Bayesian "No Miracle Argument" and the Priors of Truth

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1. How to spell out the "no miracle argument"

A rough version of the "no miracles argument" (NMA) is as follows:

(i) The only (non-miraculous) explanation why a theory has success is that it is true.
(ii) Theory T has success.

Therefore

(iii) T is true (save miracles).

Notice, the strength of (i) is such that, assuming that every event has (at least) one explanation, this argument is no longer not abductive, but deductive. As it is, however, (i) is not true, and it in order to become true it needs at least four refinements:

Refinement (1):

Various types of success can be explained without assuming that a theory is true. The success in accommodating previously known phenomena is explainable by the skill and patience of theoreticians. The prediction of phenomena similar to the already known ones can be explained by analogical or inductive extrapolation. What we need instead, is novel success, i.e., the prediction of phenomena that were previously unknown, or at any rate neither used in construction the theory, nor similar to those used (Alai 2104a: §§ 3.3, 3.4)

Refinement (2)

The prediction of probable phenomena can be explained by luck: for instance, if one's false theory follows that the next number on the roulette will be even, this prediction will succeed approximately 50% of the times. On the contrary, it is extremely improbable that a false theory gets right a very improbable prediction.[1] Based on Newton's theory and the irregularities of Uranus' orbit, Leverrier predicted the existence of a new planet (later called 'Neptune'), and its position with an error of less than 1°. Since there are 360° on the horizon and 360° on the altitude, the probability of predicting that position with an approximation of ±1° was 2/360=1/180 on each axis, and the joint probability was 1/180·180 = 0,00003. Other predictions are even less probable: the prediction of the magnetic moment of the electron made by quantum electrodynamics was accurate to the 9th decimal, so its probability was 0.000000001 (Wright 2002: 143–144).

Refinement (3):

As stressed by Kitcher (1993) and Psillos (1999), novel predictive success can be explained even without assuming the truth of the whole theory T, but only of the hypotheses of T which were *essentially* employed in deriving the prediction.[2] For instance, suppose we hold the mythological theory that

(T) When the barometer is low, *Zeus sees to it that* it rains.

If we observe that the barometer is low, we can then predict that it will rain. Thus, T is successful, yet it is false. However, only a part of T was actually essential to our prediction, viz.,

(H) When the barometer is low, it rains,

and sure enough, it is true. A refined formulation of the NMA is therefore:

(i') The only (non-miraculous) explanation why T (1) predicted a novel (i.e., not used or similar to those used) and (2) improbable phenomenon NP is that (3) the hypothesis(es) H of T that was(were) essentially involved in predicting NP are true.
(ii') T predicted a novel and improbable phenomenon NP.

Therefore,

[1] Alai (2014a: § 3.2), (2014b: §§ 4, 5).
[2] Alai (2014a: 307); (2014b: 268-269, § 7); (2021).

(iii') it is extremely probable (i.e., save miraculous coincidences) that the hypothesis H essentially involved in predicting NP is true.

Yet, objections have been raised even against this formulation of the NMA, as we shall see now.

2. The "base-rate fallacy" objection

Objection (1):

It has been objected that the NMA commits the base-rate fallacy:[3] Bayes' theorem shows that the probability of a hypothesis H given its prediction of a novel and improbable phenomenon NP —i.e., p(H/NP)— cannot be computed only from the fact that, while NP was a priori improbable (e.g., that p(NP) = 0,0003), the truth of H made NP certain (i.e., that p(NP/H) =1]: as shown by Bayes' theorem, p(H/NP) depends also on the prior probability that H is true (i.e., p(H)):

$$\text{(Bayes theorem) } \mathrm{p(H|NP)} = \frac{\mathrm{p(NP|H)} \cdot \mathrm{p(H)}}{[\mathrm{P(NP|H)} \cdot \mathrm{p(H)}] + [\mathrm{p(NP|\neg H)} \cdot \mathrm{p(\neg H)}]}$$

Now, antirealists argue that, due to the empirical underdetermination, there are infinitely many false hypotheses and only a true one compatible with all the empirical data. Therefore, the prior probability of any hypothesis is null (p(H) =1/∞ $\approx$ 0). There follows that also its conditional probability is practically null (p(H|NP) ≈ 0):[4]

$$\mathrm{p(H|NP)} = \frac{1 \cdot 0}{(1 \cdot 0) + (0{,}00003 \cdot 1)} \approx 0$$

This reasoning, however, has the paradoxical consequence that no hypothesis can ever be confirmed by any prediction or any empirical evidence whatsoever. This conclusion, of course, crucially depends on assuming that p(H) ≈ 0 . In fact, as we shall see, if p(H) is even slightly greater than 1/∞ and NP is improbable, p(H|NP) increases dramatically. Moreover, if p(H) is updated in the light of a few more predictions NP', NP'', etc., by taking as the new prior probability of H first P(H|NP), then P(H|NP'), etc., it soon converges to 1. Thus, we must ask: is really p(H)

[3] Howson (2000), Magnus & Callender (2003).
[4] See Dieks (2024), Morganti (2024).

≈ 0? To answer this question, consider another possible objection to our NMA.

3. How hypotheses entailing novel predictions can be found

Objection (2):

The successful prediction of NP is already trivially explained by the fact that H (together with the appropriate background assumptions) entailed NP, without any need to assume that H is true (Alai 2014a: 299).

To resist this objection another refinement is needed:

Refinement (4):

Consider this: all possible consistent hypotheses entail a tautology, no one entails a contradiction, and in general, the less probable is a prediction, the fewer hypotheses entail it. Saying that the a priori probability of NP is (e.g.) 0.000000001 is saying that NP is entailed by about 1 hypothesis out of 1,000,000,000 possible hypotheses, and by a negligible proportion even of the possible hypotheses compatible with the already known data. If the probability of NP is 0.00003, it will be entailed by roughly 3 out of 100.000 possible hypotheses. Therefore, what must be explained is

(Q) how have scientists been able to find such a rare hypothesis H entailing NP?[5]

They couldn't find it by constructing it in order to entail NP, because NP was novel, nor by picking it randomly, because the chance to find it was 0.00003 for the position of Neptune, and 0.000000001 for the magnetic moment of the electron. In other words, it is almost certain (e.g., there is a probability of 1-0.00003, or of 1-0.000000001) that H wasn't chosen randomly, but by a reliable procedure. Granted, if two, or three, or … *n* different hypotheses are tried by scientists, the probability to get NP by one of these attempts becomes 2 or 3 or … *n* times higher,[6] but still remaining very low, and seldom more than a few attempts are made. For instance, if astronomers had tried 10 different models of Neptune, the probability to predict its position would have been 0.00003·10 = 0.0003.

The reliable procedure by which novel predictions are found is obviously the one followed by scientists, i.e., the *scientific method* (SM): in fact, the

[5] Alai (2014a: 299), White (2003: 659–663).
[6] See Dawid and Hartmann (2018: § 8).

frequency of novel scientific predictions which are as improbable as Neptune's position is substantially higher than 0,0003, and the frequency of novel predictions which are as improbable as the magnetic moment of the electron is substantially higher than 0.00000001.

4. The truth-conduciveness of scientific method

To see why SM is so effective in producing novel predictions, consider that true hypotheses entail true consequences, and if they are strong enough, they entail *many* and *informative* consequences, just like NP is. Therefore, we can assume that H was found by looking for *true* and strong hypotheses through a reliable method, so to *actually* find one (H), which happened to entail NP. If this assumption is right, it follows that H is true.

This presupposes that SM is, to begin with, reliable in finding true and strong hypotheses. Antirealists will deny this assumption, but here is my argument to support it: SM is reliable in tracking truth because it prescribes to conceive, constrain and control theories and hypotheses by means of (I) data *ultimately* based on direct observation, and (II) by reliable ampliative theoretical inferences (ATI), like analogy, abduction, or inference to common causes. Let's examine (I) and (II) in sequence.

(I) The data used by scientists are based data ultimately based on direct observation through a hierarchy of *recursive empirical foundation* (REF) consisting of the following levels:

Level 1: data provided by direct observation, which ensure that theories are true about observed phenomena and probably true (through induction) about observable but not yet observed phenomena.

Level 2: data about directly unobservable entities which however can be gathered by direct observation plus elementary computation, because sometimes the divide between directly observable and unobservable entities is just one of size. This, for instance, is how Perrin measured the size of molecules and Millikan the charge of electrons.

Level 3: data gathered through instruments whose reliability is established by direct observation (i.e., by level 1 data). For example, in Venice Galileo demonstrated the reliability of his telescope by asking bystanders to observe the city of Chioggia across the lagoon; thus, they realized that what they saw trough it was precisely what they used to see by the naked eye at a close distance.

Another example is van Leeuwenhoek: a cloth merchant, he originally used his rudimentary optical microscope to gain enlarged images of his fabrics, hence he trusted it when it showed him the first bacteria ever observed. This kind of confirmation is recursive: the reliability of optical microscopes can be tested by direct observation, and the reliability of electronic microscopes can be tested by optical microscopes.

Level 4: theories conceived on the basis the data collected at levels 1-3 and controlled by data of the same kind. Even antirealists should grant that they are very probably true, to the extent that they are constrained by data at levels 1-3.

Level 5: data provided by new more sophisticated instruments which were designed on the basis of level 4 theories.

Level 6: new theories, based on data from level 5 instruments and earlier levels. They allow to design new instruments.[7]

Level 7: etc.

(II) Granted, hypotheses are not based only on empirical data, but also on *ampliative theoretical inferences* (ATI) like analogy, abduction, inference to common causes.[8] Still,

(1_{ATI}) We know that these inferential patterns are reliable because most of the times they produce true hypotheses about currently unobserved, but observable and eventually observed, entities.

(2_{ATI}) Even the most plausible hypotheses are *definitely accepted* (DA) only after they have been confirmed either by data from the levels 1-3, or by data from levels 5 (or 7, etc.), provided that the theories which validate them on level 4 (or 6, etc.) are themselves DA. This is what scientists mean when they explain that in science an entity, a fact or an event is *merely hypothetical* until it is "observed". Of course, by 'observed' they don't mean by sense organs, but by instruments based on the REF. For instance, theories about atomic processes in the stars can be tested by spectroscopes, and spectroscopes can be tested by direct observation in the laboratory.

[7] Kosso points out that theories are typically tested by instruments based on independent theories (1992: ch. IX). More precisely, however, theories at one level are usually tested by instruments at lower levels.

[8] No need here to presuppose a particular metaphysics of causation: it can be understood even as a simple Humean connection between observable regularities and their unobservable "causes".

(3_{ATI}) *In principle* any new hypothesis must be consistent with the already DA hypotheses. *In practice* certain contradictions are tolerated when theories are otherwise very promising, but this is considered as a problem for the inconsistent hypotheses. I assume that at least 90% of current hypotheses are DA or at least consistent with DA hypotheses.

Notice, data and tests delivered by the REF

(i) should be acceptable by empiricists;

(ii) don't make the truth of theories or hypotheses certain, but *highly* probable at least up to level 4, and only somewhat less probable at the higher levels.

(iii) warrant that theories are *at least partly true: they may contain false hypotheses along with the true ones. The safest hypotheses are those strongly* constrained by the REF data. However, novel predictions can confirm beyond practical doubts the truth of the hypotheses that are essentially deployed in deriving them,[9] even if not directly based on or confirmed by REF data, but suggested by the ampliative theoretical inferences ATI;

(iv) show that in the once accepted theories (including the now discarded ones) true hypotheses have been fairly frequent.

Many scientists say: we don't really believe in a theory until we see the predicted particles or effects (for instance, my colleague Catia Grimani). Of course, they don't actually "see" them, they refer to instrumental observation. For instance, take the detection of Higgs boson (predicted in 1964) by the LHC at Cern in 2012, or the detection of gravitational waves (predicted by Einstein in 1916) by LIGO e VIRGO interferometers in 2015, etc. Similar events are so sensational because, even if the theory has by then been plainly accepted from many decades, only they are considered as its definite proof. They mark the passage from acceptance to belief. It would not be so if experiments themselves would be completely theory-laden, as for instance claimed by van Fraassen (2024), for then they would not add much to whatever credit is already enjoyed by the theory. They are so important for scientists, because they implicitly trust that the results of those experiments, complex as they are, are not themselves pure theoretical hypotheses, but ultimately warranted by direct observation through the REF.

[9] Hence, the partial truth of the hypotheses deployed non-essentially in the derivation.

5. The right prior probability of hypotheses and the resulting conditional probability

We are now ready to go back to the NMA and to the base-rate objection. In order to face it, I asked: is really the prior probability that H is true close to zero ($p(H) \approx 0$)? The answer is provided by the foregoing: the prior probability p(H) would be ≈ 0 if hypotheses were chosen randomly, but they are chosen through the SM. Therefore, p(H) is nothing but the probability that the SM produces a true hypothesis, or the relative frequency of true hypotheses in past science.

For the hypotheses exclusively based on data from levels 1-3 of the REF this probability is well above 0.5, but it is not negligible even for hypotheses based on data from levels 4 and up, where the ATI play a role (especially if the theories involved are DA). I don't know how to estimate exactly the probability of a hypothesis of the latter kind (and of course, it will vary from field to field and from one hypothesis to the other, depending on how it was arrived at). From a historical point of view, however, not seldom the frequency of the true hypotheses over those actually proposed on the same subject is often quite high. For instance, concerning the structure of the Solar system, only two basic hypotheses have been proposed (geocentrism and heliocentrism), and one was true. On the structure of light only two basic hypotheses (corpuscular and undulatory) were advanced before the currently accepted one. Concerning the structure of the atom, only five or six models have been proposed, etc. Even considering the variants of each hypothesis, the frequency of the true ones is still fairly high.

Admittedly, this may seem to simplify things in various ways. So, to be safe, let just assume that the prior probability of a typical hypothesis H arrived at through SM is 0.02, i.e., that only 2 out of 100 plausibly conceived and seriously tested hypotheses are true (recall, we are talking here of particular hypotheses, not of whole theories, which probably are always at least partly false). Therefore, considering a not particularly improbable prediction, like that of Neptune, the conditional probability p(H/NP) can be computed as follows:

$$(2)\ p(H|NP) = \frac{P(NP|H)=1 \cdot p(H)=0.02}{[P(NP|H)=1 \cdot p(H)=0{,}02]+[p(NP|\neg H)=0.00003 \cdot p(\neg H)=0{,}98]} =$$

$$(2)\ p(H|NP) = \frac{0.02}{[0{,}02]+[0.00003 \cdot 0{,}98]} =$$

$$(2)\ p(H|NP) = \frac{0.02}{[0{,}02]+[0.0000294]} =$$

(2) $p(H|NP) = \frac{0.02}{[0.0200294]} = 0{,}9985321577$

That is, an improbable novel prediction makes the truth of the hypothesis essentially involved in it practically certain. Even if one complained that my 0,02 prior probability is too optimistic, things don't change radically. Suppose one is so pessimist to suggest that p(H) = 0.0001, i.e. that only one out of 10,000 hypotheses put forth by scientists is true. Even in this case p(H|NP) would come out as

$$p(H|NP) = \frac{0.0001}{0.0001+[0.00003 \cdot 0{,}9999]} = 0{,}7692485211$$

That would still be a very significant confirmation, but if H produced also another equally improbable prediction NP', we could update our assessment by using this value as the new prior probability of H, and the conditional probability p(H|NP') would become 0,999991001.

Therefore, a fully explicit formulation premise (i) of the NMA should read approximately as the follows:

(i") The only (non-miraculous) explanation why T predicted a novel (i.e., not used or similar to those used) and improbable phenomenon NP is that, thanks to the scientific method, in constructing T scientists found a true and sufficiently strong hypothesis H which entailed NP.

In practice, scientists may have predicted NP using a stronger hypothesis H', entailing H, which however was not essential to the prediction, and may well be partly false. However, if H was essential, i.e. the minimal hypothesis entailing NP, we know it is true.

A corollary is that, *by itself,* the NMA is not a decisive argument for scientific realism, because it presupposes an argument like the just given one, based on the REF, to the effect that the prior probability of H is substantially higher than zero. Even the latter argument, however, would not be enough by itself, because in the absence of a NMA from novel predictions, the probability that a hypothesis is true coincides with its prior probability, which may be around 0,5 for simple and shallow hypotheses (mainly based on data), but much lower for the deeper and more speculative hypotheses (mainly based on the ATI, which are also the most interesting ones).

6. Further objections

Objection 3:

It may be pointed out that, among the *possible* hypotheses entailing NP, the merely empirically adequate or predictively similar[10] ones are many more than the true ones; therefore, it is more probable the hypothesis H we found is an empirically adequate (predictively similar, etc.) hypothesis than a true one.

The reply is that, for that matter, the hypotheses which entail NP but are not even empirically adequate or predictively similar are still many more. However, even these are *so few* with respect to *all* possible hypotheses compatible with all the previously known data which one might come up with, that if hypotheses were picked randomly, it would be practically impossible to find one which entailed NP.[11] Therefore, the greater a priori probability of empirically adequate or predictively similar hypotheses is heuristically irrelevant.

Objection 4:

We can look for empirically adequate or predictively similar hypotheses not by random choice, but through a method, i.e. SM itself, just like we look for true hypotheses. Thus, we will find hypotheses entailing NP even more easily than by looking for true hypotheses (Dieks 2024).

The response is that there is no method for finding sufficiently strong hypotheses which are empirically adequate, or predictively similar, *without* being also true (Alai 2014c: 57-61): one can draw reliable empirical predictions either from true theoretical hypotheses, or by analogy and induction from observed phenomena. The latter strategy, however, allows to predict only phenomena that are similar to the observed one, while novel predictions concern radically heterogeneous phenomena. SM is no exception: it leads to novel predictions (sometimes, not always) only in so far as it leads to the truth: if a hypothesis was conceived by the best possible scientific practice but happens to be false (as it is quite possible) it won't produce any novel predictions, and it is practically certain that it is not empirically adequate or predictively similar.

[10] A hypothesis is predictively similar iff it licenses the same predictions as the true one.
[11] See (Alai 2012, footnote 6), (Alai 2014a: 299), (Alai 2014c: 50).

Objection 5:

Against Level 1 of the REF van Fraassen (1980) and many, many others have objected that instruments or inference patterns which have proven reliable for observable entities cannot be trusted for unobservable entities without begging the question.

The answer is that observability is not an intrinsic property of entities, it only depends on the specific properties of human sense organs, which of course have no causal influence on the physical relation between certain instruments and certain entities, or on the argumentative soundness of certain inference patterns. Typically, the only intrinsic difference between observable and unobservable entities is in size, but observation itself shows that in many cases size does not significantly affect the behavior of entities. When it makes a difference, of course, this can also be recognized through the REF and taken in due account.[12] Without assuming the uniformity of nature (i.e., that similar things behave similarly in any respect R, except when they differ in ways causally affecting R) even elementary empirical beliefs could not be supported.

Objection 6:

Timothy Lyons (2002, 2006) has discussed many historical cases in which certain novel predictions were derived from false hypotheses, concluding that novel success is not a reliable indicator of truth.

However, this is only because those hypotheses had not been essential to those predictions, and the NMA commits the truth exclusively of the hypotheses which are deployed essentially in a novel prediction.[13] For instance:

Example 1:
Various novel predictions (among which those concerning Neptune) have been derived from Newton's false hypothesis that

(N) Bodies are moved by a gravitation force proportional to their masses and inversely proportional to the square of their distance, and space is flat.

(N) is false, because there is no gravitation force and space is curved, but (G) was not essential, only its true part was essential:

[12] Kitcher (2001:174,178); (Alai 2010).
[13] Alai (2014b: 268-269, § 7); Alai (2021).

(E) The movement of physical bodies is due to their masses through a mechanism [actually the curvature of space, not gravitation force] which in particular conditions approximates Newton's law.

Example 2:
According to Dieks (2024: 118),

> It is now widely accepted that our familiar ontology of stable objects governed by classical 'laws' represents a limiting case that differs drastically in ontology and principles from what is supposed to be valid at more fundamental levels. Therefore, classical descriptions cannot be considered true in the sense of representing fundamental insights that survive theory change, even approximately.

Obviously, many novel predictions have been drawn and can still be drawn from hypotheses based on the ontology of stable classical objects. For instance, suppose that certain novel phenomena have been predicted starting from a chemical hypothesis like

(1) there exist molecules of sodium chloride, each one consisting of an atom of sodium and an atom of chlorine.

(1) is false in the sense explained by Dieks, but even if it had licensed a novel prediction NP, this would not refute the NMA, because quite likely NP could equally have been derived from

(2) at certain conditions and at certain scales there are things [i.e., particular clusters of QFT entities] which we call "molecules of sodium chloride", each one consisting of one thing [i.e., a certain cluster of QFT entities] we call "chlorine atom" and another thing we call "sodium atom".

(2) is just a weakening of (1),[14] i.e., a part of its content, and it can be safely assumed that if NP was derived from (1), only (2) was essential to it, so that NP cannot constitute a counterexample to the NMA.

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[14] Although it is still theoretical, not empirical.

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