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Smooth Lines in Confirmation Theory

Carnap, Hempel, and the Moderns

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The past two decades have seen a reviving interest in logical empiricism. Distance in time typically engenders the equanimity characteristic of the historical attitude. The historical perspective mellows old front lines and tends to transform previous warfare into nuanced analysis and more detached consideration. After Karl Popper's attacks on Rudolf Carnap have shifted away from the philosophical combat zones and after the battle smoke of the fighting over theory change, as initiated by Thomas Kuhn's paradigm approach, has cleared, it is precisely this historical attitude that has begun to dominate the study of logical empiricism. If winning or losing is no longer the issue, the woodcut type approach of marked contrasts gives way to expounding multifaceted shades and variegation. Continuing scholarly occupation with logical empiricism has brought to light a wide variety of views among its advocates and has shown that there never was anything like a monolithic Viennese ideology. Moreover, it never was the primary objective of logical empiricists to debunk statements as meaningless gibberish. Rather, the top of the agenda was characterized by more positive challenges. For instance, the double-language model paved the way to the eventual recognition of a genuine contribution of theory to conferring meaning to scientific terms (Irzik and Grünberg 1995, 289–90). In sum, logical empiricism was more contrasting and more modern than its opponents would have it.

I wish to broaden this recent reevaluation of logical empiricism by bringing confirmation theory into the picture. Carnap, Hans Reichenbach, and Carl Hempel contributed to laying the foundations of present-day confirmation theory. So it was logical empiricists, among others, who planted the seeds that were later brought to fruition.

Reshaping the Ground in Confirmation Theory

Conventional wisdom has it that science provides us with insights that are more accurate and more trustworthy than the commonsense views we entertain in everyday life. Most of us are willing to grant a high degree of credibility to scientific tenets. The reason is that we take such tenets to be better confirmed than the usual folklore, which in turn places the issue of the nature of scientific confirmation on the agenda.

Let me prepare my sketch presentation of logical-empiricist contributions to this issue by delineating in broad strokes the most striking lines in the development of confirmation theory. This development is characterized by two peaks, separated by a period of roughly two decades in which the relevant interest dropped to a low. The first peak extends from roughly 1930 to 1960 and includes the relevant work of logical empiricists. Outstanding among them are Reichenbach's *Experience and Prediction* (1938), Hempel's "Studies in the Logic of Confirmation" (1945), and Carnap's *Logical Foundations of Probability* (1950). All these accounts placed the logical or probabilistic relationship between a hypothesis and a piece of evidence at the center of consideration. It was asked whether or to which degree a given observation report was capable of supporting a given assumption. Within this framework it was conceded at once that general theories are in need of empirical assessment as well. However, the evaluation of individual hypotheses was considered primary. Overarching theories were construed as collections of hypotheses so that the support of the former was thought to be derivable from the confirmation of the latter.

The publication of Kuhn's *Structure of Scientific Revolutions* (1962) shifted the focus to a different ground and initiated a distinct approach to the evaluation of scientific achievements. Let me call this approach the tradition of theory change, as opposed to confirmation theory proper. Kuhn regarded the issue of the viability of comprehensive theoretical traditions or paradigms as the fundamental one.

The evaluation of individual hypotheses was held to be inextricably tied up with the credibility of the associated paradigm. Thus, the theory-change tradition replaced the emphasis on individual assumptions by a holistic approach according to which large-scale theories constitute the primary object of scientific assessment. Second, the historical development of a theory was considered essential in addition. In the Kuhnian framework, the paradigmatic principles are decreed exempt from critical examination during the periods of normal science but might well be subjected to severe tests in the times of crisis or imminent revolution (Kuhn 1962, 35–37, 66–68).

Imre Lakatos's methodology represents another approach within the theory-change tradition. According to Lakatos, one of the chief measures of acceptability is whether a theory manages to anticipate relevant data or whether it merely accommodates observations after their discovery and only responds to anomalies. Although two theories might be able to account for the same set of data, their support by these data might yet be different. If one of the theories predicted the relevant findings while the other had to be adapted to new problems and fitted to known results, the former is buttressed more strongly by these data than the latter (Lakatos 1970, 32–36; Carrier 2002).

In sum, there is a twofold contrast between confirmation theory and the theory-change tradition as to the evaluation of scientific achievements. First, confirmation theory considers the appraisal of individual hypotheses in light of the relevant evidence as the core and kernel of judging scientific merit. The tradition of theory change, by contrast, places comprehensive theories at the focus and regards confirmation as a profoundly holistic endeavor. Second, confirmation theory distinguishes logical or probabilistic relations between the data and the theoretical claims as exclusively relevant for assessing these claims. The theory-change tradition, on the other hand, additionally features historical patterns of development and temporal relations between the enunciation of a theory and the discovery of the pertinent empirical effects.

The thriving of the theory-change tradition corresponded to the eclipse of confirmation theory. The latter was revived after about 1980 when interest in theory change began to fade. This period constitutes the beginning of the second peak of confirmation theory. It is characterized, first, by Clark Glymour's bootstrap model of confirmation, which takes up essential principles from Hempel's entailment approach, and, second and predominantly, by Bayesian confirmation theory, which incorporates elements of the probabilistic accounts of Carnap and Reichenbach. In each case the later theories owe much to their logical-empiricist sources. Confirmation theory can be regarded as a thoroughly cumulative endeavor. When confirmation began to re-attract attention and the second peak came into view,

the work was resumed at the locus, where it was dropped decades ago. Today's theories of confirmation have smoothly grown out of their logical-empiricist predecessors. My chief example is Hempel's approach, which profoundly shaped the bootstrap model. But let me begin by offering some remarks on the joint characteristics of probabilistic theories of confirmation.

Probabilism in Confirmation Theory

Underlying all relevant approaches is the attempt to clarify confirmation by taking advantage of the probability calculus. Degrees of confirmation are intended to be captured by the probability of a hypothesis in light of the available evidence. The differences between Carnap and Reichenbach, on the one hand, and present-day Bayesianism, which largely goes back to Bruno de Finetti, on the other, predominantly concern two aspects. Bayesianism of this sort is characterized, first, by the commitment to Bayes's theorem as the measure of empirical support and, second, by the subjective interpretation of the relevant probabilities (and of prior probabilities in particular). Probabilities of hypotheses are supposed to rely on or to merely express personal belief strengths that are only constrained by the condition that their relations are in agreement with the probability calculus (Howson and Urbach 1989, 10, 67).

On both counts, Carnap and Reichenbach held dissenting views. Their approaches to confirmation differ in detail but agree on invoking the theorem of conditional probability rather than Bayes's theorem, and on trying to confer objective meaning to all relevant probabilities. Carnap's inductive logic employs language-dependent measures of the ratio of the favorable cases to the possible ones; Reichenbach's approach is based on frequentist assumptions. Adopting Bayes's theorem rather than conditional probability marks an important improvement but does not indicate an in-principle change. Bayes's theorem features the likelihood or expectedness of data, which is crucial to the reconstruction of theory choice and theory change. Still, this is a technical point that in no way indicates a switch in the fundamental orientation. In this vein, Colin Howson and Peter Urbach, in their now standard account of Bayesianism, regard Bayesian confirmation theory as the continuation of inductive logic by other means (Howson and Urbach 1989, 290; Howson 1997, 278).

The gap between the objective probabilities of the empiricist tradition and the subjective probabilities of standard Bayesianism is deeper and has wider ramifications. Still, there are factions in the present debate, Wesley Salmon prominently among them, who advocate an objective interpretation of probabilities within the

Bayesian framework (Salmon 1967, 115–31; Salmon 1990, 180–87). All in all, there is a striking continuity between the early and the modern debates. In spite of superficial dissimilarities, strong conceptual ties bind Carnap's views of confirmation to latter-day Bayesianism. This bears testimony to the fecundity of logical empiricism. In confirmation theory logical empiricism was not abandoned but gradually transformed. Probabilistic confirmation theory proceeded along smooth lines.

Hempel's Entailment Account of Hypothesis Confirmation

I want to support this claim of gradual transformation by reviewing one example more extensively and more carefully. This example concerns the relationship between Hempel's entailment account of confirmation and Glymour's bootstrap model. So I set aside the grand lines for the moment and give a more detailed account of what I take to be the salient aspects of the transition.

Hempel's account of confirmation is based on the intuition that a hypothesis is confirmed by its positive instances rather than its consequences—as the hypothetico-deductive approach has it. Hypothetico-deductive confirmation involves the derivation of the data from tentatively presumed assumptions. If these empirical consequences are found in experience, the theoretical premises of the deduction are considered confirmed. Thus, the key to hypothetico-deductivism is what Hempel calls the *"converse consequence condition."* This condition stipulates that if an observation report *e* confirms a hypothesis *h*, which is in turn implied by another hypothesis h^* (that is, $h^* \Rightarrow h$), then *e* also confirms h^*. In the hypothetico-deductive framework, it is in virtue of this condition that pieces of evidence are able to bear out general theories. Suppose the observation of a freely falling body can be accounted for by the law of free fall and thus confirms this law. Since the law is a consequence of Newtonian mechanics (drawing on appropriate initial and boundary conditions in addition), the observation supports the overarching theory as well. Hempel rejects the converse consequence condition. His objection is that the hypothetico-deductive approach is circular: the move from the correctness of the consequences to the soundness of the premises is nondeductive and for this reason in need of justification. However, any such justification presupposes the very concept of confirmation one is about to establish in the first place (Hempel 1945, 28–29, 32–33).

Hempel's objective is to give an explication of a qualitative relation of confirmation that moreover is, in contrast to hypothetico-deductivism, deductively valid. The aim is to clarify what it means that a piece of evidence *e* confirms a hypothesis *h*: c(h,e). Hempel's suggestion is that confirmation involves the derivation of

the hypothesis from the data rather than the other way around. The basic relation is *instantiation:* hypotheses are confirmed by their positive instances. An instance of a hypothesis is characterized by the fact that variables contained in it are replaced by individual constants. That is, $\forall x\,(Px \rightarrow Qx)$ is a hypothesis; $Pa \wedge Qa$ is a positive instance. These instances are observation statements; they ascribe certain properties to individual objects. The general assumption that all pixies are quirky is instantiated by Archibald, the quirky pixy. Observation statements are critical to confirmation; hypotheses are appraised on their basis. The key intuition is captured by Hempel's "*entailment condition:* Any sentence which is entailed by an observation report is confirmed by it" (Hempel 1945, 31; my emphasis). That is, a hypothesis is confirmed if instantiations of this hypothesis follow from the data.

However, as Hempel proceeds, this account has the awkward consequence that confirmation relations may depend on the formulation of a hypothesis. In particular, logically equivalent hypotheses may come out confirmed differently by the same data. Consider the contrapositive to the mentioned schematic hypothesis: $\forall x\,(\neg Qx \rightarrow \neg Px)$. What is nonquirky is not a pixy. This version is no longer instantiated by Archibald, the quirky pixy. The evidence which supported the hypothesis is confirmatory neutral to its contrapositive reformulation. Hempel considered this feature an unacceptable flaw of his model and suggested fixing it by adopting the *"equivalence condition"* as an additional constraint (Hempel 1945, 13, 31). It says that logically equivalent hypotheses are confirmed by the same evidence: If c(h,e) and $h \Leftrightarrow h^*$ then c(h^*,e). Accepting this further condition means that instantiation is merely sufficient, not necessary, for confirmation. If a hypothesis remains noninstantiated but is equivalent to a positively instantiated one, the former receives empirical backing as well.

A further condition brings out the spirit of Hempel's account more distinctly. This "*special consequence condition*" says: "If an observation report confirms a hypothesis *h*, then it also confirms every consequence of *h*" (Hempel 1945, 31). Hempel argues that this condition should be obvious. Deriving consequences from a statement does no more than making the content of this statement explicit. It should be clear, then, that the logical consequences of a confirmed hypothesis are confirmed themselves.[1] It thus militates against the adequacy of the hypothetico-deductive approach to confirmation that the special consequence condition comes out violated within its framework. If hypothesis *h* entails evidence *e*, it is by no means guaranteed that a weaker hypothesis *h'* that follows from *h* still entails *e* (Hempel 1945, 31–32).

These considerations make it clear that the converse consequence condition, on the one hand, and the entailment and special consequence conditions, on the other, are conceptually antagonistic. They belong to divergent approaches to confirmation—namely, traditional hypothetico-deductivism and Hempel's entailment account, respectively. In particular, it is impossible simply to conjoin all three conditions. The result would be that each observation e would support a completely arbitrary hypothesis h. Here is the argument: e entails and thus confirms itself; hence, in virtue of converse consequence, it also supports $e \wedge h$ which, by dint of special consequence, implies the confirmation of h (Hempel 1945, 32; Carnap 1950, 474). Consequently, the two sets of conditions have to be kept separate.[2]

Hempel specifies one more requirement, namely, the "consistency condition." One of the clauses attached to this condition says that all the hypotheses an observation statement (which is not self-contradictory) confirms are logically compatible with one another. Given the special consequence condition, there is no way to avoid the demand for consistency. If an observation statement supported two incompatible hypotheses, it also confirmed all the consequences of this contradiction. But anything is entailed by a contradictory premise. The acceptance of a violation of the consistency condition would amount to regarding arbitrary hypotheses as confirmed. This is an unwholesome result that needs to be ruled out (Hempel 1965, 33–34).

Hempel proceeds by specifying a conception of confirmation that satisfies these three conditions. The challenge is to show that general hypotheses are subject to confirmation in this sense by observation reports. The pivot of Hempel's conception is the notion of the "development of a hypothesis." The development serves to unfold the content of the hypothesis for a finite class of objects. The development represents a list of the cases to which the hypothesis is supposed to apply. This is achieved by substituting the variables in the hypothesis by the relevant individual constants. Consider the hypothesis "all swans are white" or $\forall x\, (Sx \rightarrow Wx)$ for a finite class of objects {a, b, c}. The development of this hypothesis is: $(Sa \rightarrow Wa) \wedge (Sb \rightarrow Wb) \wedge (Sc \rightarrow Wc)$. Hempel's condition of "direct confirmation" says: An observation statement e directly confirms a hypothesis h, if e entails the development of h for those objects that are mentioned in e. Let the observation statement be: $Sa \wedge Wa$, "Albert is a swan and Albert is white." It implies the first clause of the development, which is the only one that mentions Albert.[3] It follows that the hypothesis is directly confirmed by the observation report (Hempel 1945, 36–37).

The idea underlying the entailment account is to conceive of confirmation as deduction of positive instances of a hypothesis from the data. This idea is realized using the notion of development. The point is that hypotheses are of a general nature, whereas observation statements refer to individuals. Thus, the latter cannot imply a general claim. The development serves to remove the universal quantifier from the hypothesis and to make its content explicit for each of the relevant objects. The key to confirmation is that an observation report entails the entire content of the hypothesis with respect to the objects the report refers to. The hypothesis says no more as to these objects than the report does. This is why the observations are capable of confirming general hypotheses.[4]

As yet, Hempel has delivered precisely what he had advertised: a qualitative relation of confirmation that is deductively valid. The conception of deriving the relevant parts of the development of a hypothesis makes it transparent how a piece of evidence can possibly bear on a general assumption in a logically sound fashion. In contrast, it is obvious that this procedure cannot capture all there is to confirmation in the sciences. After all, scientific evaluation draws on judgments of the kind of how well a hypothesis is doing in light of the available evidence. This goes beyond assessments such as that a given piece of evidence supports a given hypothesis. What is needed is a comparative or quantitative concept of confirmation. In order to tackle this task, Hempel takes recourse to auxiliary criteria that have a traditional ring. The overall confirmation of a hypothesis, namely, is said to depend on the amount of confirming instances, the simplicity of the hypothesis, and its coherence with other relevant assumptions (Hempel 1945, 41–42). At this juncture, the nondeductive aspects of the confirmation process resurge.

Shortcomings of Hempel's Account

Let me highlight two shortcomings of Hempel's account that turned out to be significant for its transformation into the bootstrap model. First, the notion of development requires that hypotheses are couched in observational terms. There is no development of theoretical hypotheses. The reason is that the development of a hypothesis is supposed to catalog the observational content of this hypothesis. But without assistance of further assumptions, a hypothesis such as "the wavelength of red light is 700 nm" lacks observational content. Wavelengths are not accessible to the unaided human senses so that auxiliary assumptions are needed for endowing the hypothesis with empirical indications. It follows that no observation statement is able to entail, all by itself, the relevant content of a theoretical hypothesis.

The dependence of the observational content of a hypothesis on additional assumptions makes it impossible to unambiguously develop a theoretical hypothesis into the list of its empirical instantiations. A theoretical quantity can be measured by a multiplicity of methods. Current intensity, for instance, can be evaluated using electromagnetic interaction or electrochemical effects. In both cases the observational indications are disparate. It follows that one and the same hypothesis may translate into the observation report e_1, if auxiliary h_1 is invoked, or, alternatively, into observation report e_2, if auxiliary h_2 is resorted to. This change in the empirical indications, depending on which further assumptions are adduced, vitiates considering both reports as simply bringing out the observational content of the hypothesis. Not a single, unambiguous development is attached to the hypothesis, but rather a context-dependent multitude of disparate observational indications (Earman 1992, 68; Earman and Salmon 1992, 52).

Another trouble of Hempel's lies with the consistency condition. This condition requires that a given piece of evidence can only confirm hypotheses that are compatible with one another. But consider the notorious problem of fitting a curve to measurement results. The problem is that a given set of measurement values may lead to a number of distinct, incompatible hypotheses as to the underlying law. More than one curve can sensibly be drawn through a cloud of points representing the measurement results. One might assume that all the hypotheses instantiated by these results are supported by the results. But this prima-facie plausible judgment is ruled out by the consistency condition. Hempel grants the objection (Hempel 1945, 33), which makes Carnap wonder why Hempel sticks to a condition faced with such "a clear refutation" (Carnap 1950, 476). In the 1964 postscript to his seminal 1945 paper, Hempel acknowledged his predicament. He conceded, on the one hand, that the curve-fit objection seems "to carry considerable weight," but he insisted, on the other, that giving up consistency would be tantamount to abandoning the condition of special consequence as well—which went against the grain of the instantiation approach (Hempel 1945 [1964], 49). In fact, if the special consequence condition is retained, the confirmation of two incompatible hypotheses by the same data would imply that all the consequences of these hypotheses were confirmed as well—which would mean to regard arbitrary hypotheses as confirmed. Given the special consequence condition, preservation of the consistency condition is inevitable.

This finding may raise doubts as to whether special consequence is a kosher condition. In fact, closer inspection reveals that it is not. It gives rise to two paradoxes—namely, the conjunctive and the disjunctive irrelevance paradox. For the conjunctive paradox, consider the hypothesis: "trout are gill-breathing and sparrows are warm-blooded." The observation of the gill-breathing trout Frederick counts as a positive instance of this hypothesis. Actually, an observation report to this effect implies everything the hypothesis says on the objects mentioned in the report—as demanded by Hempel. So we may conclude that the hypothesis is confirmed by the observation statement. Further, the hypothesis can be considered as a conjunction of two partial claims, one referring to trout and the other to sparrows. Each of these partial claims, and the one on sparrows, in particular, follows from the comprehensive assumption. That sparrows are warm-blooded is a special

consequence of the hypothesis that trout are gill-breathing and sparrows are warm-blooded. In virtue of the special consequence condition, the observation of a gill-breathing trout should support the presumption that sparrows are warm-blooded.

Drawing a little on the machinery of formal logic, the conjunctive irrelevance paradox amounts to the following. Let the hypothesis be: $\forall x\, [(Tx \rightarrow Gx) \wedge (Sx \rightarrow Wx)]$. The observation report may be: $Tf \wedge Gf$. On Hempel's account, this statement counts as a positive instance and thus as a confirmation of the hypothesis. A special consequence of the hypothesis is: $\forall x\, (Sx \rightarrow Wx)$, which is thus supported by the evidence as well.[5]

The disjunctive paradox is similarly structured. Take the hypothesis "trout are gill-breathing" and assume it to be confirmed by the observation of trout Frederick. Among the special consequences of this empirically confirmed hypothesis is the assumption that "trout are gill-breathing or sparrows are warm-blooded." Classical logic permits us to weaken a claim by appending another clause through disjunction. The truth of an assumption entails that this assumption or some other is true. Consequently, judging by Hempel's lights, the disjunctive hypothesis should be confirmed by the observation as well—albeit the second disjunct is not supported separately.

Again speaking in terms of formal logic, let the hypothesis be represented by the expression $\forall x\, (Tx \rightarrow Gx)$, with the supporting evidence $Tf \wedge Gf$. The hypothesis implies: $\forall x\, [(Tx \rightarrow Gx) \vee (Sx \rightarrow Wx)]$, which disjunction is likewise confirmed by the evidence in virtue of the special consequence condition.

Thus, the special consequence condition issues licenses for appending irrelevant clauses to hypotheses and having them confirmed by evidence relating to the original hypothesis. Irrelevant clauses turn out to be free riders of confirmation. Actually, the conjunctive irrelevance paradox is known to haunt hypothetico-deductivism.[6] The special consequence condition serves to import the conjunctive paradox into the entailment account, for one, and to bring forth the disjunctive paradox, for another.

Basics of the Bootstrap Model

The bootstrap model, as suggested by Glymour in 1980, owes its fundamental approach to confirmation to Hempel's account but substantially alters most of the technical machinery of the latter. Glymour accepts Hempel's basic idea to place qualitative confirmation at the top and to characterize confirmed hypotheses as being entailed by the data. The most important changes concern the conception of the development and the special consequence condition. Both are replaced by what I call the "overall instantiation requirement." Let me briefly sketch these modifications.

Within the general framework of the entailment account, the confirmation of hypotheses is appraised by examining their positive or negative instances. On the one hand, Glymour's bootstrap model involves a liberalization of Hempel's demands in that it permits one to perform the derivation of such instances by drawing on additional principles. That is, the hypotheses to be confirmed need no longer be couched in observational vocabulary; they need no longer be translatable into the collection of their empirical instances. Rather, it is acknowledged that hypotheses may be expressed in theoretical terms so that their instances could only be identified using auxiliary suppositions. This means that the notion of the development of a hypothesis is dropped and that, consequently, the theory-ladenness of empirical confirmation is recognized. On the other hand, Glymour tightens the demands in requiring that the values of *all* the quantities in the hypothesis in question are fixed uniquely by the evidence and that the agreement between the data and the hypothesis was not guaranteed in advance on logical grounds.

More specifically, an empirical test of a hypothesis is performed by producing a positive or, as the case may be, negative instance of it. In such an instantiation of a hypothesis all the variables figuring in it have assumed definite values. If these values match the hypothesis, the instantiation is positive; if not, it is negative. Hypotheses are confirmed by their positive instantiations and discredited by their negative ones. As a rule, the quantities in scientific hypotheses are not directly observable but need to be inferred from the data using additional assumptions. The auxiliary assumptions serve to furnish instantiations of hypotheses couched in theoretical terms. A positive instantiation is disqualified as a confirmation if the nature of the situation ruled out the appearance of a negative one.

Bootstrap confirmation is thus characterized by the following conditions.

1. *Overall instantiation:* Each quantity in the hypothesis in question has been unambiguously evaluated on the basis of the data and by eventual recourse to auxiliary assumptions.
2. *Positive instantiation:* the values are in agreement with the hypothesis.
3. *Risk of failure:* accordance between data and hypothesis is not made sure by the logical characteristics of the test (Glymour 1980, 114–23; 130–32).

The adoption of the overall instantiation requirement marks the crossroads where Glymour parts Hempel's company. In virtue of this commitment, instantiation becomes necessary for confirmation (and is not alone sufficient as in Hempel).

The recognition of theory-ladenness calls for the adoption of an *auxiliary*

condition. If arbitrary assumptions were allowed to be employed for producing positive instances of a hypothesis, the instantiation requirement could be trivially satisfied. The auxiliary condition demands that the ancillary assumptions used in instantiating a hypothesis be confirmed themselves. If this was meant to say that each bootstrap confirmation needs to rely on bootstrap-confirmed hypotheses, an infinite regress would ensue. But Glymour specifies three options for judging particular hypotheses without prior recourse to bootstrap confirmation. First, some hypotheses can be supported by applying them twice to the same situation. One can employ the ideal-gas law for evaluating the gas constant and check the invariance of this constant by drawing on another application of the same law (Glymour 1980, 111, 121–22, 140; Mitchell 1995, 244; see, however, Culler 1995). That is, a hypothesis is used as its own auxiliary hypothesis. Second, under suitable circumstances it can be decided in a noncircular fashion that a hypothesis is not confirmed. The bootstrap conditions imply that a hypothesis remains unsupported if either definite values cannot be obtained for all relevant quantities on the basis of the data or if these evaluations are not liable to risk of failure (Glymour 1980, 118–21, 134–35, 143). Third, a "concordance procedure" can be used for establishing the mutual support of auxiliary assumptions, none of which is bootstrap confirmed in advance. In this case one and the same theoretical quantity is evaluated by relying on different auxiliary hypotheses or different data sets. If the results of these calculations are in agreement with one another, the correctness of the relevant ancillary assumptions employed is thereby buttressed (Glymour 1980, 122–23; see Carrier 1994, 52–55).

I will not go into these ramifications but will focus on the bearing of the overall instantiation condition. This condition is apt to dissolve both the conjunctive and the disjunctive irrelevance paradox. The reason is that the requirement makes it impossible to regard hypotheses or their consequences as empirically supported if one of the relevant variables fails to be uniquely determined by the data. The conjunctive paradox is removed on the grounds that evidence relating only to partial claims entertained in a hypothesis is disqualified as confirmation of the entire hypothesis. Data on trout alone fail to fully instantiate the conjunctive hypothesis on trout and sparrows. The overall instantiation requirement is violated so that the comprehensive hypothesis remains without support. The disjunctive paradox is dismissed in virtue of the fact that the special consequences of an instantiated hypothesis may fail to be instantiated themselves. The hypothesis on gill-breathing trout is, in fact, confirmed by the observation of gill-breathing trout Frederick. But these data are unsuitable for instantiating the logical consequence of this hypothesis that is generated by appending a disjunctive clause. Since this clause remains uninstantiated, the entire hypothesis receives no empirical support. This shows that adopting the overall instantiation requirement is tantamount to abandoning the special consequence condition.

It follows that there is no need to retain the consistency condition whose application to problems like curve fitting appeared implausible. If consequences of confirmed hypotheses are no longer supposed to be supported automatically, consistency can be dropped without detrimental effects. Two incompatible hypotheses may be considered confirmed by the same set of data without having to admit that everything implied by an inconsistency (that is, arbitrary assumptions) are borne out as well. Hempel's consistency condition is not part of the bootstrap model.

Let me expound the characteristics of the bootstrap model by briefly turning to a famous example of confirmation by deduction from the phenomena—namely, Newton's derivation of a central inverse-square force from Kepler's third law and his own laws of motion. For reasons of simplicity let us confine to the case of the circular motion of a single planet of mass *m* orbiting the sun at a distance *r*. It follows from Newton's laws of motion that a centripetal force $F = mv^2/r$ is necessary for maintaining the circular motion. That is, this force is exerted from the sun on the planet. Assume that it takes the period *T* for the planet to complete one revolution around the sun so that its uniform velocity comes out as $v = 2\pi r/T$. Plugging in this quantity in the equation for the centripetal force gives $F = 4\pi^2 mr/T^2$. Kepler's third law of planetary motion says that the squared periods of revolution are proportional to the cubes of the semimajor axes of the planetary orbits. In the simplified case of circular motion under consideration, the semimajor axis coincides with the radius of the planetary orbit. Kepler's third law thus amounts to $T^2 = kr^3$ (with some constant *k*). Plugging in yields for the centripetal force $F = 4\pi^2 mr/kr^3 = 4\pi^2 m/kr^2$. The result is that the centripetal force of gravitation decreases with the squared distances from the sun $F \sim 1/r^2$.

This example places essential features of bootstrap confirmation at the focus. First, the basis of the derivation is Kepler's third law, which is regarded as the relevant "phenomenon." However, it is obvious that this law involves a general claim and is not to be identified with a single experience. So, what bootstrap confirmation actually amounts to is the derivation of instances of more comprehensive hypotheses from more restricted ones.

Second, the procedure essentially draws on the invocation of additional laws and on the assumption of initial and boundary conditions. The central nomic premise is the equation of centripetal force that derives from the Newtonian equation of motion. The factual premise involves the constraint to a single planet. From these premises the existence of an inverse-square attractive force from the sun to the planet can be deduced, indeed. This demonstrates the importance of loosening the demands on the derivation of instantiations of hypotheses from the data. In

contrast to Hempel, Glymour licenses the intrusion of theory in this process. It is only through this liberalization that realistic examples can be brought into the scope of confirmation theory.

Third, in contrast to hypothetico-deductivism, empirical support in the bootstrap vein concerns specific hypotheses. Glymour shares Hempel's nonholistic approach to confirmation. These nonholistic features are codified by the overall instantiation requirement that says only the instantiated parts or aspects of an assumption are confirmed by the relevant data. Let us take hypothetico-deductivism as a template so as to realize more distinctly the contrasting features of bootstrap confirmation. Within the hypothetico-deductivist framework, Kepler's third law is thought to be derived from Newton's laws of motion and his law of gravitation, along with the relevant initial and boundary conditions. Thus, Kepler's third law is shown to be a consequence of this set of premises. The empirical success of the law indiscriminately supports all the premises used in the deduction. Hypothetico-deductive confirmation is directed at large-scale theoretical networks; it is holistic in kind. Kepler's third law confirms the "science-wide web" of Newtonian mechanics.

The bootstrap picture is essentially different. The overall instantiation requirement entails that confirmation is restricted to the instantiated parts or aspects of the hypotheses at issue. Conversely, what is not instantiated remains unsupported. The only part of the law of gravitation that is actually instantiated by the sketched deduction is the assumption of an inverse-square force from the sun to the planet in question. Consequently, in virtue of the overall instantiation requirement, this one assumption alone is confirmed by Kepler's third law. This means, in particular, that neither the reciprocality nor the universality of gravitation, which are both essential to the Newtonian conception of gravity, receive any support from the third law. Nothing is derived with respect to a force exerted from the planet on the sun; nothing is deduced as to the forces among various planets. So, it is only a restricted aspect of the law of gravitation, and by no means the entire network of Newtonian mechanics, that is confirmed by Kepler's third law. Bootstrap confirmation is directed at specific assumptions and is thus nonholistic.[7]

Glymour joins Hempel in considering qualitative confirmation as central. The core issue is whether or not a piece of evidence supports a given hypothesis. Just as in Hempel's original version, additional criteria have to be invoked in order to assess degrees of confirmation. The comparative or quantitative merits of a hypothesis or theory are only appraised at a later stage of the procedure. Glymour resorts to standards such as the paucity of untested hypotheses, the variety of evidence brought to bear on a theory, the uniformity of the explanations achieved, and so on (Glymour 1980, 153–54). Neither Hempel nor Glymour leave any doubt that qualitative confirmation is insufficient for capturing the whole of hypothesis appraisal in the sciences. Further criteria of a nondeductive nature have to be taken into account in any event. The purpose in this section was to reveal the strong conceptual ties between the basic principles of Hempel's and Glymour's approaches. This can be accomplished by focusing exclusively on the fundamental notion of qualitative confirmation.

Hempel's Paradox of Confirmation

The irrelevance paradoxes, as sketched earlier in this chapter, are not to be confused with what is usually called "Hempel's paradox of confirmation" or "the ravens paradox." This paradox, in contrast to the irrelevance paradoxes, is not due to the special consequence condition, but arises from the equivalence condition. This condition requires that a piece of evidence that supports a hypothesis also confirms each hypothesis that is logically equivalent with the first one. The catch is that this not implausible demand has somewhat tricky ramifications. Let the hypothesis be "all ravens are black." This statement is equivalent to its contrapositive, "all nonblack things are nonravens." A pink elephant is neither black nor a raven; its observation instantiates and thus certainly supports the latter claim. But then, in virtue of the equivalence condition, it should also confirm the original version that all ravens are black—which has a somewhat paradoxical ring (Hempel 1945, 12–15).

The entailment approach to confirmation is in no way particularly liable to Hempel's paradox. After all, the nonravenhood of nonblack things is a consequence of the presumption that all ravens are black, so that pink elephants bear out this presumption by hypothetico-deductive lights as well. Each theory of confirmation is threatened by the difficulty, and the extant literature contains a large number of attempts to cope with it (Maher 1999, 57–65). The reason I briefly want to go into the matter is that the entailment approach in general, and the bootstrap model in particular, allows for a natural treatment.

Let me begin by briefly sketching Glymour's own suggestion for handling the issue. He requires that genuine confirmation be selective. A hypothesis is borne out by only such data that do not also indiscriminately confirm alternative hypotheses, expressed in the same concepts as the first one but incompatible with it. What makes the support of the raven hypothesis by the pink elephant appear suspect is that this piece of evidence, using the same logic, likewise buttresses the claim that all ravens are green, or that they are yellow and littered with blue spots, or what have you. After all, pink elephants do not alone constitute nonblack nonravens but also nongreen nonravens or nonyellow, nonspotted nonravens. The

piece of evidence at issue fails to undermine any competing hypothesis. Its confirmatory impact is highly diffuse and nonselective, and this is the reason why it is bereft of corroborating force (Glymour 1980, 156–60).

I do not deny that the selective-confirmation requirement is plausible and suitable for coping with the paradox. Still, its acceptance is less than satisfactory since it involves the introduction of a special condition of adequacy so as to defuse one particular problem. It would certainly be more appealing to resolve the difficulty by drawing on the natural virtues of the instantiation account. Each confirmation theory could invoke the selective-confirmation requirement as additional principle; nothing hinges on featuring positive instances as the key to confirmation. Adopting the condition of selective confirmation does not confer a selective distinction to the instantiation account.

So let me try to advance bootstrapping a little further. There appears to be a way out of the quandary that is paved, indeed, by the emphasis on instantiations. It deserves notice that insistence on instantiations helps avoid the emergence of the paradox. A pink elephant is no positive instance of the generalization that all ravens are black and should fail to support it for this reason. The confirmatory force of such observations wholly derives from the equivalence condition; it does not arise from the first principles of the entailment approach. This constitutes a natural advantage over hypothetico-deductive theories of confirmation. Whatever the particulars of such theories may be like, they all subscribe to the converse consequence condition. This condition embodies the spirit of hypothetico-deductivism. But each hypothesis qualifies as a premise for the derivation of its contrapositive so that each confirmation of the latter is automatically transferred to the hypothesis itself. No additional condition is needed for generating the paradoxical result.

The bootstrap model, by contrast, demands positive instances. The overall instantiation requirement stipulates that each quantity in the hypothesis in question must be subject to unique evaluation on the basis of the data. It follows that noninstantiated hypotheses receive no support. But the pink elephant is unsuitable for fixing any quantity in the hypothesis about ravens. It only instantiates the contrapositive, not the hypothesis itself. The paradox does not arise in the first place.

It is obvious that this type of approach exacts renunciation of the equivalence condition; the very pivot of this treatment is that logically equivalent hypotheses could be borne out differently. However, in all the benign cases the equivalence condition is not needed, and in the malign ones it issues in paradoxes. So the condition could or should be dropped, respectively. Consider the law of gravitation: $F = Gm_1m_2/r^2$. A relevant piece of evidence, such as a given planetary constellation, indiscriminately instantiates all the logically equivalent versions of this equation: $r^2 = Gm_1m_2/F$ or $m_1 = Fr^2/Gm_2$. If the quantities are instantiated in one case, they are automatically instantiated in the others as well. Demanding equivalence explicitly is quite superfluous. Problems only emerge with laws in the form of material conditionals. To be sure, there are real-life laws of this sort. The law of inertia can be expressed to the following effect: if a body is not subject to any external force, it performs a uniform rectilinear motion. If the equivalence condition is renounced the curvilinear motion of a body under the action of an external force is not covered by this law. But there is nothing to worry about that. Noninertial motion is captured by a different law, the equation of motion. After all, these two types of situations were treated separately in Newton's original axiomatization of mechanics; they were addressed by the first and the second law of motion, respectively. If we want to have it one way and the contrapositive way alike, we should state it both ways.

Abandoning the equivalence condition serves to resolve Hempel's paradox of confirmation without the need to appeal to a particular, tailor-made requirement. It is true that it might prove difficult to extend this treatment to cover comparative and quantitative notions of confirmation (Maher 1999, 53); but given Hempel's and Glymour's strategy of placing qualitative confirmation at the top, degrees of confirmation are not yet at issue.

Passing on the Torch: Hempel and Glymour

Glymour places his model explicitly in the tradition initiated by Hempel (Glymour 1980, 128–29). Hempel's theory of confirmation is said to possess "admirable qualities" but to suffer from its restriction to simple cases (Glymour 1980, 27). This supposedly means that Hempel's basic conception is all right but needs to overcome its limitation to toy propositions of the "all swans are white" variety. What is called for, Glymour suggests, is to enlarge the framework so as to make real-life cases tractable.

I have attempted to point out that the fundamentals of the bootstrap model are directly linked to Hempel's approach. In the rational reconstruction I have given, the bootstrap tenets are shown to grow naturally out of the deficiencies of the Hempelian views. Hempel's notion of the development of a hypothesis is abandoned and Hempel's special consequence condition is dropped (although Glymour fails to recognize the fatal properties of the latter condition) (Glymour 1980, 132–33, 155, 174). The two are replaced by the overall instantiation requirement. So, what Glymour did in 1980 was to take up, pursue, and improve ideas from the heyday of logical empiricism. The connection is tight, as I have tried to argue,

and it stretches right across the "theory-change period" in which interest in confirmation theory proper had dropped off to almost nothing.

Further, none of the criticisms leveled against Hempel's account was substantially connected with the demise of logical empiricism—a change in the philosophical landscape that happened right in between the enunciation of the two approaches in question. The odd properties of the special consequence condition could have been noted at any time. And the restriction to observational terms, as expressed by the commitment to the development of hypotheses, should have appeared inadequate at any point after the acceptance of the double-language model. This model was advocated by Carnap and Hempel from the 1950s onward and involved the claim that science encompassed two linguistic levels—namely, observational and theoretical terms. Logical empiricists insisted that both levels are to be kept separate. To be sure, so-called correspondence rules were supposed to establish links between the two linguistic levels. But since one theoretical term might be tied to several observational ones and vice versa, the theoretical language was thought not to be reducible to observation predicates.

The pivotal aspect is that the double-language view is incompatible with the notion of development. And since Hempel was among the chief proponents of this view, he himself could have well conceived all the objections that were later directed against this notion. Abandoning the notion of the development of a hypothesis has nothing to do with the transition to postempiricism; the changes within logical empiricism would have suggested this move anyway. In this area, nothing hinges on the passage of philosophical time.

Consequently, the bootstrap model smoothly continues the lines Hempel had drawn in confirmation theory. To be sure, the bootstrap model significantly modifies Hempel's earlier approach. If the equivalence condition is dropped (as suggested above), nothing but the entailment condition is left from Hempel's original version. On the other hand, this condition is the key to Hempel's view; it embodies the very spirit of the entailment account. The severe changes introduced by Glymour do not militate against regarding the bootstrap model as a continuation of Hempel's conception. Rather, this is how progress in philosophy is produced. It hardly ever happens that a philosopher takes over another philosopher's views unchanged; and if it happens it is a boring episode that deserves to pass unnoticed. To take up philosophical ideas in a fruitful fashion means to change them; fertile philosophical traditions are characterized by frequent alterations. Philosophical argument thrives on continuing lines of thought by improving them. As I tried to make plausible, this is precisely what is distinctive of the relationship between Hempel and Glymour. My point is that this testifies to the lasting fecundity of Hempel's views on confirmation. To be philosophically alive is to be criticized, to be pursued, and to be modified. In this vein, Salmon took up Hume's challenge to identify causal processes by relying exclusively on conceptual means acceptable to an empiricist and advocated his process theory of causation (Salmon 1984, 136–37, 182–83). Although the result is largely at variance with Hume's own opinion on the subject, the attempt to meet Hume's challenge bears witness to the enduring force of his philosophy. The indication of philosophical fecundity is not acceptance but the power to stimulate new thoughts. I hope to have shown that Hempel's theory of confirmation passes this test easily.

It follows that it is unjustified to pass in silence over Hempel's contributions to confirmation theory when it comes to appraising the "spirit of logical empiricism" (Salmon 1999). It is true that Hempel, in the 1964 postscript to his original article, lists objections to his proposal and comes close to abandoning the entire project in favor of Carnap's inductive logic: "My general formal definition of qualitative confirmation now seems to me rather too restrictive. . . . Perhaps the problem of formulating adequate criteria of qualitative confirmation had best be tackled, after all, by means of the quantitative concept of confirmation. This has been suggested especially by Carnap" (Hempel 1945 [1964], 48–49, 50). Analogously, Hempel does not even mention his own earlier efforts in the chapter on confirmation in his introductory *Philosophy of Natural Science* of 1966. Instead, Carnap's inductive logic is presented as a promising approach (Hempel 1966, 45–46). The foregoing considerations suggest that Hempel should have stuck to his earlier views more tenaciously. The theory in its original shape could not be upheld; it was bound to collapse. But there were jewels to be found in the debris.

Notes

1. The special consequence condition implies the equivalence condition since equivalence amounts to reciprocal implication (Hempel 1945, 21). For this reason, the adoption of the special consequence condition makes it superfluous to adduce the equivalence condition as a separate constraint.

2. In view of the fact that the two sets of conditions are part of incongruous approaches to confirmation, it is a queer endeavor to probe into options for nevertheless reconciling the converse consequence condition with Hempel's conditions of entailment and special consequence—as Le Morvan (1999) does.

3. The relevant logical rule is $p \wedge q \Rightarrow p \rightarrow q$.

4. For this reason the restriction to a finite domain of application is inessential and could be dropped. To be sure, the development of a hypothesis cannot be stated comprehensively for an infinite class of objects, but an observation statement could still imply those parts of the development that deal with the objects mentioned in the statement.

5. It is important to realize that the argument does not invoke the converse consequence condition. Hempel used a reply to this effect in order to rebut a similar but more schematic objection. Let an observation *e* confirm a hypothesis h_1; then *e* might be thought also to confirm $h = h_1 \wedge h_2$ where h_2 may be completely irrelevant to *e*. However, as Hempel replies, the move from the confirmation of h_1 to the confirmation of *h* tacitly appeals to the converse consequence condition that appeal is illicit in the framework of the instantiation account (Hempel 1945, 33).

But in the more detailed scenario sketched in the text, the corresponding move to the confirmation of the conjunctive hypothesis is not licensed by the converse consequence condition but by drawing more specifically on the concept of the development of a hypothesis. In the example given in the text, the piece of evidence directly confirms the conjunctive hypothesis in question. No auxiliary recourse to any general condition is necessary.

6. If a hypothesis *h* entails evidence *e*, the conjunction of this hypothesis with some irrelevant clause *i* likewise entails *e*: $h \rightarrow e \Rightarrow h \wedge i \rightarrow e$ (Glymour 1980, 31).

7. See Carrier (1994, 56–61) for another, more extensively discussed example of bootstrapping.

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Changing Conceptions of Rationality

From Logical Empiricism to Postpositivism

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One of the central issues that came into focus in the sixties and the seventies with the transition from the logical empiricist to the postpositivist philosophy of science was scientific change. This issue was bound to arise when a historical-developmental approach to science replaced a logico-structural one adopted by the logical empiricists. It involved, among others, questions such as these: How does scientific change occur? What sort of criteria, standards, or norms are employed in preferring one scientific theory over another? Are they fixed and universal or local and historically changing? Clearly, these are questions about the rationality of science, and while they interested the logical empiricists and received considerable attention by the falsificationists, they became the center of stormy debates only after the publication of Thomas Kuhn's *The Structure of Scientific Revolutions* in 1962.

As the questions in the preceding paragraph indicate, these rationality debates were at the same time debates about scientific methodology, which was typically understood as laying out the rules that govern scientific practice—in particular, the acceptance of a theory or the choice among alternative theories. The relationship between methodology and rationality was taken to be straightforward: if the methodology involved, say, rules like "always formulate your conjectures boldly and test them severely," it was rational to prefer the hypothesis that was bolder and