minimalism, the expression " 'is true' is not used to attribute to certain entities (i.e. statements, beliefs, etc.) an ordinary sort of property—a characteristic whose underlying nature will account for its relations to other ingredients of reality." (Horwich 1990, 2; cited in Field 1992, 321). Rather, the function of the truth predicate is to make possible the generalization of a proposition. The minimalist theory of truth will take the proposition that '*p* is true if and only if *p*' to be a sufficient account of truth, without assuming that such proposition is corroborated by an underlying entities. For Horwich, the coherence theory of truth is as problematic as the correspondence theory of truth.

Coherence theory of truth presents problem in theory choice between rival scientific theories. Since the coherence theory does not guarantee truth, it is impossible to make a rational choice among several equally coherent theories. There is no ground to claim that one coherent theory is truer than its equally coherent rivals. In addition, it is impossible to precisely and objectively determine the degree of coherence by holding that one theory is more coherent or less coherent than its rivals. Thus, it seems questionable for coherence relation to serve as a criterion of theory choice.

However, the main strength of the coherence theory over the correspondence theory is that it provides "a more realistic and feasible account of the way in which beliefs are justified."(Alcoff 1999, 228). For coherence theory is more convincing in demonstrating the rigorous semantic relation between beliefs. If a belief is true, its justification is apparently clear to grasp.

The pragmatist theory of truth does not assume corresponding external facts or coherent relation among propositions, though it would not reject both of them. Pragmatists hold that truth does not require an ontological status (as in the correspondence theory) or a semantic relation (as in the coherence theory) in order to be validated. In fact, the only virtue of a true theory is being pragmatic. A theory is deemed true, according to pragmatist, if it serves a pragmatic purpose such as usefulness (e.g., useful in industrial application, prediction, proliferation of theories, etc).

Pragmatist theory of truth is originated from American Pragmatism. Pragmatist theory characterizes truth as the aim of inquiry. The aim of inquiry constitutes a wide range of objectives, such as simplicity, applicability and so on. Pierce, one of the most prominent advocates of the pragmatist theory of truth, defines truth as the aim of inquiry and expectation that set up for inquirers to acquire (Misak 2005, 149). Truth is obtained as long as the aim of inquiry has achieved. It is not necessary to go beyond the aim of inquiry (such as the corresponding external facts) in the quest for truth. Pragmatists claim that

> Once we get what we aim at in inquiry, once we get the very best inquiry could produce, we have true beliefs. There is no further step to be taken. There is nothing further to aim for in the search for truth. There is nothing to be gained by wondering whether such a belief is really true.
>
> (Misak 2005, 149)

The aim of inquiry is grounded in true belief. Pragmatists take the true belief as the characteristic of truth which is a good basis for scientific activity (Horwich 2009, 598). However, this interpretation is circular as true belief has to recourse to truth to justify itself, but truth is defined in terms of true belief. It is noteworthy that since pragmatist theory is a form of perspectivism, it is conceivable that truth according to the pragmatist can possess pluralistic meanings. For example, a scientist may have a belief that a true theory is always simplest in its mathematical form. However, he still needs to account for the truth of his belief (simplicity), otherwise his belief about truth is not justified because true belief is the characteristic of truth. In this example, believing that this is a true belief (simplicity) is likely to be a mere good will which is arbitrary. The position of pragmatists is at a stone's throw from relativism. It is so because the pluralism and the pragmatic utility embraced by a pragmatist are two aspects that can be found in relativism. The arbitrary elements that are usually implicit in these aspects thus draw pragmatist and relativist closer. Though some pragmatists may not hold a relativist position about truth, they need to explicitly make clear that their notion about the pragmatic goal of science is pragmatic yet non-relativistic in nature.

The proponents of correspondence and coherence theory of truth are representationalists. Pragmatists, on the other hand, are antirepresentationalists who reject the mirroring

relationship between theory and reality. Representationalists construe knowledge as a representation of the reality. This account assumes the dualism of knowledge/reality, and a bridging principle that seamlessly connect these two distinct domains. Rorty, who dubs himself as an antirepresentationalist, urges to abolish the dualism of knowledge/reality and the traditional epistemology (Nielsen 2003, 267). He defines antirepresentationalism as "a matter of acquiring habits of action for coping with reality." (Nielsen 2003, 267). Contra to representationalists, who are necessarily realists according to Rorty, antirepresentationalists do not think that there is one and only one way the world is in itself. Rorty believes that scientific progress, from the perspective of antirepresentationalists and pragmatists, "is a matter of finding ever more effective ways to enrich human life." (Rorty 2007, 134) In Rorty's account, knowledge does not represent reality but converge on reality (Nielsen 2003). He holds that we do not have certainty about the reality (Nielsen 2003, 270). Rorty's account does not abolish the theory of truth but invites agnosticism about reality into science.

### 2.3 An Overview of Scientific Realists' Criterion of Truth

Scientific realists advocate correspondence theory of truth. They claim that a true scientific theory must correspond to the scientific entities. They hold that truth is the only epistemic criterion of theory choice. This criterion is asserted with three assumptions:

i) Truth does exist and can be found.

ii) There is only one truth for each physical phenomenon.

iii) Truth is the last resort to warrant an objective and rational scientific activity.

Assumption (i) drives scientific realists to believe that the rational aim of science is getting closer towards truth. Although they may have a disagreement of the current status of science in the search for truth, they believe that truth is the goal of science and there is an ultimate truth at the end of the journey of science. This epistemic optimism derives from scientific realist's central doctrine that "science can and does attain theoretical truth no less than it can and does attain observational truth" (Psillos 1999, xx), where the theoretical truth posits the existence of unobservable entities and processes (Psillos 1999) in explaining the observational phenomena. Since scientific realists hold that scientific theory explains the reality, and they assume the correspondence between theory and phenomenon, the assumption (ii) is thus the corollary. They believe that there is only one reality and hence there should not have a multiplicity of true theory.

Assumption (iii) is best exhibited in Putnam's 'no miracle argument', which claims that the explanatory and predictive power of science do not make the success of science a miracle. However, it has been widely challenged by three rebuttals (Psillos 1999). First, it is circular because it is itself an instance of inferential rule it attempts to defend for the reliability of the thesis of inference to the best explanation (IBE). Second, if 'no miracle argument' is favorable, we have to admit that the history of science is a series of abandoned IBE at that historical period of time. Hence, it is reasonable to claim that a currently successful theory may turn to be a false theory in future. Third, the underdetermination of theory by evidence denies that there is a possibility of rational theory choice.

The assumption (i) as illustrated above is a consensus among many scientific realists, anti-realists and relativists, though pragmatists and constructive empiricists may hold that truth is not the primary criterion for theory choice. The assumption (i) is irrelevant to my thesis of theory choice and hence will not be discussed. The assumption (ii) signifies different meaning of truth to scientific realists, anti-realists and relativists, respectively. It is an issue of the nature of truth. For different proponents, different views of the nature of truth lead to the identification of either there exists a single absolute truth or an array of relative truths. The view on the nature of truth is significant in determining theory choice. In next section, I am going to discuss the challenges of underdetermination thesis posed to scientific realism, which is a threat of anti-realists to the assumption (iii) of scientific realists.

## 2.4 Versions of the Underdetermination Thesis

There are three popular categorizations of the underdetermination thesis. They are underdetermination in terms of methodology, of scope and of degree.

Psillos holds that there are two types of underdetermination thesis in terms of methodology. First, deductive underdetermination asserts that the relation between evidence and theory is not deductive (Psillos 2005, 1). In other words, the truth of a theory is not deductively justified regardless what the evidence is (Psillos 2005, 1). Psillos claims that evidence cannot adjudicate between rival theories because the auxiliary assumptions, which are entailed by theory with evidence, may change over time.

Change of auxiliary assumptions will lead to the evidential shift which may favor the rival theory (Psillos 2005, 1-2).

On the other hand, Psillos identifies inductive underdetermination as a second type of underdetermination thesis which rests on the claim that no evidence can prove a theory (Psillos 2005, 2). However, it is known that the evidence can confirm a theory on the scale of probability. The confirmatory role of evidence is empowered by assigning different initial probability to the rival theories (Psillos 2005, 2). Psillos argues that initial probability does not have epistemic force because its source is questionable (Psillos 2005, 2-3). Thus, inductive underdetermination leads to the conclusion that any evidence cannot confirm a theory probable (Psillos 2005, 2-3).

Magnus interprets underdetermination thesis in terms of scope. He argues that the scope of underdetermination has to be identified, which is specific to the investigated subject matter (Magnus 2004, 4). He defines scope as "the range of circumstances across which responsible choice is impossible" (Magnus 2004, 4). According to Magnus, the scope of underdetermination "includes not only our present circumstance but also most any circumstances we can expect to find ourselves in" (Magnus 2004, 4). The consequence of this version of underdetermination thesis, according to Magnus, is that it allows a "widespread underdetermination" where "the choice among *all or most rival theories* is underdetermined in a similar way" (Magnus 2004, 5). However, this version of underdetermination thesis exposes the impossibility of exhaustively enumerating all rival theories in the scope. Furthermore, it will inevitably lead to epistemological skepticism

because the scope of underdetermination expands wider in the course of scientific development. Magnus can hardly avoid skepticism because his notion of "scope of underdetermination" aims to include as many potential rival theories as possible.

The third version of underdetermination thesis is defined in terms of scope, that is, weak/local underdetermination and strong/global underdetermination (Ladyman 2012). The weak underdetermination is concerned with practical scientific problem, which may implicate genuine problem of theory choice (Ladyman 2012, 44); the strong underdetermination, however, is always thought to be artificial and mere imaginative construction. One of the examples of the contrived strong underdetermination is Descartes's evil demon hypothesis (Ladyman 2012, 44).

The weak underdetermination considers the significance of all gathered data in the course of scientific development. It argues that all the gathered data to date "are consistent with more than one theory" (Laydman 2002, 165). All data should be treated equally important and the judgment of theory choice should be suspended until the emergence of more precise data (Ladyman 2002, 165). There are three components in the argument of weak underdetermination:

> (1) Some theory, T, is supposed to be known, and all the evidence is consistent with T.
> (2) There is another theory T# that is also consistent with all the available evidence for T. (T and T# are *weakly empirically equivalent* in the sense that they are both compatible with the evidence we have gathered so far.)
> (3) If all the available evidence for T is consistent with some other hypothesis T#, then there is no reason to believe T to be true and not T#.
>
> (Ladyman 2002, 163-164)

On the other hand, strong underdetermination is a general form of skepticism that against a necessary connection between causes and effects (Ladyman 2002, 167). The idea argues:

> (1) We think we know the observable p.
> (2) If we know p then we must know the alternative hypothesis q.
> (3) We can't know q is false.
> (4) Therefore we don't know p after all.
>
> (Ladyman 2002, 168)

The strong underdetermination argues that it is impossible to know that the alternative hypothesis q is false because all predicted observed phenomenon is consistent with q (Ladyman 2002, 168). Therefore, there is no way to rule out alternative hypotheses in evaluating rival theories. Hence, theory choice is impossible.

### 2.5 Duhemian Underdetermination Thesis

Underdetermination thesis is a claim that scientific theory is underdetermined by evidence, where scientists cannot make a rational choice between two empirically equivalent rival theories. Underdetermination thesis holds that theory is woven with observational evidence. It goes far beyond theory-ladenness of observation by holding that a crucial experiment is impossible because the experiment cannot decide between rival theories. For "the realization and interpretation of no matter what experiment in physics imply adherence to a whole set of theoretical propositions" (Duhem 1976, 21)

Since evidence entails auxiliaries and hypotheses of theory, falsification of theory becomes impossible. Such entailment does not reveal which hypothesis in the holistic part of a theory is problematic. The equal epistemic status of each hypothesis of a theory incurs impossibility in deciding which theory outruns the rest.

Underdetermination thesis has its deeper root in setting a barrier between observation and theory. Although evidence entails hypothesis, it "does not uniquely entail a hypothesis which accounts for it." (Psillos 1999, 163) For, to ensure the one-to-one correspondence of theory to reality would unavoidably permitting unobservable entity, which is forbidden by Duhem. Unobservable entity is deemed necessary by scientific realists to account for the experimental results which cannot be explained by observed entity alone. Furthermore, it is irrational to think, as also held by Psillos (1999), that all evidence should *uniquely* entail only a single hypothesis, for it does not have a scientific ground. Hence, the adoption of observable entity without permitting the role of unobservable in choosing among rival theories, in the opinion of realists, is far more doctrinal than rational.

To save scientific realism from the threat underdetermination thesis poses to theory choice, Psillos objects the fact that the entailment of same body of observational data by rival theories implies the dilemma of theory choice (Psillos 1999). He raises two points. First, Psillos asserts that theory choice is possible as it "depends on the account of confirmation which one adopts".

> … on standard Bayesian accounts of confirmation, the mere fact that inductive inferences from a finite segment of data do not entail law-like generalisations does not show that a particular segment of data does not inductively support one law-like generalization more than another. (Psillos 1999, 163)

However, Psillos has overlooked the fact that Duhem does not think that induction and generalization are significant in the formation of new theory. Duhem points out that Newton's principle of universal gravitation is not a mere generalization of Kepler's laws (Duhem 1976, 14). He claims,

> The principle of universal gravity, very far from being derivable by generalization and induction from the observational laws of Kepler, formally contradicts these laws (Duhem 1976, 14)

Duhem goes further to explain how Newton's theory is deemed valid though it contradicts Kepler's law:

> … it [the principle of universal gravity] will also involve all the principles of dynamics; besides, it will call in the aid of all the propositions of optics, the statics of gases, and the theory of heat…. It is no longer a matter of taking, one by one, law justified by observation, and raising each of them by induction and generalization to the rank of a principle; it is a matter of comparing the corollaries of a whole group of hypotheses to a whole group of facts. (Duhem 1976, 15)

Underdetermination thesis is of empiricism as it does not deem unobservable entity valid in science. Laws and theories are justified only by observing the observable evidence (Duhem 1976, 15). It denies the role played by inference to the best explanation in theory choice. Neither does it accept induction and generalization as contributing factors in theory choice.

The second reason Psillos denies the dilemma of theory choice is exhibited by his assertion that it is rational to believe that "future evidence can favour only one of the two theories" (Psillos 1999, 163). However, his defense is weak because the contrary may be possible, viz., future evidence may not favor only one theory. Obviously, Psillos's claim is based on the view that there is a continuous progress of science towards the truth. Indeed, his good faith that future evidence will favor only one theory among rivals is amount to Putnam's God's Eye point of view, which is a metaphysical doctrine.

Hence, it is clear that the main threat underdetermination thesis poses to scientific realism is not merely that theory choice is impossible in the context of scientific development. For, a realist may argue that the impossibility of rational theory choice is a temporal issue, which can be explained by the impoverishment of human knowledge in the current state of scientific development. As time elapses, realists may argue, science progresses continuously and the cumulative knowledge can arbitrate between the past undecided rival theories. The real issue posed by underdetermination thesis to scientific realist is the impossibility of singling out one theory among rivals that truly describes the reality epistemically. Furthermore, underdetermination thesis does not favor the idea that only one theory should prevail. Hence, it is a stone's throw distance from underdetermination thesis to epistemological pluralism. In short, underdetermination thesis has undermined the correspondence theory of truth held by scientific realists.

## 2.6 Misconception of Observation Statement: A Failure of Realist's Counterattack

The core spirit of underdetermination thesis is the impossibility of crucial experiment. One of the promising ways for scientific realists to defend the plausibility of rational theory choice is to demonstrate that the observed contradiction in data suffices to falsify one of the two rival theories, thus make possible theory choice.

Gillies adopts this strategy for counterattacking on underdetermination thesis. In his first step, Gillies attributes the observation statement as a statement that can be "agreed to be either true or false on the basis of observation and experiment." (Gillies 1998, 303). He then states that Duhemian underdetermination thesis proclaims the infalsifiability of an isolated hypothesis by an observation statement. Lastly, Gillies holds that the impossibility of falsification is not true from the perspective of hypotheses as a whole. He supports his claim with the falsifiability of Kepler's first law by observation:

> Consider, for example, Kepler's first law that planets move in ellipses with the Sun at one focus. Suppose that we observe a large number of positions of a given planet and that these do not lie on an ellipse of the requisite kind. We have then surely falsified Kepler's first law. (Gillies 1998, 303)

However, the counterattack of Gillies is based on a false base. First of all, his notion of observation statement is not laden with theory. His example of the falsification of Kepler's first law by observation does not take the theory, which underlies the observation, into consideration. In other words, Gillies's account of observation statement is a direct report of mere observation without background knowledge. This crude empiricist stance has been shown to be untenable by many philosophers of science.

Theory-ladenness of observation will not favor the falsification of an isolated hypothesis by an observation statement, as what has claimed by Gillies. An observation statement is always laden with more than one hypothesis, which is woven in a larger background theory. Hence, the counterattack of Gillies is unsuccessful.

Besides, Gillies's strategy lies in a distinctive truth value of observation statement based on observation (in Gillies's sense, that is, pure observation without laden with theory). It is misplaced as the truth value of observation statement is not determined by mere observation but by theory-laden observation.

Another problem of Gillies's strategy is that he places too much weight on the power of falsification of a single observation statement instead of a range of observation statements. The contradictory reports of a single observation statement might be possibly a coincidence or false statement, for it is detached from the whole body of observation statements when we consider it alone as a sole arbitrator between rival theories. If Gillies's strategy is favorable, a choice for geocentric principle subsequent to a single observation statement "sun rises in the east and sets in the west" will seem, though it is false, to be rational.

Realists who endorse the possibility of crucial experiment are hardly subscribing to Duhemian holism of physics. In Duhem's account, "experimental verifications are not the base of theory but its crown."(Duhem 1976, 25). Duhem rejects the idea that

inductive method is the wheel of physics. It is because the facts gathered via ordinary observations and experiments are sufficient for proposing new hypotheses but insufficient to verify them (Duhem 1976). Before a physicist explains his observation in observation statement, he needs a theoretical framework for such explanation.

> … it is only after he has constituted an extensive body of doctrine and constructed a complete theory that he will be able to compare the consequences of this theory with experiment. (Duhem 1976, 25)

Thus, a holistic set of intertwining hypotheses is presumed in Duhemian account. Realists' attempt to isolate an observation statement, in favor of crucial experiment, from the whole set of theoretical structure will introduce absurdity. For, Duhem asserts that there are hypotheses whose statement has no experimental meaning (Duhem 1976, 33). It is because they are universally accepted rules that ground the experiments.

> Not only can these principles not be refuted by experiment because they are the universally accepted rules serving to discover in our theories the weak spots indicated by these refutations, but also, they cannot be refuted by experiment because *the operation which would claim to compare them with the facts would have no meaning*. (Duhem 1976, 34)

Duhem further illustrates this point by describing an experiment involving the principle of inertia. He claims that "we can observe only relative motions" (Duhem 1976, 34). We are unable to give an experimental meaning to the principle of inertia because it is the principle that the interpretation of our observation of motion is relying on (Duhem 1976). Thus, we cannot verify the principle of inertia by experiment because it would require an isolated system, which is impossible to exist:

> Can we make this verification? For that it would be necessary for isolated systems to exist. Now, these systems do not exist; the only isolated system is the whole universe. (Duhem 1976, 35)

Void of empirical meaning of theoretical principle reintroduces the predicament of theory choice. It is hard to be dissolved by realists' position which states that isolated systems do exist and it is implausible to deprive them of empirical meaning. According to antirealist, experiment is incapable to decide which symbolic part of a theory is erroneous when the disagreement arises between observation and hypothesis (Duhem 1976). Duhem advises us no matter "whatever facts we may observe, we shall hence always be free to assume our principle is true." (Duhem 1976. 35)

## 2.7 Unobservable Entities

The ontological and epistemic stance toward the unobservable entities marks the divergence between empiricists and scientific realists. The repudiation and defense of unobservable entities are argued from many angles by the philosophers of science. Realists claim that unobservable entities that constitute the reality are mind-independent. They prove such existence using the "no miracle" argument, that is, success in science is not a coincidence, and using the inference to the best explanation (IBE). However, "no miracle" argument and IBE are not persuasive as they are making inference about why one should believe in the existence of unobservable entities. It is an inference to the rational belief of the existence of unobservable instead of the proof of the real existence of unobservable. Any inference will introduce counterfactuals, which will easily expose realist's argument at stake.

The reason unobservable entities are posited by realists is to explain the observed behavior of observable entities. Due to the incompleteness of scientific knowledge at each epoch of science, realists need to assume the existence of unobservable entities, which are too tiny to be observed by scientific instruments or due to the immaturity of current techniques, underlying the observed phenomena. Such assumption helps scientists to explain the unknown entity that causes an observed phenomenon. Without the assumption of unobservable, scientists are unable to persuasively explain the observed phenomenon. In the eye of realists, abandoning the unobservable is almost amount to abandoning truth as the primary virtue of scientific enterprise.

### 2.7.1 An Argument for Scientific Realism from the Perspective of Instrumental Reliability

Boyd argues that unobservable entities explain the instrumental reliability of the methodology (Boyd 1985). He argues that both realists and almost all empiricists agree on the reliability of methodological practice of science. Such consensus presupposes that the theory-dependence of experiment and methodology must ensure the reliability of experiment. Boyd contends that empiricists fail to explain the instrumental reliability of the scientific methodology because they embrace the notion of instrumental knowledge. Besides, scientific realists and empiricists disagree on whether scientific methods "are adequate to establish knowledge of unobservable phenomena." (Boyd 1980, 616) Boyd contends that the knowledge of unobservable is plausible as it is warranted by the reliable

methodology which is determined by the background theories which are approximately true.

> The realistic account of scientific epistemology… explains the causal reliability of scientific method with respect to instrumental knowledge not by appealing to a priori principles but by assuming that the relevant background theories which determine the method's operation are approximately true and comprehensive descriptions of the unobservable causal factors which underlie the relevant observable properties of observable phenomena. Whereas the empiricist tradition proposes to reduce talk of underlying causal powers or mechanisms to talk about regularities in nature, on the grounds that knowledge of underlying powers is impossible, the realistic account maintains that our knowledge of regularities in nature is parasitic upon our knowledge of underlying mechanisms.
>
> (Boyd 1980, 626-627)

Boyd is somehow misplacing on the issue of instrumental reliability in defense of unobservable entity. He has presupposed that the ultimate virtue of instrumental reliability is the truth of the theory-dependence feature of scientific methodology. Hence, he argues that unobservable entities can warrant the truth. He accuses empiricists for subscribing to a truth-less based theory-dependent experimental methodology. He holds that empiricists' stance fail to warrant the instrumental reliability.

In short, Boyd's arguments emphasize that it is only a truth-based theory-dependent experimental methodology that will warrant the reliability of methodology in discovering truth. However, empiricists may not admit that the reliability of methodology has an important role to play in science, since they do not hold that the aim of science is to discover the correspondence truth. The proponents of underdetermination thesis may dismiss Boyd's attack by arguing that the reliability of methodology is impossible to attain, because the choice of methodologies and instruments is literally a choice of the

governing background theory. Since the theory is underdetermined by evidence, it is hence reasonable to claim that the rational choice of methodology and instrument is impossible. Thus, Boyd's use of unobservable entities to argue for the instrumental reliability does not present a serious challenge, in terms of truth, for empiricists. They may view the instrumental reliability from the perspective of pragmatism rather than of truth. Furthermore, Boyd's claim of the existence of unobservable entities does not make the choice between the rival background theories which govern two instruments or methods intuitively plausible.

Suppose that Boyd might hold that if the choice of methodology and instrument is impossible, there will be no scientific observation. Empiricists may again defense their position by contending that scientific observation is still possible without the possibility of a definite "absolute" choice of methodology and instrument. The difference between Boyd and empiricists is that the former believes in an "ultimate" choice while the latter insist on an "empirically-right" choice of methodology.

Boyd raises a strong form of attack on empiricist objection of unobservable entities by holding that empiricist account of instrumental knowledge leads to the unreliable scientific activity. It is because the repudiation of scientific realist interpretation of theory-dependent factor of methodology results in the impossibility of employing a reliable instrument (Boyd 1985, 14). He means that without recognizing the fact that a methodology is grounded in a truth-based governing theory, empiricist account of instrumental nature of theory-dependent factor of methodology cannot ensure a reliable

scientific activity to access to truth. He implies, implicitly, that empiricists are unable to employ their instruments and methodologies meaningfully at all.

Again, Boyd's attack is assuming that an instrument must base in a truth-based background theory to warrant its reliability of use. Empiricists may rebut in four ways. Firstly, Boyd does not show how a truth-based background theory of an instrument always warrants the discovery of truth. Secondly, Boyd assumes that reliability of an instrument leads to the reliability of discovering the truth. It is not necessarily the case because theory may be underdetermined by observed phenomena. Thirdly, if Boyd's assumption in the aforementioned second point is acceptable, he still needs to show that there is a connection between the reliability of truth discovery and the reliability of a mind-independent truth. To do so, Boyd has to recourse to the unobservable to account for such connection, which is looping back to the first rebuttal of empiricists. Fourthly, empiricists may argue that the reliability of an instrument is usage context-dependent. For example, a truth-based theory-laden of telescope is reliable in observing a distant star but not reliable in observing a tiny microorganism. Hence, the reliability of an instrument, unlike what was held by Boyd, is not warranted by its truth-based background theory but by its context of use.

Another approach which can be used by realists to defend scientific realism from the perspective of instrumental reliability is to follow Laymon's concept of idealized initial experimental condition (Laymon 1984). Although Laymon does not apply the concept of idealization to argue for instrumental reliability, he holds that the "idealized theories of

the measuring instruments are used to justify the employed measure of goodness of fit." (Laymon 1984, 115). He argues that idealization was adopted widely in the history of science and it would be impossible without the presumption of unobservable (Laymon 1984, 114). Realists may extend Laymon's claim of unobservable-posited idealized initial condition from securing the fitness of experiment to the warranty of instrument reliability. To do so, it is necessary to hold that a fit experiment is a reliable experiment. According to Laymon, unobservable entities explain the fitness of an experiment. Realists may go beyond to claim that unobservable entities also explain the reliability of an experiment by explaining its fitness.

Empiricists may refute this realist strategy by maintaining that the fitness of experiment embraced by Laymon is justified on the consistency between theory and evidence. Unobservable cannot justify the fitness of an experiment, as fitness is an evidential criterion which cannot be verified by unobservable entities.

### 2.7.2 Rebuttal of Realists Towards the Threats of the Theory-dependence of Experiment

Although scientific realists agree that experimental instruments and methodologies are theory-laden in their manipulation (i.e. the operation of instruments and the protocol of experiments are based on scientific principles. The operation of electron microscope is an example of this kind), they have realized that this acceptance of theory-dependence of experimentation is potentially leading to relativist appraisals of scientific theory. It is so because there is no neutral data that arbitrates between rival theories. Data are theory-

laden and they are as fallible as theories, as they are laden with theory. Theory choice is impossible as both theory and evidence are underdetermined (Chalmers 2003, 493).

> The theory-dependence thesis can be seen as opening the way to extreme skeptical or relativist appraisals of science. The results of observation and experiment become as fallible as the theories they presuppose. Not only are theories underdetermined by evidence, but the evidence itself is underdetermined. Thus, added to the problem of locating the source of a faulty prediction in the maze of assumptions that yielded it is the possibility that it is the observations involved in the counter instance that are at fault. (Chalmers 2003, 493)

To dismiss the dilemma of theory choice caused by the theory-dependence of experiment, realists may either adopt the account of the neutral experiment or demonstrate that theory-dependent experimentation does not lead to the underdetermination of evidence. The latter alternative seems more promising because the former alternative requires a realist to show that experimental instruments are not, to any extent, the products of theory. Although scientists may grant that the manufacture and operation of experimental instruments does not require knowledge of high-level theory, it is implausible to conceive of an instrument to be completely independent of scientific theory. That is to say, the advent of a scientific instrument (e.g. telescope) is always dependent on the advance in science (e.g. progress in optics).

Chalmers subscribes to the latter alternative by holding that although the operation of an experimental instrument is theory-dependent, the experimental results it produces "can be established in a way that does not involve high-level theory." (Chalmers 2003, 508). However, Chalmers does admit that there are cases where experimental results are highly theory-dependent, which he uses "argument from coincidence" to interpret the results.

Chalmers's first step is to exhibit that theory-dependence and fallibility of experiment and instrument do not lead to the indecisiveness of choice between rival theories. He claims that "the use of instruments in physics can be theory-dependent in a deep sense, but this does not prevent the data collected with their aid supporting theory, even the theory involved in their use." (Chalmers 2003, 494)

Chalmers narrates the finding of Kosso pertaining to the theory-independence of experimental results obtained through the use of theory-dependent instruments. Kosso's premise of his conclusion is that observation made through an instrument is theory-dependent (Chalmers 2003, 495). However, Kosso deems that theory-dependent observation does not entail a theory-dependent observed result, for "the theory about the object under investigation is distinct from and does not include the theory of the microscope and its interaction with the specimen." (Chalmers 2003, 495) The important argument of Kosso, which is held by Chalmers too, is that he differentiates between theory-ladenness of observation, of instrument, and of experimental result. The only way Kosso accounts for the claim that theory-independent experimental results can be obtained from the theory-dependent observation is by holding that the instrument in use does not have a common governing theory with that of the observation and experimental results.

> So, according to Kosso, (i) use of the electron microscope necessarily involves an appeal to the theory of the microscope and its interaction with the specimen, and (ii) that theory should be independent of the theory under test, a violation of which amounts to nepotism. (Chalmers 2003, 496)

The differentiation between three kinds of theory-ladenness, which are theory-ladenness of observation, of instrument, and of experimental result does not save realists from the underdetermination of evidence as stated above. What Chalmers tries to demonstrate is that the governing theory of instrument is not the same theory that governs the observation and observed results. Nonetheless, even if his argument is cogent to show such differences of governing theories, his argument does not warrant absolutely neutral data which is necessary to arbitrate between rival theories. It is because Chalmers does not show the possibility of obtaining a neutral experimental result which is required to decide between two rival theories. On the contrary, his admission of theory-ladenness of experimental result opens the way to the underdetermination of observed result by the evidence that backs the theory which laden by this observed result. Notwithstanding Chalmers's argument fails to warrant absolutely neutral data, it is still plausible that the obtained experimental data rests upon a theory that is not one of the rival theories. However, this data could not be useful to adjudicate between rival theories as the theory upon which it rests is not relevant to the context of the process of theory choice.

Chalmers has gone astray by falsely contending that the independence of theory of observed result from the theory of instrument sets the observed result free from being underdetermined by the evidence that backs the theory of instrument. Chalmers's arguments fail to show (i) the reliability of instrument in obtaining the observed result, as he claims that instrument is theory-laden which in turn leaves the underdetermination of theory by evidence unsolved; (ii) the underdetermination of observed result by *any* evidence can be avoided. For (ii), one still can further hold that the observed result, if not

underdetermined by the evidence underlying the theory of instrument, is possibly underdetermined by the evidence underlying the theory that loaded by observed result.

Chalmers's distinction between the governing theory of observation, of instrument and of observed result incurs in the impossibility to interpret the observed result in the light of the theory of observation and of instrument. Chalmers has adopted the "arguments from coincidence" to "vindicate both the data and the theory used to interpret that data" (Chalmers 2003, 506). The reason for such vindication is that the use of instrument which is theory-dependent "seems to threaten the extent to which the output of those instruments can act as an independent arbiter of theory" (Chalmers 2003, 493). He recognizes that "the only plausible explanation of the match between theory and data is the validity of both" (Chalmers 2003, 506). However, he attributes such match to coincidence, in the sense that "the theory and data are not conclusively established in a logical sense." (Chalmers 2003, 506) According to Chalmers, the match between theory and data does not confirm the theory. Rather, such match may be influenced by a variety of factors, all of which are coincidental to yield the predicted result. For Chalmers, there is no empirical way to demonstrate the validity of the match between theory and data, but to accept such validity as empirically coincident yet genuinely and necessarily so. Though Chalmers claims that the coincident match between theory and data is a "logical possibility", he has recognized that only the "suitable arguments from coincidence can provide convincing arguments for the truth of the interpretation of data." (Chalmers 2003, 507). In other words, though Chalmers grants that the data produced by theory-

dependent instruments can validly be used (in principle) to arbitrate between rival theories, he does not hold that *any* data can serve as a *decisive* arbiter of theories.

Chalmers's "argument from coincidence" is based upon the fact that there are always alternatives of theory choice. He claims that theory choice is possible but it does not lead to the disclosure of total truth but a portion of truth. Notably, Chalmers is by no means an epistemological relativist. The "argument from coincidence" presupposes the validity between the data and the matching theory but such match is a coincidence in the context of truth. Chalmers provides a detailed illustration with the example in the history of science:

> One of the three series of tests carried out by the Eddington eclipse expedition to investigate deflection of starlight by the sun gave a result that matched very closely the prediction of Newtonian gravitational theory. Did this match confirm Newton's theory? No it did not. There was independent evidence that this particular series of measurements could not be trusted because the telescope had become distorted by the heat of the Sun. The match between theory and data turned out to be a mere coincidence. (Chalmers 2003, 506)

Chalmers further narrates:

> Similarly, the Hirsch theory of image formation was confirmed insofar as it got it right about a range of otherwise unexpected detail in the images. But the fact that these theories got it right about the experimental phenomena in question does not mean that they get it right about everything… Perrin's brilliant experiments on Brownian motion left no room for doubt that the kinetic theory correctly predicts the basic features of that motion…Did this establish the kinetic theory in its generality? Well, no it did not, because that theory is false and gets it wrong about the specific heats of gases. (Chalmers 2003, 507)

Chalmers claims that "the arguments from coincidence do constitute support for those theories, but support that falls short of proof" (Chalmers 2003, 507). What Chalmers

means is that the match between theories and data implies the correctness of a high-level theory but does not prove its correctness in all aspect. In other words, Chalmers holds that a single experiment is far from establishing a total truth.

> Arguments from coincidence of the kind in question do not establish the truth of the theories involved but they do put important constraints on future modification or replacement of those theories. The modified or replacement theories need to explain the success of the replaced theories in the arguments from coincidence in which they figured, otherwise we are left with the coincidences. Modern theory of the electron microscope has developed well beyond Hirsch's early efforts but is able to grasp the sense in which the latter's theory was "basically correct" just as he claimed. (Chalmers 2003, 507)

Chalmers's "argument from coincidence" is established to explain how does the theory-dependent experimental result possible to decide between rival theories and "survive the subsequent theory change" (Chalmers 2003, 507). His arguments imply that there is a possibility of multiple rival theories which explain the phenomena equally well. The sole reason a scientist chooses a theory over another is that it supports the high-level theory.

Chalmers's account of rival theories is not a set of contradicting and incommensurable theories but replaceable in the course of the development of science. Chalmers's declaration of the independence between theory of observation, of instrument and of experimental result does not save the experimental result from being equally well explained by rival theories. Hence, Chalmers can hardly escape from the attack of underdetermination thesis because the substitutability of rival theories implies that theories are underdetermined by evidence. "Argument from coincidence" does not rationalize the choice of one theory over its rivals.

### 2.7.3 Can Hacking's Manipulated Unobservable Overcome Underdetermination Thesis?

Scientific realists diverge on the "argument from coincidence" in accounting the match between theory and data. Those subscribe to this conception are the proponents of truth-based governing theory of instruments such as Boyd and Chalmers, as discussed above. They claim that the reliability of an experimental instrument must be warranted by truth of its governing theory.

However, there is another group of scientific realists, one of the representatives is Hacking, who has rejected the "argument from coincidence" as the sole explanation to account for the possibility of theory choice. They do not conceive the reliability of experimental instruments in terms of truth-based governing theory. On the contrary, they claim that the reliability of an instrument is warranted by its manipulation.

> Thus I do not advance the argument from coincidence as the sole basis of our conviction that we see true through the microscope. It is one element, a compelling visual element, that combines with more intellectual modes of understanding, and with other kinds of experimental work. (Hacking 1985, 148)

Hacking maintains that "argument from coincidence" alone is insufficient to verify a true match between data and theory. For him, the use of instrument does not lead an observer straight to truth. He holds that additional conceptions are required to explain the experimental results.

> … Only a greater understanding of what a gene is can bring the conviction of what the micrograph shows. We become convinced of the reality of bands and

> interbands on chromosomes not just because we see them, but because we formulate conceptions of what they do, what they are for. (Hacking 1985, 148)

In Hacking's account, though he does not claim explicitly, the use of instrument alone is incapable of arbitrating between rival theories to explain the experimental results. He requires additional theories or conceptions on top of the use of instrument in theory choice. In the example given by him, he implies that additional background theory is required in explaining the experimental results. This additional background theory includes high-level theory and the relevant scientific principles and laws.

> Biological microscopy without practical biochemistry is as blind as Kant's intuitions in the absence of concepts. (Hacking 1985, 148)

The requirement of additional background theory leads Hacking unavoidably into the dilemma of Duhemian underdetermination thesis, for he needs to answer how to arbitrate between rival theories when crucial experiment is impossible in the holistic context of theory.

To do so, Hacking has recourse to unobservable entities. Unobservable entities "are regularly manipulated to produce new phenomena and to investigate other aspects of nature." (Hacking 1984, 154) Hacking goes further to contend that unobservable entities are real in the sense that they can be manipulated to produce new phenomena.

> Only at the level of experimental practice is scientific realism unavoidable—but this realism is not about theories and truth. The experimentalist need only be a realist about the entities used as tools. (Hacking 1984, 154)

> Electrons are no longer ways of organizing our thoughts or saving the phenomena that have been observed. They are now ways of creating phenomena in some other domain of nature. Electrons are tools. (Hacking 1984, 156)

Hence, it is clear that the reason Hacking conceives unobservable entities as real is because they are tools. He interprets realism not in terms of epistemology and ontology but in terms of experimentation. His position is known as entity realism which takes "middle ground between scientific realism and empiricist antirealism" (Clarke 2001, 701). It is a position that maintains realism about causal explanation (Clarke 2001, 702). According to Hacking, unobservable entities are real not because they are governed by underlying truth or real-in-itself, but because they are able to be manipulated to produce new observable phenomena.

> *The vast majority of experimental physicists are realists about entities but not about theories*. Some are, no doubt, realists about theories too, but that is less central to their concerns. (Hacking 1984, 155)

Hacking differentiates between two important experimental contrasts, which are realism about entities and realism about theories (Hacking 1984, 156). He confers temporal attributes to them. In his opinion, realism about entities aims at the experimental entity presently when the experiment is taking place. However, realism about theories aims at the truth, which is "something about the indefinite future." (Hacking 1984, 156) The former is neutral between values while the latter requires adoption of certain values (Hacking 1984, 156).

Hacking adopts realism about entities. He holds that a scientist does not need to take stance on the controversy between two rival theories in order to carry out an experiment.

Experiment is value-independent rather than value-dependent. As such, it seems that theory change would have little or no impact on the experimental practice, if one is to follow Hacking's arguments. It appears to Hacking that it is the experiment that determines and drives the theory change, and not the other way round. The issue of the continuity of experimental practice across theory changes has never been raised by Hacking as an issue that is worth paying attention to.

> Various properties are confidently ascribed to electrons, but most of the confident properties are expressed in numerous different theories or models about which an experimenter can be rather agnostic. Even people in a team, who work on different parts of the same large experiment, may hold different and mutually incompatible accounts of electrons. (Hacking 1984, 156)

Hacking claims that the chief role of value-independent experiment "is the creation of phenomena." (Hacking 1984, 155) Unobservable entities, such as electrons, are deemed real because they can be manipulated to create observed phenomena. In Hacking's account, real observed phenomena cannot be created out of void. Thus, unobservable entities must be real ontologically and experimentally.

One may question Hacking by asking "how do we know it is always the case that the observed phenomena must be produced by some unobservable entities, whose existence cannot be directly empirically verified? Isn't it too doctrinal by holding that unobserved entity is the cause of observed phenomena?"

This question is posed at an ontological level and ignoring the fact that Hacking has differentiated two kinds of real unobservable entities, which are experimental real entities

and ontological real entities. Experimentation commits one to believing that an unobservable entity is real in the sense that it is manipulate-able but suspending the issue of existence. Manipulability of experimental real entities commits us to their existence when they are manipulated to experiment on something else.

> Experimenting on an entity does not commit you to believing that it exists. Only manipulating an entity, in order to experiment on something else, need do that. (Hacking 1984, 156)

An experimental entity may be hypothetical though it is real in terms of manipulability. But once it is used to manipulate other things, it will be conceived as ontologically real.

> At that time this postulated "neutrino" was thoroughly hypothetical, but now it is routinely used to examine other things. (Hacking 1984, 168)

The link from experimental real entities to ontological real entities is a causal property that explains the manipulation of unobserved entities on other entities. (Hacking 1984, 170) Thus, the aforementioned question is not a real threat to Hacking's account of unobservable entities because it assumes the causal relationship to be held firmly in the production of observed phenomena, which is agreed by Hacking too. The main point in Hacking's claim is not about the fact of ontological existence of the cause of observed phenomena, which is unobservable entities, but the fact of experimental existence of the causal relation of the manipulation that takes place in an experiment. In other words, when Hacking maintains that an unobservable entity is real, he implies that it exerts causal relation, which is its manipulability, on other entities to yield observed phenomena. Unobservable entities are real ontologically because they are warranted by the causal

relation that they exert. Without viewing unobservable entities in the context of causal relation, it is meaningless of saying an unobservable entity exists ontologically.

> The best kinds of evidence for the reality of a postulated or inferred entity is that we can begin to measure it or otherwise understand its causal powers. The best evidence, in turn, that we have this kind of understanding is that we can set out, from scratch, to build machines that will work fairly reliably, taking advantage of this or that causal nexus. Hence, engineering, not theorizing, is the best proof of scientific realism about entities. (Hacking 1984, 170)

Hence, causal relation, which is the experimental manipulation of unobservable entities on other entities in yielding new observed phenomena, plays a significant role in theory choice in Hacking's realist account. Hacking's value-independent characteristic of experiment requires additional background theory to decide between rival theories, as elaborated above. To make theory choice possible, Hacking's conception of experimental manipulability is the key.

Hacking is subscribing to the general manipulability theory:

> Causes can be understood as "handles" for bringing about effects in the sense that causes can be manipulated to bring about different outcomes. (Waters 2008, 5)

To manipulate the unobserved entities such as electrons, scientists need to have their aim and background theory that drive such manipulation. As we have seen that Hacking holds that experiment is value-independent, which is not theory-driven, theory is serving as a secondary aiding tool, which is not a primary guide, that helps an experimenter to carry out an experiment.

In fact, Hacking's conception of experimental manipulability which rejects the traditional role of theory in experiment inevitably suggests an exploratory nature of experimentation. Exploratory experimentation is an account of scientific practice that was proposed by Friederich Steinle and Richard Burian independently in the 1990s (O'Malley 2008, 2). It is a variant of Hacking's account of experimental manipulability. Exploratory experimentation is exploratory in nature which is not always guided by theory (Waters 2008a, 2). It is "theory-informed" instead of theory-driven (Waters 2008a).

However, theory-informed exploratory experimentation is not totally free of theory (Waters 2008a, 3). Theory is not playing a governing role but a secondary aiding role in experimentation. To make an analogy, theory-informed exploratory experimentation makes use of theory as its wheel, not as a steering as in the theory-driven experimentation.

Theory-driven experimentation, which is the traditional account of philosophy of science, is directed by theory about what will be observed (Waters 2008a, 4). According to Burian, theory-informed exploratory experimentation "comes into play when theory does not provide expectations of what investigators will find" (Waters 2008a, 6). Most importantly, exploratory experimentation is "often conducted without specific theoretical tests in mind as new phenomena and processes are explored."(O'Malley 2008, 2) Eventually, new conceptual frameworks and bodies of knowledge are the outcomes. (O'Malley 2008, 2)

At a cursory glance, it seems that Hacking's experimental manipulability of unobservable entities and exploratory experimentation are immune from the threat posed by underdetermination thesis to theory choice. It is because Hacking has claimed that observation or experimentation is not driven by theory (except those basic ones). In other words, when the experimenters use observations to test theories, they do not need to make use of some other theories or auxiliary hypotheses, which is required by Duhemian holism, in drawing the conclusions about the expected observed outcome (Bird 2005, 175). Thus, crucial experiment is possible where a decisive abandonment of the tested theories can be made when the observation is in conflict with the prediction of that tested theories. The experimental significance of an array of other theories is not an issue here since these two approaches do not subscribe to a holistic view of theory-driven of observation. If this is the case, theory choice is thus possible.

However, the above promising possibility of decisive theory choice cannot be well defended. Firstly, it is illusory in holding that theory-informed exploratory experimentation and experimental manipulability are not all driven by theory (though Hacking does allow for *some* basic theoretical drivers, it is not sufficient to account for the experimentation which is driven by a highly specific theory). In fact, the direction of exploratory experimentation and experimental manipulation in the course of experiment is largely driven by unobservable entities, as unobservable entities are basically product of theories. Consider the case of the invisible genome of an organism. It has been widely recognized by patent attorneys and philosophers of biology that a genome consists of sequences of presentation (Bostanci and Calvert 2008, 115). Some of them assert that

genome is a computer-related invention (Bostanci and Calvert 2008, 115). Genome sequencing, which is the manipulation of invisible genes, is made possible only if geneticists base their experiment on DNA theories. Anyhow, the invisible genome is postulated not as an independent unobserved entity which can be explored or manipulated in a fashion of theory-free. Genetic materials are indeed a theory-driven entity.

Secondly, theory outlines the expected outcome even before embarking on an experiment. Theory guides an experimenter to know what to look for in the results of an experiment. The experimenter will not be able to recognize the meaning of his findings in the absence of theory. Thus, theory is not just a secondary aiding tool, as held by Hacking, but the principle that drives experiment. Furthermore, an experimenter is unable to formulate his question to put to nature without the guidance of theory.

Thirdly, it is dubious to claim that the use of experimental instruments is not driven by theory. Despite some philosophers reject the effects of governing theory of instrument in the process of observation and experimental result, they cannot deny the fact that the use of experimental instruments requires scientific knowledge in explaining the observed results. At the minimal degree, inference is always required in an observation in order to draw conclusion. Experimenters inevitably need to use theory in his inference.

> Thanks to the electron microscope the delicate threads of DNA can actually be photographed bridging the gap between one haploid bacterium and another. These photographs add a dimension to the actual experiment, which refers to the mechanism of direct genetic transfer only very indirectly and via a network of inferences, the validity of which depends upon our being ready to accept the general picture. (Harré 1984, 133)

The above quotation pertaining to the use of electron microscope suggests two things. Firstly, instrument itself is insufficient in providing explanation for an observed result. The role of instrument is limited to providing evidence for explanation. An experimenter needs to use inferences, which are based in existing scientific theories, to explain the observed evidences provided by instrument. Secondly, the explanation which results from the evidence-based inference requires a general theoretical framework for its acceptance. The theoretical framework serves as a background theory or a paradigm for an experimenter to draw his inference from. Two experimenters who are subscribing to different theoretical frameworks would arrive at different explanations on the same observed evidence.

Proponents of exploratory experimentation might possibly recourse to another strategy by arguing that the primary objective of experiment is not to explain but to describe the observed results. They may argue that the descriptive nature of exploratory experimentation does not introduce the predicament of theory choice. However, this is not a persuasive argument because description of an observed phenomenon always requires underlying theory as presupposition. To describe the observed phenomenon "sun rises at the east and sets at the west" one has already based his description in the assumption of geocentricism. Harwit's elucidation on the astronomical observation exhibits the role of theory in description:

> Any actually performed astronomical observation may be described in terms of the five parameters just discussed. We can
>
> 1 Report the spectral wavelength at which the observations were made

2 Specify the angular resolution obtained
3 Give the spectral resolution
4 State the time resolution
5 If the equipment also is sensitive to polarization, specify whether our observations tested for plane or for circular polarization of the received light

(Harwit 1984, 164)

To describe an astronomical observation in terms of spectral resolution, Heisenberg's uncertainty principle is needed (Harwit 1984, 169). Similarly, a theory for the age of the universe is presupposed in describing an observation in terms of time resolution (Harwit 1984, 169). Thus, it is apparent that descriptive experimentation is impossible without the use of theory. The strategy, which recourses to descriptive experimentation, does not overcome the predicament of theory choice.

In a nutshell, Hacking's account of instrumental manipulability and Burian's assertion of exploratory experimentation do not provide a promising way to get out of the predicament of theory choice. On one hand, Hacking's account is merely recognizing the existence of unobservable entities through manipulation of instrument instead of the conception of truth. He still acknowledges the significance of theory in explaining the experimental results. On the other hand, Burian's theory-informed exploratory experimentation does not expel theory from the domain of experimentation. Indeed, his distinction between theory-driven and theory-informed experimentation merely demarcates between the styles of experiments. Theory-grounded inference is still required in experiment to explain the observed result.

## 2.8 The Empirical Equivalence Thesis

The empirical equivalence thesis is embraced by empiricists in upholding their claim on underdetermination of theory by evidence. In the initial account of Quine, underdetermination thesis requires "theory formulations that are empirically equivalent, logically incompatible, and irreconcilable by a re-construal of predicates" (Gibson 1986, 87). A promising way for realists to defeat the predicament of theory choice is to argue convincingly that there are no empirically equivalent rival theories.

Psillos holds that underdetermination thesis bases primarily on the empirical equivalence thesis, which contends that any theory has empirically equivalent rivals (Psillos 1999, 164). It results in the entailment thesis which asserts that the entailment of same observational consequences by rival theories places constraints on rational theory choice (Psillos 1999, 164). Hence, theory choice becomes inevitably arbitrary.

According to Quine, two empirically equivalent rival theories imply the same set of observation categorical (Gibson 1986, 87). The latter is "compounded of observation sentences" that links "theory logically to observation" (Quine 2003, 10). Quine holds that observation sentences are the basic units that provide evidential support for science. They are occasion sentences "on which speakers of the language can agree outright on witnessing the occasion" (Quine 2003, 3).

Quine has enumerated several instances of observation sentences, some of which are "It's raining", "It's getting cold", "That's a rabbit", "The sun is rising and birds are singing"

and etc (Quine 2003, 3-4). The truth value of observation sentences hinges on the occasion of making an observation. They can be true on one occasion while false on others (Quine 2003, 3). To be applied in science, an observation sentence must fulfill two requirements, viz., intersubjectivity and correspondence to stimulation, in order for one to use as an evidential support for a conjectured theory (Quine 2003, 2-6).

Quine maintains that an observation categorical is compounded of two observation sentences. It forms the basis for an experimenter to test his hypothesis (Quine 2003, 9-10).

> A generality that is compounded of observables in this way—'Whenever this, that'—is what I call an *observation categorical*. It is compounded of observation sentences. The 'Whenever' is not intended to reify times and quantify over them. What is intended is an irreducible generality prior to any objective reference. It is a generality to the effect that the circumstances described in the one observation sentence are invariably accompanied by those described in the other.
>
> (Quine 2003, 10)

From the last sentence of the above-quoted passage, the salient feature of observation categorical is that there exists a causal relation between two observation sentences. It is corroborated by his example of observation categorical: "When a willow grows at the water's edge, it leans over the water" (Quine 2003, 10)

For Quine, any theory has empirically equivalent rivals which share the same set of observation categorical (Gibson 1986, 87). Since observation categorical is compounded of two observation sentences and it must be treated as a standing sentence, meaning to say that the component observation sentences are not two self-sufficient observation

sentences (Quine 2003, 10-11), Quine has to ensure that one observation sentence is always necessary and sufficient to bring forth the subsequent observation sentence. Unfortunately, Quine does not provide any indication about it. This unsolved issue becomes complicated if an observation categorical is a composite of more than two observation sentences. Scientists will not be able to inter-subjectively agree on the causal chain of the order of observation sentences that make up an observation categorical. If this phenomenon happens, realists may legitimately point out that there are no genuine empirically equivalent rival theories in the sense that the same set of observation categorical, which is shared by the rival theories, may contain an array of observation sentences which have a variety of causal chain order.

Quine's account of observation sentence and observation categorical opens way to the criticism of realists from the perspective of quantum physics. Quine's observation sentence is the description of what is perceived naively. His account fits perfectly into the classical interpretation of physical science where the human observers are independent from the observed phenomena. However, this account is untenable in the context of quantum interpretation of the structure of world. Classical physics is deterministic in nature whereas quantum physics is a statistical theory (Bohm and Hiley 1993, 13). The latter raises two fundamental postulates: "(a) the indivisibility of the quantum of action and (b) the unpredictability and uncontrollability of its consequences in each individual case." (Bohm and Hiley 1993, 13-14) These postulates suggest that a quantum phenomenon consists of experimental conditions and the meaning of the experimental result as a whole, which is not further analyzable (Bohm and Hiley 1993,

16). Thus, the meaning of an experiment cannot be unambiguously referred "to the properties of a particle that exists independently of the rest of phenomenon" (Bohm and Hiley 1993, 16). The yielded measures are probable rather than deterministic. Indeed, it is impossible to provide a meaningful account of the state of a particle even if the same results are obtained in different experiments (Bohm and Hiley 1993, 18). With this feature of quantum theory in mind, it is suspicious that two rival quantum theories would entail the same observational consequences. In fact, empirical equivalence thesis appears to be a moot point to quantum physicists because the independent reality, unlike under the interpretation of classical physics, cannot be reflected unambiguously in the theory (Bohm and Hiley 1993, 16-17). John von Neumann has even proved mathematically that the quantum theory is a complete system in itself which offers no evidence that an underlying physical world exists (Hoffmann 1959, 178). Thus, underdetermination thesis is less tenable if it claims that any theory, in the context of quantum physics, always has empirically equivalent rivals.

What is perceived in the quantum state may not be rightly judged as the identical empirical phenomenon for two rival theories. Perovic claims that the perceived "coinciding energy values for the hydrogen atom" is unlikely to be deemed "as an evidence of the empirical equivalence of Matrix Mechanics and Wave Mechanics" because these values only indirectly relevant to the two theories (Perovic 2008, 450).

Perovic further maintains that experiments are not always capable of determining the empirical equivalence in quantum physics:

> Nor could the experiments concerning the related issue of quantization of the orbital angular momentum… have contributed to the presumed (by Muller) agreement on the empirical equivalence. By introducing the quantized angular momentum of electron, Bohr's model predicted correctly the spectral lines (i.e., Balmer lines) that corresponded to the allowed rotational frequencies of the electron…. it was not clear whether the spectral lines indicated the nature of *individual* corpuscular-like interactions of radiation with the matter…, or whether they were the consequence of the way wave-packets, not individual corpuscles, interacted with the matter. (Perovic 2008, 450)

The main reason that contributes to the uncertainty in agreeing that two rival quantum theories entail empirically equivalent quantum phenomenon is the realist belief in the unobservable entities. Moreover, the observables, which are technically defined as "quantities such as position, velocity, momentum, and energy that can be experimentally measured" (Thornton and Rex 2006, 184), cannot be precisely measured in the quantum state. It may then be argued that there is no real sense of equivalent phenomena due to the unpredictability of the phenomena. As such, underdetermination does not appear as a genuine threat, according to Perovic, for underdetermination is always tied with the thesis of empirical equivalence. It further leads to a claim that there is no real sense of empirically equivalent rival quantum theories. Indeed, Perovic suggests that the inter-relation between interpretation, formalism, and experiment should be considered together in theory choice instead of considering the experimental result alone (Perovic 2008, 460). Hence, Quine's observation sentence itself is insufficient to determine the empirical equivalence of any two rival theories.

The definition of observable phenomena in quantum state diverges from its ordinary meaning. It is defined in terms of the measuring equipments and observed objects

(Evanston 1949, 215; Quoted in Sauer 2007, 885). However, a quantum-state observable phenomenon is deemed fundamental and cannot be analyzed reductively to the measuring equipments and observed objects that yield it (Evanston 1949, 215; Quoted in Sauer 2007, 885). Nor does the holism of quantum theory allow the observed phenomena to be reduced to the spatiotemporal relations of the constituting parts (Maudlin 2007, 639). The role of measuring equipments in yielding the observable phenomena leads to Duhem's holism (Chang and Cartwright 2007, 369). Realists need to deal with holism in order to defend their realist stance (Chang and Cartwright 2007, 369)

> As Bohr has made clear…. the measuring apparatus plus observed object must be regarded as a single indivisible system which yields a statistical aggregate of irregularly fluctuating observable phenomena…. They must simply be accepted as fundamental and not further analyzable elements of reality, which do not come from anything else but just exist in themselves. (Evanston 1949, 215; Quoted in Sauer 2007, 885)

The observable phenomena in quantum state present a pluralistic account of reality in the Everett interpretation of quantum mechanics. It is a "many-worlds interpretation of quantum mechanics" (Baker 2007, 153-154) which is not coherent with scientific realist coherence theory of truth. Many-worlds interpretation holds that there is more than one possible world at the subatomic level. Each possible world implies a potential behavior of a particle, which is treated as a vector in an abstract space (Davies 1990, 71).

In quantum mechanics, the real world can only be defined "within the context of a particular type of measurement or observation" (Davies 1990, 123). "Measurement outcome is a class of branches" (Baker 2007, 165) which consists of elements of a superposition of quantum states (Baker 2007, 154). The experimenters are required to

"know which worlds (if any) are the branches." (Baker 2007, 165) and this knowledge requires probability rule (Baker 2007, 165) which is not inferable from observables (Hemmo and Pitowsky 2007, 337). However, the observable is not deterministic in yielding the measurement outcome.

> … the observer is involved in reality in a very fundamental way: by choosing the experiment he chooses which alternatives are on offer. When he changes his mind, he changes the selection of possible worlds. Of course, the experimenter cannot pick precisely which world he wants, for they are still subject to the rules of probability, but he can influence the available choice. (Davies 1990, 123)

> … the combinatorial majority of observers would find that quantum mechanics contradicts their experience. So, as a general rule one clearly cannot claim that the quantum probabilities might be inferred (say, as an empirical conjecture) from the observed frequencies. (Hemmo and Pitowsky 2007, 337).

The non-deterministic feature of measurement outcome opens the door to the Everett pluralistic account of quantum state. This account assumes that "the entire universe has a quantum state" (Butterfield 2002, 19). It asserts that all "definite macrorealms are actual." (Butterfield 2002, 19). It is impossible to obtain a precise measurement outcome as the pluralistic nature of quantum states is real (Hemmo and Pitowsky 2007, 337). However, this impossibility of knowing the determinate position of a measured particle can be accounted by the fact that the particle is "in a superposition of mutually incompatible positions." (Barrett 1995, 2)

> Moreover, even if one were to define (by brute force) the squared modulus of a branch as its probability it would still be irrelevant, since all branches are actual. In other words, in the absence of measurement as a genuine stochastic process the combinatorial majority of worlds is still a-typical. (Hemmo and Pitowsky 2007, 337)

The problem of pluralism that posed by Everett interpretation of quantum mechanics to realists has its root in observables. The observables are unable to adjudicate between an array of branches because all of them are equally real. Everett and De Witt propose this pluralistic account as the solution to the uncertainty of experimental measurement (Hemmo and Pitowsky 2007, 334-335). The many-worlds theory cannot determine if one branch is more real than another because it does not provide a precise measure over branches (Hemmo and Pitowsky 2007, 338). It asserts that "the usual quantum-mechanical states provide complete descriptions of all possible physical situations." (Albert and Barrett 1995, 35) Hence, the many-worlds theory does not support the realist correspondence theory of truth.

The empirical outcome becomes indeterminate and it is determined by the context of measurement. The Everett interpretation posits that "the number of branches is equal to the number of all possible outcomes" (Hemmo and Pitowsky 2007, 346). If the empirical outcome is unable to be precisely measured, it is suspicious if there exists any two empirically equivalent rival quantum theories.

There are more and more scholars who doubt about the late 1920s agreement on the empirical equivalence of matrix mechanics and wave mechanics (Pevoric 2008). The empirical equivalence thesis of these two rival theories was initiated by Schrödinger's 1926 isomorphism proof (Pevoric 2008). In his isomorphism proof, Schrödinger demonstrates that the wave equation is corresponding to the energy spectrum of the hydrogen atom (Darrigol 2003, 346). However, Schrödinger's proof is deemed

unsuccessful because it merely demonstrates "the domain-specific ontological equivalence of Matrix Mechanics and Wave Mechanics, with respect to the domain of Bohr's atom." (Pevoric 2008, 444). Gibbins holds that Schrödinger's proof shows that the two theories are equivalent ontologically but not empirically. (Gibbins 1987, 24; Cited in Pevoric 2008, 452)

According to Muller, the two experiments presented by Schrödinger as a proof of the empirical equivalence of matrix mechanics and wave mechanics are insufficient (Muller 1997a; Cited in Pevoric 2008, 447). The first experiment concerns the problem of smeared charge densities. Pevoric argues that Schrödinger's early treatment of the atom as a charged cloud does not accurately explain for the radiation of the atom (Pevoric 2008, 449). The second experiment concerns the issue of quantization of the orbital angular momentum. Wave mechanics is unable to explain for Balmer lines, which is a kind of spectral lines that correspond to the rotational frequencies of the electron, in a convincing way as matrix mechanics does (Pevoric 2008, 450).

There are scholars who claim that the imprecise measurement in quantum mechanics renders the measurement outcome to the status of theoretical claim rather than an experimental claim (Morrison 2007, 548). The theories are deemed "observational indistinguishable" (Belousek 2005, 670)

> However, if we are unable to measure the spin of a single electron then the assignment of a value in so-called 'spin measurements' is a largely theoretical claim rather than an experimental one. So, while spin lies at the foundation of a good deal of modern technology, like the use of MRI, it may be that our

> knowledge of it is via detection and inference rather than direct experimental measurement. (Morrison 2007, 548)

Barrett goes further from this stance by stating that there is no real understanding of the physical world (Barrett 1995, 4).

> In addition to giving up on any real understanding of the physical world, one would have to be content with the fact that there is a class of experiments (which would b extraordinarily difficult to perform but are at least in principle possible) for which the standard theory (even when supplemented with our intuitions concerning what constitutes a measurement) can make no empirical predictions whatsoever. (Barrett 1995, 4)

Barrett's claim is a typical quantum physicist view on the nature of quantum system. Physicists regard quantum theory as a mathematical theory rather than a physical theory (Weinert 2004, 63-65). It is because the Hilbert Space, a mathematical reference frame, is assumed in the experiment. Physicists claims that "reality cannot depend on particular reference frames. What is real must be what remains invariant across different reference frames." (Weinert 2004, 64) Physicists go beyond to assert that the particle or the wave theory does not depict the true nature of the quantum system which is independent of observation (Weinert 2004, 65).

> In the view of many proponents of quantum mechanics, the observation of particle or wave properties is dependent on the experimental arrangement. The quantum system displays particle- or wave-like characteristics, depending on the setting of the experimental apparatus. For many proponents of quantum theory this meant that the quantum system, if undisturbed, does not possess any intrinsic properties associated with particles or waves. Rather, in the course of different measurements, mere potentialities jump into certain actualities. (Weinert 2004, 65)

Apart from repudiating the empirical equivalence thesis from the perspective of quantum physics, a realist may also claim that this thesis does not hold in the classical physics and other physical sciences too. Brush claims that the physical law, for the purpose of theory consistency, is not merely accommodating empirical facts but also forcing the facts to accommodate to it (Brush 2007, 257). The example of accommodating facts to laws is the modification of atomic weights of beryllium and tellurium (Brush 2007, 257). According to Brush (2007), the reason for accepting the periodic law is that theoretical consistency as its virtue has led to the precise description of physicochemical properties and atomic weights of elements such as beryllium and tellurium. Hence, a realist may argue that the role of evidence in theory choice is secondary because it can be subjected to alteration for the purpose of theory consistency. It further leads to a feasible claim that a theory choice is possible in the presence of empirically equivalent rival theories by accommodating the evidential facts to these theories. The theory with the well-accommodated facts is epistemically merit and so should be chosen eventually. Thus, the theory-choice problem posed by empirical equivalence thesis is resolved.

Psillos claims, from the perspective of semantics, that the proof of empirical equivalence thesis is trivial. He argues that one can create another rival theory of *T* by adding any statement to it, or by "just permuting two theoretical terms of *T* (e.g. 'electron' with 'proton', etc)" (Psillos 1999, 164). In his account, empirically equivalent rival theories can be arbitrarily constructed without concerning their truth-content.

Psillos attempts to show that one can artificially construct an array of empirically equivalent rival theories, which do not pose any real threat to the original theory *T*. He avows with Laudan's viewpoint that "there is 'no algorithm for generating genuine theoretical competitors to a given theory'." (Laudan 1996, 61. Quoted Psillos 1999, 164) The point Psillos has missed is that the underdetermination thesis does not assert that empirically equivalent rival theories are the product of artificial modification of the original theory. Such artificial construction of rival theories indeed will not yield genuine scientific rival theories but empirically equivalent trivial theories. These artificial rival theories are not epistemically significant because they are redundant.

The study of underdetermination thesis in immunology carried out by Atlan shows that empirically equivalent rival theories are not necessarily redundant and trivial, as alleged by Psillos and Laudan. He claims that two or more different automata immune network theories

> may have the same attractors which correctly predict the same observable facts, and yet neither of them may be at all redundant, in the sense that every isolated modification of the network would result in different attractors and therefore would change it into a false theory. Going from one theory to the other in the equivalence class does not imply acting on redundant features: a given network structure with no unnecessary element or connection is just replaced by another completely different structure, no more redundant and yet characterized by the same attractors (Atlan 1989, 251)

Atlan further asserts that the artificial construction of rival theories, as suggested by Psillos, demonstrates the indeterminacy in theorization (Atlan 1989, 251). Occam's razor should be applied to eliminate these rivals (Atlan 1989, 251)

> Indeterminacy in theorization is often confused with redundancy in the sense of unnecessary additional features in the theory which do not change anything in its predictive power… Obviously such redundancy implies indeterminacy, since the same facts would be accounted for by several theories, different in that they would be more or less redundant, or redundant by different features. (Atlan 1989, 251)

There are two versions of empirical equivalence thesis. The first version asserts that the rival theories are underdetermined by the identical empirical content, as described above. The theories T and T' are underdetermined if T→O and T' → O.

However, the second version of empirical equivalence thesis does not insist on the identical empirical content. A scientist is unable to adjudicate between two theories based on their largely overlapping empirical predictions, regardless if their empirical contents are identical. If two theories "make no predictions that would allow us to differentiate between them" (Magnus 2004a, 6), they are regarded underdetermined by the evidence. This second version of empirical equivalence thesis may take two forms. If the empirical predictions are identical, the underdetermination can be illustrated as in the first version (T→O and T'→ O). If the empirical predictions are non-identical, yet they are somehow similar or near-identical, the underdetermination thesis can be represented in the form of T→O and T'→ O'; where O and O' overlap in a large domain of empirical contents. The finding of the compatibility of six rival hypotheses of pneumococcal transforming substance with the evidence has demonstrated the latter case of near-identical empirical equivalence (Cresto 2008, 70-76). The main research question on pneumococci that caught the attention of biologists in the early 1940s is the nature of the chemical composition of the pneumococcal transforming substance (Cresto

2008, 70). The virulent variant of pneumococci was found to be surrounded by a capsule which is indigestible by the host's immune cells; the non-virulent variant, by contrast, does not come with capsule. It is the question on the chemical properties of the substance that transforms a non-virulent variant to virulent pneumococci that has led to various hypotheses. Notably, regardless which hypothesis is applied (be it RNA, capsular protein, DNA and so on), the experimenters will observe the similar phenomenon where the capsule formation and the gene-like substance are reduplicated in the daughter cells (Cresto 2008, 70). This is a case study that demonstrates the overlapping (but non-identical) yet indistinguishable empirical evidence. The six rival hypotheses are incompatible in the sense that they used different hypotheses (e.g. of capsular protein, RNA, DNA etc) to account for the empirical observation; yet these rival hypotheses are compatible in the sense that they are corroborated by overlapping (but non-identical) evidence of the pneumococcal transforming substance.

Scholars are unaware of these two versions of empirical equivalence thesis, and they tend to mix them into one. The above-mentioned first version takes "empirical equivalence" to mean "empirical sameness". The above-mentioned second version takes "empirical equivalence" to mean "empirical similarity". Two sets of evidence are said to be in a state of "empirical sameness" when they are identical in all respects. If they are found deviating in some minor respects, yet be identical in most respects, they are in a state of "empirical similarity". The conceivable example for empirical sameness is the measurement of the weight of an object by two persons, independently. The example for empirical similarity is the measurement of gene sequences of two individual organisms in

a same species, for each individual organism does not have identical gene sequences in the genome.

The first version of empirical equivalence thesis is exposed to harsh attack by realists. It is hard to be defended because the identical evidences are required to be entailed by two rival theories. One may reasonably refute by pointing out that there were no identical empirical predictions entailed by rival theories in the history of science (Psillos 1999, 165). Besides, one may argue that the change of auxiliaries may dismiss empirical equivalence thesis because the observational sequences can be determined only with the aid of auxiliaries (Laudan 1996; Cited in Psillos 1999, 165). The latter argument contends that the size of the empirical consequence class is not fixed a priori but changeable as science grows, for the today's unobservables may become observables in future (Laudan and Leplin 2007, 250). The discovery of microorganisms is the prominent example of the expandability of the empirical consequence class.

The second version of empirical equivalence thesis is easier to defend. It is because this version does not require identical empirical consequences. It is easy to hold that the similar empirical outcome which is entailed by two rival theories will lead to the underdetermination of theory, at the level of background theory. Hudson has demonstrated that the choice between quantum physics and classical physics, which are two rival background theories, is underdetermined by the evidential results of black body radiation. He holds that the observed distribution of radiant energy, which is an element of Planck's law, can be interpreted in classical theorem mathematically (Hudson 1997,

250). Hudson arrives at a conclusion that the compatibility between classical physics with the existence of quanta has raised the problem of theory choice between quantum and classical physics.

The problem posed by the second version of empirical equivalence thesis to underdetermination thesis can be dismissed by adopting Nancy Cartwright's pragmatic approach towards theory choice. Her criterion of theory choice is not based on the resulting evidence at hand but the future evidence which might be predicted by the selected theory. That is to say, the empirical evidence that is entailed by the candidate theories has no role in arbitrating a choice. Hence, the problem posed by the empirical equivalence thesis to theory choice has lost its force.

> To accept a theory is to decide to use it to make all those predictions about what we might observe that will help us chart our actions. The justification for using the theory in this way is not an epistemic one. Belief in what the theory says about what is observable is the proper epistemic attitude to the theory we accept because that is just the point of accepting the theory. We do not otherwise have to accept or reject any theory at all. We are not compelled by principles of rationality to have any epistemic attitudes at all to a theory (Cartwright 2007, 40).

## 2.9 Conclusion

The core tenet of scientific realists is the existence of a mind-independent reality. They hold that reality consists of observable and unobservable entities and processes which really exist. Realists claim that truth lies in the correspondence between theory and reality. They need to demonstrate the possibility of crucial experiment in deciding the only true theory, among the rivals, which corresponds to the reality. However, antirealists rebut the possibility of crucial experiment by holding that theories are

underdetermined by data. Theory always contains excessive contents (auxiliary assumptions, logical constructs and etc) which could not possibly be arbitrated by data. This predicament is not easy to resolve as the realists' ontological commitment for the correspondence between reality and theory is too strong. The epistemic criterion of a chosen theory is that it must be a true theory, but the data is underdetermining all rival theories and unable to single out the true theory. The strong commitment in the correspondence theory of truth does not allow realists to be contented with the best available theory. It is because a best theory might be merely pragmatic and coherent but possibly not true.

Scientific realists attempt to resolve the theory choice problem which is posed by the underdetermination thesis by holding that falsification is possible at the level of observation statement, which in turn makes the crucial experiment possible by weeding out the falsified rival theories. They reject the Duhemian claim of infalsifiability of an isolated hypothesis by an observation statement. They hold that observation statement is capable of deciding the truth based on the experiment. They further claim that falsification is possible because the observation statement constitutes raw data which is not laden by theory. This strategy of getting rid of Duhemian holism has ignored the fact that the observation statement is theory-laden. This realists' recourse to the verification power of observation statement does not demonstrate a promising solution to the problem of theory choice.

Unobservable entities which are held real by realists appear to be a promising way to account for the possibility of theory choice. Unobservable entities are posited as the cause of some observable phenomena. They cannot be observed due to their size and distance. Besides, some unobservable entities may not possibly be observed because they are not tangible entities but processes or effects (such as gravitational force and electromagnetic field). If realists have reasons to posit the existence of unobservable entities, they may proceed to claim that the unobservable data might play a major role in arbitrating among rival theories. They may conclude that data (both observable and unobservable) may arbitrate among rival theories, thus making theory choice possible. Arguments for the possibility of theory choice can be used by realists to defend the correspondence theory of truth. They may argue that theory choice is a direct consequence of a one-to-one correspondence between reality and theory. The correspondence between theory and reality is true because theory choice is always possible.

Scientific realists adopt the perspective of experimentation in defending the existence of unobservable entities in favor of the possibility of theory choice. Boyd claims that the unobservable entities are real because their existence explains the instrumental reliability of the methodology. In Boyd's account, experimental methodology is theory-dependent which is grounded in a truth-based theory. A truth-based theory in Boyd's account is a theory that corresponds to reality. He holds that in most time theory is corresponding to unobservable entities. Unobservable entities explain the reliability of theory-dependent instrument and methodology. Boyd holds that the choice of a methodology is amounting

to the choice of an underlying theory. He concludes that the fact of the possibility of methodology choice implies possibility of theory choice. The choice of methodology and theory is possible because they are corresponding to the unobservable entities.

Boyd's assumption in the theory-based experimental methodology fails to account for the connection between the reliability of instrument and the possibility of theory choice. Boyd has ignored the fact that the governing theory of the instrument is different from the theories that are drawn based on the experimental results. The absence of a connection between the choice of an instrument and the choice of a theory has indicated that the issue of theory choice cannot be solved by accounting for the instrumental reliability.

Putnam refutes reliabilism of methodology from the perspective of pragmatism (Putnam 2005, 82-84). He holds that methodology is not objectively reliable but subjectively reliable. Putnam asserts that the reliability of methodology is solely determined by the experimenters (Putnam 2005, 82). Unobservable entities which are posited in Boyd's account do not play any role in Putnam's assertion of the reliability of methodology. If it is true that the reliability of methodology is context-dependent as held by Putnam, Boyd's claim of "possibility of methodology choice implies possibility of theory choice" would set theory choice in the light of relativism.

Chalmers, who is also subscribing to the perspective of experimentation in favor of the possibility of theory choice, has recognized the threat of theory choice posed by the theory-based experiment. He realizes that Boyd's account of theory-based experiment

will produce non-neutral experimental result which does not possess decisive power in arbitrating among rival theories. Chalmers proposes a solution by distinguishing between the governing theory of observation, of instrument and of observed result. He attempts to show that the governing theory of instrument is not the same theory that governs the observation and observed results. Chalmers argues that the observed results may not involve the high-level theory as the instruments do. He proceeds to claim that observed results have not deeply theory-laden and hence they are neutral in some degree to be able to arbitrate among rival theories. However, assuming Chalmers's distinction of three different governing theories is proper, his argument still does not warrant theory-independent neutral data which is necessary to decisively arbitrate between rival theories.

Hacking is another scientific realist who also adopts the perspective of experimentation in favor of the possibility of theory choice. Contrary to Boyd and Chalmers, Hacking does not think the truth-based governing theory has contributed to the reliability of instrument and methodology. Hacking claims that the reliability of an instrument is warranted by its manipulability. The manipulability of instruments demonstrates the existence of unobservable entities because observed phenomena can be derived from them in the experiment. The unobservable entities are posited to exist because they exert causal relation, through the manipulability of the instrument, to yield the observable phenomena. According to Hacking, the nature of unobservable entities is manipulation-dependent but theory-independent. If Hacking's claim is true, he may safely escape from Duhemian holism by holding that the neutral unobservable entities will cause neutral observable phenomena via the manipulation of instruments. However, neutral data is still not

decisive in arbitrating among rival theories when these theories are empirically equivalent.

Empiricists rely on the empirical equivalence thesis in upholding the underdetermination thesis. Empirical equivalence thesis states that any theory has empirically equivalent rivals. The entailment of the same observational consequences by rival theories places constraints on rational theory-choice. Theory choice is inevitably arbitrary because it is impossible to evaluate the rival theories based on the empirically equivalent evidence.