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FROM OBSERVABILITY TO MANIPULABILITY: EXTENDING THE INDUCTIVE ARGUMENTS FOR REALISM*

ABSTRACT. In recent years there have been several attempts to construct inductive arguments for some version of scientific realism. Neither the characteristics of what would count as inductive evidence nor the conclusion to be inferred have been specified in ways that escape sceptical criticism. By introducing the pragmatic criterion of manipulative efficacy for a good theory and by sharpening the specification of the necessary inductive principle, the viability of a mutually supporting pair of argument forms are defended. It is shown that by the use of these forms, taken together, a sequence of inductive arguments could be constructed, given suitable cases histories to serve as evidence. It also shown that the best inductive argument for the most daring realist claim is the weakest when compared with similarly structured arguments for less daring claims.

1. IDENTIFYING THE TARGET: SCEPTICISM OR RELATIVISM?

In the recent literature we can discern two main positions that stand opposed to Scientific Realism. There is Relativism and there is Scepticism. According to Relativists there is no final, unique and true account of natural phenomena towards which the knowledge obtained by the use of the methods of the Natural Sciences converges. Sceptics do not doubt that some account of natural phenomena is the correct account but they do not think we can know, even by the use of the methods of the Natural Sciences, which one that is.

The arguments that follow are intended only as a defence of Scientific Realism against Scepticism, as the latter has been exemplified in the writings of Laudan (1984) and van Fraassen (1980). Scientific Realism will be defended by bringing together two recent insights that will enable us to extend the range of existing inductive arguments for Scientific Realism (Newton-Smith 1981; Lipton 1991), to cover the kinds of theories difficulties in the verification of which have given comfort to Sceptics. These insights are as follows:

a. The manipulative efficacy of a technique is not reducible to the empirical adequacy of the theory which suggested it (Hacking 1983; Harré 1986).

Synthese **108:** 137–155, 1996.

b. The verisimilitude of a theory is not to be assessed directly by how near it is to the truth, but indirectly by how well the model or models upon which it is based, depict some relevant aspect of reality (Giere 1988; Aronson 1991).

With the help of these insights I shall be defending to the appropriate degree three varieties of realism, a sequence of doctrines with progressively weaker inductive support. Each member of the sequence is a necessary condition for that which follows. These are

(1) *Policy Realism*: that it is reasonable to read scientific theories as if the models upon which they are based resemble the aspects of the world they represent to some degree.
(2) *Depth Realism*: that models which stand in for unobservable aspects of the world resemble those aspects in relevant respects and in some degree, provided that the theories expressing them were empirically adequate, ontologically plausible and manipulatively efficacious.
(3) *Convergent Realism*: that in the progress of science as measured by the improving empirical adequacy, ontological plausibility and manipulative efficacy of successive theories, the models for those theories are of greater verisimilitude.

The main focus of the arguments will be on establishing (1) and (2) as necessary conditions for the possibility of assembling historical evidence for (3). That is, I hope to establish the viability of a certain form of argument, leaving it to historians to flesh it out with case histories.

2. THEORIES AND THEIR MODELS

The inductive arguments to be developed below are concerned with justifying the projectability of a certain property of theories, namely their degree of verisimilitude, from cases in which the match between model and world has been assessed to cases where it has not. The verisimilitude of a theory will be defined as the degree to which the most ontologically plausible model for the theory resembles some feature of the real world in relevant respects. Neither the concept of 'theory' nor of 'model' are univocal, so an account of what is I shall mean by them is needed. This account is abstracted from Aronson, Harré and Way (1994).

A model for a physical theory is to be understood as a set of entities and relations which fulfils the following functions:

a. It provides an interpretation of the terms of the theory, such that the theoretical propositions thereby created are true of the model. In this respect models in the physical sciences are like models in logic.
b. It serves as an idealised representation of those entities, structures, processes, properties and so on in the real world which are implicated in the production and origin of the phenomena in the field of the theory. In this respect a model serves as a virtual or surrogate world (Cartwright 1983; Giere 1988; Aronson 1991).

For the purposes of this paper a theory will be taken to be a structured set of propositions, a certain fragment of the discourse of science. The function of a theory is to map phenomena onto those real world states, processes, entities or structures that are thought to be implicated in their production. For example the theory of continental drift maps the shape and location of the continents, the lay out of mountain ranges, the occurrence of earth tremors and so on onto the locations and relative motions of tectonic plates. The mapping is achieved by specifying a model, some of the properties of which are abstract representations of the phenomena in question and other properties of which represent the causal mechanisms responsible for those phenomena.

3. FOUR RELEVANT PROPERTIES OF THEORIES

I shall assume that it would be widely agreed that a 'good' theory should display empirical adequacy, ontological plausibility and manipulative efficacy understood as follows:

a. Empirical adequacy: that the theory (as a set of statements) coupled logically with another set of statements which describe some conditions of application of the theory, yield, deductively predictions and retrodictions that turn out predominantly true.
b. Ontological plausibility: that the model for the theory instantiates the current ontology, for example that gas molecules are Newtonian particles.
c. Manipulative efficacy: that operations performed on some material system, guided by the assumption that certain unobserved features of reality do resemble the properties of the relevant model are more or less successful, for example that attempts to manipulate the orientation of the nuclei of silver atoms by means of a magnetic field (the Stern–Gerlach experiment) succeeded.

d. An advocate of Scientific Realism would require a fourth property for a 'good' theory, namely that it should display some degree of verisimilitude, that is that the model on which the theory is based and the reality it purports to represent are well matched.

A theory is assigned a degree of verisimilitude that expresses the degree of resemblance in relevant respects of its core model world to those aspects of the real world that model represents (Aronson 1991).

4. BASIC REQUIREMENTS FOR A PRO-REALISM ARGUMENT USING ARONSONIAN VERISIMILITUDE

To cut any ice a verisimilitude-based argument for Convergent Realism must support three conclusions:

(i) that models do more or less resemble the relevant aspect of reality;
(ii) that there are criteria by which the degree of relevant resemblance can be assessed prior to any independent and direct comparison between model and reality.
(iii) that the better a theory meets the criteria of empirical adequacy, ontological plausibility and manipulative efficacy the more verisimilitudinous is its core model than a rival which meets the inductive criteria less well.

Propositions (i) and (ii) express the thesis of Depth Realism while propositions (i), (ii) and (iii) express the thesis of Convergent Realism. Both varieties of Realism are to be understood in terms of the concept of a model as I have introduced it above. Only if (i) and (ii) are established could the history of science yield evidence for or against (iii). The purpose of this paper is to establish the first two theses. Historians may or may not be able to find evidence for thesis (iii). However, as an essential preliminary to arguing for Depth Realism, it is necessary to defend the practice of reading theories 'realistically', that is to defend Policy Realism: that it is rational to read theories fulfilling certain desiderata as if the models which they described resembled aspects of the real world in relevant ways. This will lead to model control of research projects, since it would make sense to set about trying to test the degree of resemblance between the model controlling the research and the aspect of the world it purports to represent. The rationality of Policy Realism is equally compelling when a research programme fails to disclose any resemblance between models and reality as when it succeeds. Such a programme would have had to be devised on the assumption that the model under investigation might have resembled the world in relevant respects.

Only if Policy Realism can be vindicated does the prospect of a defence for Depth Realism arise. Only if it makes sense to read theories as possibly verisimilitudinous does it make sense to ask which models, if any, of some set of theories do resemble aspects of the world, and to what degree. A defence of Depth Realism will require an account of how we could know the quality and degree of resemblance of models and the reality they are constructed to represent. The programme for the defence of realism must then proceed by first showing that Policy Realism is well supported inductively, and then go on to show that there is also inductive support for Depth Realism, making room for the programme of seeking support from the history and practice of science for Convergent Realism.

5. THE FORM OF THE INDUCTIVE ARGUMENTS FOR REALISM

The evidential premise of an inductive argument is a report that, as a matter of fact, in cases which have been examined, in this case those in which the fit of the model and what it represents has been assessed, all or some of the three basic properties of a 'good' theory are correlated with a reasonable degree of verisimilitude. The inductive conclusion is that the same correlation holds for theories the core models of which have not been examined for their model-to-world match.

The evidential properties as laid out in Section 3, a, b and c, are empirical adequacy, ontological plausibility and manipulative efficacy, and the projectible property is the verisimilitude of the model the theory describes. The argument must, in the end, be inductive, since it is logically possible that a theory should be empirically adequate, ontologically plausible, manipulatively efficacious but not verisimilitudinous.

The sort of historical evidence which would be needed to support the induction would consist of a catalogue of cases in which the majority of theories which exhibit the three evidential properties also exhibit the projectible property.

At this point we need to take account of an important feature of inductive arguments in general. Every inductive argument is acceptable only relative to some inductive principle. For example the familiar commonsense induction from the way events have been correlated in the past to an inference as to how they might be correlated in the future, is only as convincing as the degree of conviction we have in the principle that the future will resemble the past in relevant respects or to put it more grandly, that Nature is Uniform. Paradoxically we have only inductive evidence for that or any other Inductive Principle. This is a paradox we know that we must live with in the conduct of practical affairs. An inductive argument can fail either because the run of favourable evidence peters out, or because confidence in the relevant Inductive Principle is eroded, or both. An important aim of this paper is to make clear the inductive principle involved in 'historical' inductive arguments for versions of realism. That done we can enquire about the considerations that would speak in favour of the principle.

The degree to which any theory meets criteria of empirical adequacy, ontological plausibility and manipulative efficacy can always be ascertained, though sometimes with great practical difficulty and in some cases, such as geology and astrophysics, only indirectly. It is the alleged theoretical difficulties involved in ascertaining the degree to which the model at the core of a theory is verisimilitudinous in the above sense when the relevant states of the world are unobserved or worse, unobservable, that create the philosophical difficulties for a thorough-going realism. If all we can have are the above three criteria to assess the value of a theory then the question of the match of its core model to any reality other than the field of phenomena to which it is addressed, is empty. In the absence of any way in which the degree of resemblance between models and reality in relevant respects can be assessed, the progress of science could be described only in pragmatic terms.

6. DEFINING THE INDUCTIVE DOMAIN

The domain over which the 'Realist' inductions will range is a set of case studies of investigations using theories ordered by reference to the epistemic status of their core models. Models, in the sense of this paper, fall into three classes:

R1 type: those which are readily assessed for their resemblance to perceivable entities, properties or processes.

R2 type: those which could be assessed with respect to their resemblance to possibly perceivable entities, properties or processes were a technology by means of which they might be observed to become available.

R3 type: those which are thought to resemble entities, properties or processes which, in the present state of our knowledge we believe never could be observed.

Evidence for a 'Realist' induction accumulates unproblematically by establishing correlations between one or more of the three properties of 'good' theories and the verisimilitude of their models, for theories whose models are of the R1 type. The cognitive/practical successes of plumbers, surgeons and car mechanics provide a rich basis of evidence for a strong correlation between epistemic adequacy, ontological plausibility, manipulative efficacy and highly 'resemblant' models at the core of their working theories. The problem is to justify the induction from cases of this sort to enquiries in which the relevant theories are based on models of the R2 type, and then finally cases in which the operative thories are based on models of the R3 type. I will show first that it is possible to justify an induction from evidence for 'Realism' accumulated in the R1 domain to theories whose models are of the R2 type. It will emerge that the evidence adduced by philosophers (for instance Lipton 1991) for this induction is not strong enough to support a 'Realist' induction to theories of the R3 type. Without the third induction Realism would be atrophied and the effort to create the groundwork to make an inductive argument for Convergent Realism available would fail. To remedy the weakness of the third induction I shall revive the central argument of Boyle's (1666) defence of the verisimilitude of the corpuscularian model of the world.

7. THE 'MOVING BOUNDARY ARGUMENT'

This inductive argument from a successful demonstration of Realism in the domain of R1-type theories to Realism in the domain of R2-type theories, has been presented in several different forms (Harré 1961; Lipton 1991). It is based on an Inductive Principle which Aronson (1988) has called 'the principle of epistemic invariance'. This is the principle that the phenomena we cannot currently observe are likely to be of the same ontological categories, natural kinds etc., as those we can observe. I shall call it the Principle of Conservation of Kinds. It is important to be clear about what it can and cannot be used to establish. In order to set out the argument we must call on the distinction made above between the three possible epistemic standings that a model of a theory may have.

The history of science shows that the boundary between actual observables and possible observables is variable. It has turned out that some aspects of the world or some class of entities which were not observable have become observable and can now be compared with the model which was offered as a surrogate for reality in the construction of the relevant theory. For example the improvement in microscopy, the development of telescopes of increasing power and sophistication, the invention of tunnelling microscopes, the possibility of sending probes into regions previously inaccessible and so on, have allowed a vast range of models of the R2 type to be compared with the entities, properties, structures and processes that they stood in for and their degree of resemblance in relevant respects ascertained.

From the fact that the boundary between observables and some unobservables is not permanently fixed it follows that the policy of making a realist reading of models belonging to the R2 type is entirely reasonable. Technological advances have made their direct empirical assessment of model to world match possible in many cases. For instance Malphigi shifted the observable/unobservable boundary when he used the microscope to observe the capillary blood vessels that were represented in Harvey's closed circuit model of the blood vascular system of animals. Both positive and negative outcomes of research aimed at verifying the verisimilitude of R2 type models support Policy Realism. A model can fail a verisimilitude test only if it has been taken as a surrogate for a possible reality. Policy Realism can be extended by induction to theories whose models represent causal processes etc. which are assumed to be forever and in principle unobservable. It would generally be conceded, I believe, that it is reasonable to make a realist reading of such theories, provided they meet the two criteria of empirical adequacy, and ontological plausibility. It is also reasonable to make a realist reading of theories based on R3 type models. However if their models do resemble the reality they purport to represent we could never know it by observation. That we should therefore give no credence to it is the Sceptical position.

The induction to support Depth Realism for theories based on R1 and R2 type models runs as follows: there are many cases of enquiries which made essential use of theories based on models of the R1 type which are empirically adequate and ontologically plausible. Many of their models have turned out to be similar to the reality that they were introduced to represent in relevant respects. There are many cases of empirically adequate and ontologically plausible theories based on models of the R2 type in which the models have been shown to be verisimilitudinous in the relevant respects after the boundary between the observable and the unobservable has moved. So, in general, empirically adequate and ontologically plausible theories whose models belong in the R2 category, prior to the shift in the boundary between what is observable and what is unobservable can be expected to be verisimilitudinous, that is to have models of a high degree of pictorial resemblance in the relevant respects to the reality they represent.

Allowing for a difference in terminology we find Lipton presenting the 'moving boundary' argument but then extending it, without further augmentation of the evidential grounding, to theories whose models are of the R3 type (Lipton 1991: 179), as follows:

[the realist's] reasons for trusting his method in the case of observables also supply him with reasons for trusting his method in the case of unobservables . . . just as his success in sometimes observing the causes he initially inferred supports his confidence in his method when he infers unobserved but observable causes, *so it supports his method when he infers unobservable causes*' [my italics].

But since the boundary between what is observable and what can never be observed can never shift so as to reveal the real entities which models of the R3 type are built to resemble, the inductive argument from empirically establish*ed* verisimilitude to empirically establish*able* verisimilitude cannot be extended to them. A determined anti-realist can always point to the possibility of alternative models for some formal theory (such as quantum mechanics) or for alternative theories for some domain of phenomena based on different models (such as the one and two fluid theories of electricity). We cannot extend the induction to theories with R3 type models by reason of Clavius' Paradox, the underdetermination of theories for truth (or models for verisimilitude) by any observational data. As Clavius pointed out (1602) if we rely only on a comparison of observational data with the deductive consequences drawn from assuming a certain model to be correct (in his case some model of the solar system) there is an indefinitely large set of alternative models which will deductively support the same conclusions and so be indistinguishable by reference to their capacity to 'cover' given empirical data. So the moving boundary argument is not enough to establish the conditions for setting up an inductive argument for Depth Realism for theories with models of the R3 type, and *a fortiori* will be inadequate to support Convergent Realism.

I argue that the addition of the third evidential property, manipulative efficacy, to the inductive criteria, permits an induction to the verisimilitude of theories with models of R3 type, sufficiently strong to give some support to Depth Realism, though it is not as strong as the argument that supports an overall Policy Realism. The importance of the 'moving boundary' argument is not only that it supports Policy Realism, but it also identifies a segment of the set of all scientific theories for which empirical adequacy, ontological plausibility *and manipulative efficacy* are correlated with a high degree of verisimilitude of their models. This segment of the set of all possible theories will provide part of the evidence for the projectibility of the property of verisimilitude to the 'untested' cases for which the degree of relevant resemblance between model and the aspect of reality it purports to represent cannot be empirically ascertained. Can the criteria of manipulative efficacy be extended to the assessment of theories based on models of the R3 type?

8. USING THE HAND TO REACH BEYOND THE EYE: ADDING THE THIRD CRITERION

In his *Origins of forms and qualities*, Robert Boyle (1666) offers an interesting argument for the reality of the mechanical corpuscles which he took be the unobservable basis of the physical world. The argument makes essential use of the idea of indirect manipulation. Boyle was well aware that the doctrine of primary and secondary qualities that he shared with John Locke meant that the 'textures' (molecular level structures), responsible for the observed qualities of bodies were beyond all possible perception, at least with the equipment available at that time. From this Locke drew his pessimistic 'nescience' conclusion, that though we knew there must be real essences we would be unable to incorporate them into the ontology of the natural sciences. Boyle argued that it was possible to manipulate material corpuscles at the molecular level to bring about observable changes in another sense modality than that in which the manipulation had been performed. Manipulations which could only lead to changes in shape or arrangement of something could nevertheless be used to bring about changes in its colour. So, he concluded, they must effectively be manipulations of unobserved corpuscular constituents of that thing, changing them. This 'hidden change', in turn, is manifested in a change of the colour of the thing to a human observer.

Boyle seems to have assumed that we know from observation that 'mechanical' procedures bring about observable changes in 'mechanical' properties, in many cases. 'Mechanical' procedures are manipulations which change either the internal structure ('texture') or the state of motion of the parts of a material thing or both, that is they bring about changes in the quantitative or primary qualities of bodies, their bulk, figure, texture or motion. We know, for example, that by grinding corn we can produce flour, that by the impact of a moving body on a stationary body we can put it in motion, and so on. We also know that there are cases in which quantitative or mechanical procedures acting upon the primary 'mechanical' qualities of observable material stuff bring about changes in its secondary or 'non-mechanical' qualities. Crushing a green emerald yields a white powder. Crushing is a mechanical procedure, an action upon the primary qualities of the stone, breaking it up into parts, and thus changing the texture. Yet this manipulation brings about a change in the colour of emerald stuff, that is in one of its secondary qualities. The key move, assumed by Boyle, is an induction over observed cases of 'mechanical' procedures which have 'mechanical' effects, to the general principle 'Mechanical procedures have only mechanical effects'. I shall call this the 'Boyle Principle'. The corresponding generalization for electromagnetic manipulations I shall call the 'Faraday Principle'. These Principles are clearly special cases of the general inductive principle cited in the 'Boundary' argument, namely the Principle of Conservation of Kinds. If a mechanical procedure can have only effects on the primary qualities of a body, and yet sometimes such a procedure can be seen to bring about changes in a secondary quality, such as its power to induce ideas of colour or warmth in human observers, either the Boyle Principle is false, or the procedure must be a manipulation of unobserved primary qualities, such as the texture or molecular structure or motion of parts, resulting in a change in its secondary qualities. By citing many instances of changes in ideas of secondary qualities (taste, colour, felt temperature, medicinal powers etc.) brought about by the manipulations that should change only primary qualities, Boyle sets up an inductive argument for the corpuscularian metaphysics.

Boyle's argument can be reconstructed using a great many modern instances (Hacking 1983 ['if you can spray them they are real!']; Harré 1986). The Stern–Gerlach apparatus and its use of magnetic manipulations to separate the constituents of atomic and molecular beams according to the magnetic orientation of the ions is striking example of a manipulation which produces observable changes via the effect upon some unobservable property of the real system guided by the model which depicts unobservable aspects of the world. This example is important in the generalization of Boyle's argument, since it shows that the force of the reasoning does not depend on the highly contestable distinction between primary and secondary qualities. It requires only that the effect be of a different type from that which the manipulation is usually observed to produce. The Stern–Gerlach experiment yields an observed change in orientation of an image rather than an observed change in the usual effects of magnetization, though the manipulation is magnetic. So we seem to have an argument which permits the extension of the induction from an 'observed' correlation between empirical adequacy, ontological plausibility, manipulative efficacy and representational quality of models of the R1 type to the conclusion that the fourfold correlation of desirable metatheoretical properties can be ascribed to theories based on models of the R3 type.

There is an obvious Humean objection to Boyle's claim that the observations of cases of mechanical procedures bring about changes in non-mechanical qualities shows that a change has occurred in unobservable properties. If the Humean regularity theory of causality is correct we are not obliged to go beyond the observed correlation of mechanical cause and non-mechanical effect. Why should we, so to say, dip into unobservable background processes, hidden changes, when we can simply correlate the crushing of an emerald with a change in its colour? Thus, however ingenious and original Boyle's argument may be, it also seems to need upgrading to meeting the Humean objection.

9. 'BOUNDARY' WITH 'BOYLE': STRENGTHENING BY MUTUAL SUPPORT

We have seen that neither the moving boundary argument nor the Boyle manipulation argument is free from reservations when extended to theories based on R3 type models. But if these arguments are taken together they are complementary in that each makes up for the weaknesses of the other. 'Boyle' takes care of the objection to 'Boundary', that physical science has always made use of models purporting to represent real world entities, properties, processes etc. which at best have the status of fictions since they could never be observed. According to 'Boyle' we can make reality claims for the unobservable *since we can manipulate what we cannot perceive*. Our ground for claiming this, as we saw with Boyle's presentation of the argument, is a good induction from the observed effects of this or that type of manipulation. 'Boundary' takes care of the Humean objection to 'Boyle'. The justification for the claim that, say, magnetic operations modify unobserved structures of matter, is strengthened by cases where changes which, by reason of technical problems, were unobservable became observable through technical advances. For instance the fact that we can now observe the reorientation of elementary magnets as an effect of the magnetization of iron strengthens our faith in the general principle that magnetic manipulations always have direct magnetic effects whether or not they are observable. So in cases in which we observe a non-magnetic effect to be correlated with a magnetic manipulation we are licensed to infer that it is brought about indirectly. And this, of course, is a special case of the Principle of the Conservation of Kinds.

10. THE INDUCTIVE ARGUMENT IN FULL

For cases in which the enquiry was based on models that can be compared with relevant aspects of the real world by observation we have, as a matter of fact, found that empirical adequacy, ontological plausibility and manipulative success is usually followed by observational proof that the model resembles the world in the relevant respects. Digging out foxes' earths, fixing cars, unstopping the drains and a host of everyday practices testify to the criterial force of the three 'evidential' attributes of theory.

For cases in which the enquiry was based on models which could be compared observationally with the relevant aspects of the real world if certain technical advances could be made, it has also turned out, as a matter of fact, that when the boundary between the observed and unobserved but observable has been moved, the models in theories which have met the demands of the three criteria have, for the most part resembled the world, as it is now revealed, in relevant respects, and those which have not, do not. There are many instances to be found in chemistry and biology. Ionic and surface chemistry provide a rich source of examples. The ionic model of the imperceptible processes and ephemeral structures of the chemistry of solutions offered all sorts of hints and guides as to the development of manipulative techniques for operations to be performed that would affect ions, which for the most part, had the results that were to be expected. With modern microscopy ionic dissociations, transport and so on can be observed. Similarly there is scarcely an issue of *Science news* without a false colour photograph of the atomic structures that form the surfaces of all sorts of solids.

For cases in which the enquiry was based on models which, we believe, never could be compared observationally with relevant aspects of the real world, we have extended the putative scope of the inductive argument to theories whose models are of the R3 type by combining 'Boundary' and 'Boyle'. In extending the induction from R1 type models to R2 we were able to carry through both observational and manipulative criteria. But in extending it from R2 type models to R3 type the observational criterion necessarily drops out. This is where Boyle's great insight bears upon the issue. The manipulation criterion is common to models of all three epistemic standings!

The induction from the successful methods of motor mechanics and pest controllers to a realist interpretation of the Stern–Gerlach experiment involves a move from direct to indirect manipulation, the central step of Boyle's argument. Why should we accept it? The answer is very simple and in accordance with the spirit of the way of tackling metaphysical problems exemplified in this paper. *The Boyle Principle (together with the Faraday Principle) and their generalization in the above argument should be taken to be a part of physics.* And this, I assert, is true of all *effective* special cases of the Principle of Conservation of Kinds. There is no conceptual, a priori argument which could be given for them. So far as I can see it would not be self-contradictory to deny either. Indeed we have examined the possibility that a determined Humean might do just that. The Humean was defeated only by an empirical induction. Taking the moving boundary argument with the Boyle manipulation argument we are legitimised to look for inductive support for the claim that indirect manipulations are ontologically significant. In case they succeed we have inductive support for a belief that the theory is verisimilitudinous, and in case they fail we have inductive disconfirmation.

The sequence of inductions so far examined have each been dependent for their force on a specific Inductive Principle, relative to which they are presented as worthy of acceptance. I have shown that the most general Principle that could serve as the generic 'rule' for all three inductions is the Principle of Conservation of Kinds, the assumption that the same ontological type-hierarchy is appropriate for the construction of models of all three types, that is that the observed, the contingently unobserved and the necessarily unobservable beings represented by the three types of models are of the same ontological categories and in special cases of the same natural kinds. Just as in the case of the reasonings warranted by the Principle of the Uniformity of Nature, the appropriate Inductive Principle for inductions over events is inductively supported by observed event regularities, so the Principle of Conservation of Kinds is supported by historical cases of the successes of dominant type-hierarchies in the construction of models of all three types, but especially of the R1 and R2 types. And just as the inductive character of the support for the Principle of the Uniformity of Nature means that our knowledge of temporally and spatially remote events is forever revisable, so the inductive character of the support for the Principle of Conservation of Kinds means that scientific theories invoking unobservable states and processes are forever defeasible.

11. THE INDUCTION OVER ONTOLOGIES

All comparisons between models, one with another and with aspects and features of the real world, must invoke a common ontology. But is it not the case that our ontologies are underdetermined even by the joint use of the three criteria brought together in the realist inductions? Could not we reapply the Paradox of Clavius, and raise the objection that there are indefinitely many ontologies from which a picture of our system, as we observe, imagine and manipulate it, could he derived? In order to meet this objection we need another induction, an induction over types. Suppose that, as a matter of fact, the historical record shows that models instantiating a certain ontology have been checked against some newly observed state of the world, and found to be verisimilitudinous. Should that ontology not be adopted, *ceteris paribus*, for the construction of models for unobservables of the third epistemic standing? The Newtonian ontology is plausible since it is instantiated in many familiar objects and the Newtonian models used in hosts of theories have satisfied the two remaining criteria, empirical adequacy and manipulative efficacy. If the Newtonian ontology has been successfully employed for so many research programmes should it not be extensible to those yet to come? And in being so extended could it not serve as the working version of the Principle of Conservation of Kinds for physics? History does not now support this induction. The Newtonian ontology has not been so successful when generalized as the source for all physical models. For a century the 'advances of science' have required the invention from time to time of exotic ontologies. However, provided we can find a new, extensible and stable working ontology, into which the Newtonian ontology can be incorporated as a fragment, a subhierarchy of types, we can continue to lean on the Principle of Conservation of Kinds for support in defending all three Realisms, Policy, Depth and Convergent.

The Boyle manipulation argument can tolerate a wide variety of ontologies. The essential point in Boyle's argument is the induction on manipulative procedures. Mechanical procedures are observed to have mechanical effects, magnetic procedures magnetic effects and so on. Just so long as an exotic ontology includes entities that are susceptible to manipulations of the kind certified by a Boylean induction then the realist meta-induction of the last section can be applied to them. Just so long as the models instantiating the exotic ontology are taken to represent real world beings which would be sensitive to changes in the gravitational, electrical and magnetic fields, the fields with which physical manipulations are commonly accomplished, the beginnings of an argument to the existence of a class of exotica can be constructed, and at the same time a defence of Depth Realism for theories of the R3 type.

But what of the other two criteria, empirical adequacy and ontological plausibility? The former presents no problems other than a challenge to the ingenuity and skill of the theory constructors no different in kind from that presented by any theory if the first and third criteria are met. But we can hardly deny that what is taken to be ontologically plausible has changed. If both Depth and Convergent Realism for all three realms is to be defended the metaphysics of science must be based on induction over ontologies. The Newtonian ontology has failed the inductive test, while the extended electromagnetic ontology has passed it. For example the empirical adequacy and manipulative success of the photonic ontology, instantiated in the luminiferous photon, and extended to W and Z particles, in providing models for the virtual particles of quantum field theory, must speak in favour of the ontological plausibility of the generic photonic ontology.

However the greater power that the manipulating hand has to penetrate the depths of nature than has the eye to observe 'reality in all its depths', is still subject to limit. The 'moving boundary' argument reached its terminus in the realm of those kinds of beings which were for ever unobservable. Model guided manipulation allowed physicists to make inductively reasonable claims for the match between their models and the reality they purport to represent even when these models were surrogates for a reality that, we believe, could never be observed. But the manipulation criterion too has its limits. There are beings which can be manipulated directly. There are said to be beings which can be manipulated in principle, if technology develops adequate techniques. There are beings, referred to in theories and represented in the models for those theories, the manipulations which are, we presently believe, impossible. At present the quark model of the fine structure of subatomic particles does not seem to hold out any possibility for quark manipulations. The quark model must therefore lie, perhaps for ever, beyond the bounds of an assessment of its verisimilitude. If 'quarks' can find a place in our favoured type-hierarchy then the Principle of the Conservation of Kinds lends hypotheses invoking them as real beings, a measure of inductive support.

12. A FINAL OBJECTION REBUTTED

The induction to Depth Realism would fail if it could be shown that the 'pragmatic' property of manipulative efficacy of a theory/model is simply a special case of the logical property of empirical adequacy. It might seem that it would be enough to point out that manipulative efficacy is revealed in a theory-guided material practice while empirical adequacy is revealed in a discursive procedure the criteria for the correctness of which are logical. The practice and the procedure are of radically distinct categories, and therefore irreducible.

But it might be objected that this short way with the problem overlooks the fact that the claim that a practice is efficacious is supported only if the outcome, the phenomenon produced to order, so to say, fulfils certain criteria, that is it is a phenomenon of the type to be expected. These criteria are defined discursively, by the same hypothetico-deductive procedure that would have established empirical adequacy.

The reply to this objection takes us to the heart of the argument. There are two possible hypothetico-deductive procedures which would permit an efficacious manipulation to count as a test of empirical adequacy of the theory which guided it. One case is when the empirical adequacy of a mere Humean correlation between implementation of the procedure and its outcome provides the hypothetico-deductive structure, on the basis of a 'covering law'. Thus the Stern–Gerlach experiment merely demonstrates the empirical adequacy of the 'law' that activating a certain kind of circuit is correlated with a characteristic change in the pattern of light on a screen. But this requires physics to include an indefinite number of ad hoc 'laws', involving standard physical concepts, which are 'out of step' with such well-established principles as those I have called Boyle's and Faraday's Principles, each of which is a summary of a well-founded branch of physics. If indeed one were to accept the 'covering law' reduction of the Stern–Gerlach experiment it would be a disconfirmation of the Faraday Principle, and so effectively an abandonment of electromagnetism. Alternatively it might be argued that manipulative efficacy should be taken as a test only of the empirical adequacy of the full scale theory/model/ontology triad, and no more than that. But in that case the reductionist must invoke either the Boyle or the Faraday Principle (or something like it) as part of the theory. But this is tacitly to accept the ontological account of the efficacy of the manipulation with respect to the Humean phenomenological correlation revealed in the Stern–Gerlach experiment between activated circuits and reoriented images. The empirically well supported Boyle and Faraday Principles block the use of Clavius' Paradox to undercut the proof of the ontological assumptions involved in the experimental procedures by reference to the efficacy of the manipulation.

So either the putative reduction tends to privilege a weak phenomenological correlation over well-established laws and principles, or it involves tacit acceptance of an irreducible ontological assumption. This assumption amounts to the principle that what is being manipulated by the overt procedure is a covert structure, process, entity or property. The reduction is either ad hoc or ontologically concessive. So it fails as an objection in either case.

A different kind of defence of the autonomy of the manipulative efficacy of an empirical procedure as an independent criterion for the verisimilitude of the model that guides it, invokes the general incompleteness of the discursive presentation of many theories. There are many procedures that can be demonstrated to be efficacious by 'rule of thumb' in the absence of a discursive presentation of the theory sufficiently articulated to permit a water-tight hypothetico-deductive demonstration that the phenomena produced to order by the manipulation are proofs of the empirical adequacy of the theory. Medical science is full of examples of the efficacious but indirect manipulation of unobservable structures, processes, entities and properties in the admitted absence of a well-articulated hypothetico-deductive derivation of propositions describing the results.

We can now rank the three criteria on which the piggy-back sequence of inductive arguments was constructed. Ontological plausibility is parasitic upon empirical adequacy and manipulative efficacy, in that an exotic ontology which is ontologically innovative, is defensible for verisimilitude in the sense of Aronson, the sense made use of throughout this paper, just in so far as its instantiations meet the primary criteria, as we have just identified them. This step provides a philosophical ground for the defence of the important thesis that ontologies have an empirical basis, even when they are never instantiated in entities that can commonly be observed. Without this step the inductive argument for Depth Realism, in the version defended here, would be open to the objection that it is implausibly ontologically conservative.

I have tried to show that induction from 'observed' cases of correlation between the satisfaction of the three criteria based on the 'evidential' properties of theories and the 'projectible' property, that is between the satisfaction of the criteria for 'good theory' and the demonstrable verisimilitude of the model of the theory, to unobserved cases, that is cases in which the verisimilitude of the model cannot be assessed empirically, is reasonable. Theories which meet the three criteria are more likely to be verisimilitudinous than those which do not. Can we now move on to an argument for Convergent Realism, the thesis that the better a theory meets the criteria, relative to the performance of a weaker rival, based on a different model of the relevant aspect of reality, the more likely is the model of the former than the latter to resemble the relevant aspect of reality? In defending Policy and Depth Realism we have legitimised the consultation of the history of science for the evidence that would support Convergent Realism. Once again the defence would be by building an inductive argument. The future of science could throw up a countervailing multitude of cases that would defeat the induction. In this paper I hope to have shown the adoption of an inductive form of argument in this context is rational. It is another matter to accumulate sufficient evidence for Convergent Realism.

NOTES

* A popular version of this argument appeared in *Perspectives on Science*, 1994.

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