# The Simplicity of Physical Laws

Eddy Keming Chen*

Version of October 14, 2022. Comments are welcome!

**Abstract**

Physical laws are strikingly simple, although there is no *a priori* reason they must be so. I propose that nomic realists of all types (Humeans and non-Humeans) should accept that simplicity is a fundamental epistemic guide for discovering and evaluating candidate physical laws. This principle of simplicity clarifies and solves several problems of nomic realism and simplicity. A consequence is that the often-cited epistemic advantage of Humeanism over non-Humeanism is exaggerated, undercutting an influential epistemological argument for Humeanism. Moreover, simplicity is shown to be more tightly connected to lawhood than to mere truth.

*Keywords: empirical equivalence, induction, underdetermination, determinism, strong determinism, primitivism, Humeanism, non-Humeanism, laws of nature, Bayesianism, comparative probability, expert principle*

## Contents



*Department of Philosophy, University of California, San Diego, 9500 Gilman Dr, La Jolla, CA 92093-0119. Website: www.eddykemingchen.net. Email: eddykemingchen@ucsd.edu

# 1 Introduction

Physical laws are strikingly simple, although there is no *a priori* reason they must be so. The principle of simplicity plays a crucial role in the discovery and the evaluation of physical laws. However, there are unresolved philosophical issues: what the principle of simplicity is; how it is measured; how it is justified; and how it is related to truth and the world.

Debates in philosophy of science have focused on the connection (or the lack thereof) between simplicity and truth. In this paper, I suggest that a fruitful way forward is to focus instead on the connection between simplicity and lawhood, in the framework of nomic realism (to be defined below). I propose a new principle of simplicity that fills an epistemic gap in both Humean and non-Humean accounts of lawhood. This approach solves some difficult problems about laws and simplicity. As a bonus, we come to see that Humeanism has no genuine epistemic advantage over non-Humeanism.

Let *nomic realism* denote the conjunction of the following two theses:

**Metaphysical Realism:** Physical laws are objective and mind-independent; more precisely, which propositions express physical laws are objective and mind-independent facts in the world.[1]

**Epistemic Realism:** We have epistemic access to physical laws; more precisely, we can be epistemically justified in believing which propositions express the physical laws, given the evidence that we will in fact obtain.[2]

There is tension between these two aspects of nomic realism. If laws are out there in the world and not (entirely) mind-dependent, how can we claim epistemic access to the laws given our finite and limited evidence? Contrary to appearances, the tension exists in both Humean and non-Humean accounts of laws, since on both accounts laws are not a consequence of our actual evidence.

The problem can be sharpened by considering cases of empirical equivalence. If two physical laws are empirically equivalent, yielding the same data and making the same predictions, what justifies the acceptance of one law over the other? Some philosophers have tried to resist anti-realist arguments from empirical equivalence by disputing whether there really are genuine cases of empirical equivalence. They are correct that some algorithms for generating empirical equivalents are bordering on Cartesian skepticism (Stanford 2006).[3] However, there are "non-skeptical" algorithms that generate empirical equivalents (of varying degrees of complexity). I propose three new classes of algorithms that are inspired by recent discussions in philosophy of physics. They demonstrate that there is a significant gap between metaphysical realism and epistemic realism.

A promising solution is to invoke simplicity as a criterion to choose among empirically equivalent rivals:

[1]A weaker version of metaphysical realism maintains that laws are not entirely mind-dependent. That would accommodate more pragmatic versions of the Humean best-system accounts.

[2]The terminology is due to Earman and Roberts (2005). Here I've added the clause "given the evidence that we will in fact obtain." My version of epistemic realism is logically stronger than theirs.

[3]They generate, for example, the hypothesis that the universe is a computer simulation.

**Guide-to-Truth:** Simpler candidates are more likely to be true.

However, this principle is problematic. In addition to the problem of precision and the problem of justification, Guide-to-Truth just seems false. First, we live in a fairly complicated world where truths are not simple. Second, the idea that simpler laws are more likely to be true is probabilistically incoherent, because it conflicts with the axioms of probability in cases of nested theories.

I suggest that nomic realists should embrace a new principle of simplicity:

**Guide-to-Lawhood:** Simpler candidates are more likely to be laws.

Guide-to-Lawhood solves the problem of nested theories in a straightforward way and secures epistemic realism in the face of new cases of empirical equivalence. However, the principle is, in several aspects, more modest than the usual posits of simplicity in the literature. For example, the new principle can be vague, comparative, merely partial in the ordering of candidates for laws, and compatible with the complexity in the mosaic. Moreover, it need not be the only such guide; other theoretical virtues can also earn their places by contributing to epistemic realism.

Properly understood, Guide-to-Lawhood does not follow from the Humean best-system account of lawhood (BSA), but it must be added to BSA as an independent epistemic norm that constrains our beliefs about the best system when our evidence about the mosaic is fairly limited. Since both Humeanism and non-Humeanism need this independent posit, they are on a par regarding the empirical discovery of laws. As a consequence, the often-cited epistemic advantage of the former over the latter is exaggerated. This undercuts an influential epistemic argument for Humeanism (Earman and Roberts 2005).

The framework above suggests a new strategy to argue for simplicity as a fundamental epistemic guide. Given the intimate connection between laws and induction, we have reasons to believe that the rationality of induction presupposes the simplicity of physical laws. The inference can be supported by considering the class of time-dependent laws. The development of this argument is left to a longer version of the paper.

## 2 Puzzles about Laws and Simplicity

In this section, I discuss some puzzles about nomic realism and standard posits of simplicity. They motivate the search for a better principle of simplicity and a more nuanced understanding of nomic realism.

### 2.1 A Puzzle about Nomic Realism

We have seen that there is tension between two aspects of nomic realism—metaphysical realism and epistemic realism. For concreteness, let us look at a Humean account and a non-Humean account that aspire to satisfy nomic realism. The way the tension shows up in these two accounts is representative of a large class of realist accounts of lawhood.

First, consider the Humean best-system account of Lewis (1973), with some slight modifications:

**Best System Account (BSA)** Fundamental laws of nature are the axioms of the best system that summarizes the mosaic and optimally balances simplicity, informativeness, fit, and degree of naturalness of the properties referred to. The mosaic (spacetime and its material contents) contains only local matters of particular fact, and the mosaic is the complete collection of fundamental facts. The best system supervenes on the mosaic.[4]

BSA satisfies metaphysical realism, even though laws are not metaphysically fundamental on this approach. Given a particular mosaic (spacetime manifold with material contents), there is a unique best system that is objectively best.[5]

For another example, consider a recent non-Humean account according to which laws govern and exist over and above the material contents (Chen and Goldstein 2022):

**Minimal Primitivism (MinP)** Fundamental laws of nature are certain primitive facts about the world. There is no restriction on the form of the fundamental laws. They govern the behavior of material objects by constraining the physical possibilities.

MinP satisfies metaphysical realism, because the primitive facts about the world are taken to be objective and mind-independent.

Now, do BSA and MinP vindicate epistemic realism? Their metaphysical posits, by themselves, do not guarantee epistemic realism. This should be clear on MinP. Since there is no metaphysical restriction on the form of the fundamental laws, and if they are entirely mind-independent primitive facts about the world, how do we know which propositions are the laws? This is an instance of the tension between metaphysical and epistemic realism. However, I suggest that an analogous problem exists on BSA. How could that be? It is often thought that BSA has an epistemic advantage over non-Humean accounts like MinP, precisely because BSA brings laws closer to us so that we can have epistemic access to them. BSA defines laws in terms of the mosaic, and the mosaic is all we can empirically access.

The problem is that we are not given the mosaic. Just as MinP requires an extra epistemic principle to infer what the laws are, BSA requires a similar principle to infer what the mosaic is like. The latter turns out to be mediated by an extra epistemic principle of what we should expect about the best system, given our limited evidence.

To sharpen the discussion, let us suppose, granting Lewis's assumption of the kindness of nature (Lewis 1994, p.479), that given the mosaic $\xi$ there is a unique best system whose axioms express the fundamental law $L$:

$$L = BS(\xi) \tag{1}$$

with $BS(\cdot)$ the function that maps a mosaic to its best-system law. Let us stipulate that for both BSA and MinP, physical reality is described by a pair $(L, \xi)$. For both, we must

[4]A key difference between this version and Lewis's (Lewis 1973, 1983, 1986) is that the latter but not the former requires fundamental laws to be regularities. The other difference is the replacement of perfect naturalness with degree of naturalness. See (Chen 2022b, sect.2.3) for more in-depth comparisons. On Humeanism, the mosaic is often required to be about local matters of particular fact.

[5]For the sake of argument, I set aside the worry of "ratbag idealism" and grant Lewis's assumption that nature is kind to us (Lewis 1994, p.479). Even if BSA satisfies the weaker version of metaphysical realism where laws are not entirely mind-dependent, it does not automatically secure epistemic realism. Hence, this discussion also applies to recent versions of pragmatic Humeanism.

have that $\xi \in \Omega^L$, with $\Omega^L$ the set of mosaics compatible with $L$. This means that $L$ is true in $\xi$. On BSA, we also have that $L = BS(\xi)$. So in a sense, all we need in BSA is $\xi$; $L$ is not ontologically extra. But it does not follow that BSA and MinP are relevantly different when it comes to epistemic realism.

Let $E$ denote our evidence consisting in observational data about physical reality. Let us be generous and allow $E$ to include not just our current evidence but also all past evidence and all future evidence about the universe that we will in fact gather. There are two salient features of $E$:

- $E$ does not pin down a unique $\xi$. There are different candidates of $\xi$ that yield the same $E$. (After all, $E$ is a spatiotemporally partial and macroscopically coarse-grained description of $\xi$.)

- $E$ does not pin down a unique $L$. There are different candidates of $L$ that yield the same $E$. (On BSA, this is an instance of the previous point; on MinP, this is even clearer since $L$ can vary independently of $\xi$, up to a point.)

Hence, on BSA, just as on MinP, $E$ does not pin down $(L, \xi)$. There is a gap between what our evidence entails and what the laws are.

The gap becomes clearer when we consider cases of empirical equivalence.[6] If different laws yield the same evidence, it is puzzling how we can be epistemically justified in choosing one over its empirically equivalent rivals, unless we rule them out by positing substantive assumptions that go beyond the metaphysical posits of nomic realism. In the literature (see for example Kukla (1998)), there are suggestions about how to algorithmically generate empirically equivalent rivals, but some of them border on Cartesian skepticism. Here I offer three new kinds of algorithms, based on recent discussions in philosophy of physics. They have much more limited scopes, but they suffice to show that the gap exists on nomic realism.

**Algorithm A: Moving parts of ontology (what there is in the mosaic) into the nomology (the package of laws)**.

*General strategy.* This strategy works on both BSA and MinP. Given a theory of physical reality $T_1 = (L, \xi)$, if $\xi$ can be decomposed into two parts $\xi_1 \& \xi_2$, we can construct an empirically equivalent rival $T_2 = (L\&\xi_1, \xi_2)$, where $\xi_1$ is moved from ontology to nomology.

*Example.* Consider the standard theory of Maxwellian electrodynamics, $T_{M1}$:

- Nomology: Maxwell's equations and Lorentz force law

- Ontology: a Minkowski spacetime occupied by charged particles with trajectories $Q(t)$ and an electromagnetic field $F(x, t)$.

[6] Here, I use a fairly weak notion of empirical equivalence, where $L_1$ and $L_2$ are empirically equivalent with respect to actual evidence $E$ just in case $E$ is compatible with $L_1$ and $L_2$. This criterion, with the emphasis on actual data $E$, is weaker than the notion of empirical equivalence according to which two laws should agree not just on the actual data but all (nomologically) possible data. I will drop the explicit reference to $E$ in what follows. Now, for those who want to consider the stronger criterion of empirical equivalence, the arguments below can be modified. If we consider all possible data, we should also consider probability distributions over models in the theory, and compare the likelihoods of $E$. This does not change the dialectics, as there exist probability distributions that yield equal likelihood of $E$.

Here is an empirically equivalent rival, $T_{M2}$:

- Nomology: Maxwell's equations, Lorentz force law, and an enormously complicated law specifying the exact functional form of $F(x,t)$ that appears in the dynamical equations
- Ontology: a Minkowski spacetime occupied by charged particles with trajectories $Q(t)$

Our evidence $E$ is compatible with both $T_{M1}$ and $T_{M2}$. The outcome of every experiment in the actual world will be consistent with $T_{M2}$, as long as the outcome is registered as certain macroscopic configuration of particles (Bell 2004). We can think of the new law in $T_{M2}$ as akin to the Hamiltonian function in classical mechanics, which is interpreted as encoding all the classical force laws, except that specifying $F(x,t)$ is much more complicated than specifying a typical Hamiltonian. Both $F(x,t)$ and the Hamiltonian are components of respective laws of nature that tell particles how to move.[7]

**Algorithm B: Changing the nomology directly**.

*General strategy.* This strategy is designed for MinP. We can generate empirical equivalence by directly changing the nomology. Suppose the actual mosaic $\xi$ is governed by the law $L_1$. Consider $L_2$, where $\Omega^{L_1} \neq \Omega^{L_2}$ and $\xi \in \Omega^{L_2}$. $L_1$ and $L_2$ are distinct laws because they have distinct sets of models. Since $E$ (which can be regarded as a coarse-grained and partial description of $\xi$) can arise from both, the two laws are empirically equivalent. There are infinitely many such candidates for $\Omega^{L_2}$. For example, $\Omega^{L_2}$ can be obtained by replacing one mosaic in $\Omega^{L_1}$ with something different and not already a member of $\Omega^{L_1}$, by adding some mosaics to $\Omega^{L_1}$, or by removing some mosaics in $\Omega^{L_1}$. $L_2$ is empirically equivalent with $L_1$ since $E$ is compatible with both.[8]

*Example.* Let $L_1$ be the Einstein equation of general relativity, with $\Omega^{L_1} = \Omega^{GR}$, the set of general relativistic spacetimes. Assume that the actual spacetime is governed by $L_1$, so that $\xi \in \Omega^{L_1}$. Consider $L_2$, a law that permits only the actual spacetime and completely specifies its microscopic detail, with $\Omega^{L_2} = \{\xi\}$. Since our evidence $E$ arises from $\xi$, it is compatible with both $L_1$ and $L_2$. Since it needs to encode the exact detail of $\xi$, $L_2$ is much more complicated than $L_1$.[9]

**Algorithm C: Changing the nomology by changing the ontology**.

*General strategy.* This strategy is designed for BSA. On BSA, we can change the nomology by making suitable changes in the ontology (mosaic), which will in general change what the best system is. Suppose the actual mosaic $\xi$ is optimally described by the actual best system $L_1 = BS(\xi)$. We can a slightly different mosaic $\xi'$, such that it differs from $\xi$ in some spatiotemporal region that is never observed and yet $E$ is compatible with both $\xi$ and $\xi'$. There are infinitely many such candidates for $\xi'$ whose

[7] Note that we can decompose the standard ontology in many other dimensions, corresponding to more ways to generate empirically equivalent laws for a Maxwellian world. This move is discussed at length by Albert (2021). Similar strategies have been considered in the "quantum Humeanism" literature. See Miller (2014), Esfeld (2014), Callender (2015), Bhogal and Perry (2017), and Chen (2022a).

[8] See Manchak (2009, 2020) for more examples.

[9] $L_2$ is a case of strong determinism. See Adlam (2021) and Chen (2022c) for recent discussions.

best system $L_2 = BS(\xi')$ differs from $L_1$. Alternatively, we can also expand $\xi$ to $\xi' \neq \xi$ such that $\xi$ is a proper part of $\xi'$. There are many such candidates for $\xi'$ whose best system $L_2 = BS(\xi')$ differs from $L_1$, even though $E$ is compatible with all of them.

*Example.* Let $L_1$ be the Einstein equation of general relativity, with $\Omega^{L_1} = \Omega^{GR}$, the set of general relativistic spacetimes. Assume that the actual spacetime is optimally described by $L_1$, so that $L_1 = BS(\xi)$. Consider $\xi'$, which differs from $\xi$ in only the number of particles in a small spacetime region $R$ in a far away galaxy that no direct observation is ever made. Since the number of particles is an invariant property of general relativity, it is left unchanged after a "hole transformation" (Norton 2019). We can use determinism to deduce that $\xi'$ is incompatible with general relativity, so that $L_1 \neq BS(\xi')$. Let $L_2$ denote $BS(\xi')$. $L_1 \neq L_2$ and yet they are compatible with the same evidence we obtain in $\xi$. Since $\xi'$ violates the conservation of number of particles and perhaps smoothness conditions, $L_2$ should be more complicated than $L_1$.

To be sure, we can also combine these algorithms to produce more sophisticated examples of empirical equivalence.[10] Here we have three algorithms with different strategies and scopes that can establish the existence of empirically equivalent rival laws, for a world like ours. They are inspired by recent discussions in philosophy of physics. None of them requires Cartesian skepticism. If such algorithms are allowed, how can we maintain epistemic realism? We may summarize the puzzle about nomic realism:

**Puzzle about Nomic Realism:** In such cases of empirical equivalence, what justifies the acceptance of one candidate law over the other?

## 2.2 A Puzzle about Simplicity

It has been recognized, correctly on my view, that nomic realists need to invoke theoretical virtues as a way to choose among empirically equivalent laws underdetermined by evidence. An important example is the *principle of simplicity* (PoS), according to which, roughly speaking, simpler laws are better, and perhaps more likely to be true. The basic idea is that simplicity is a guide to truth. It has an intuitive appeal, as the paradigm examples of physical laws are strikingly simple and simpler than other candidates that yield the same data. Moreover, in the examples of empirical equivalence discussed before, the simpler law does seem like the better candidate.

However, PoS faces its own challenges. First, there is a problem of precision. It is difficult to say exactly what simplicity is and how simplicity should be measured. Should it be measured in terms of the number of equations, concepts, and parameters used in specifying the laws? Should they be traded off against each other? Second, there is a problem of justification. It is difficult to justify PoS in terms of epistemic principles. If PoS cannot be justified further on epistemic grounds, what epistemic justification can it confer?

The problem of precision and the problem of justification do not show that PoS is

[10]For example, in certain settings, we can change both the ontology and the nomology to achieve empirical equivalence. For every wave-function realist theory, there is an empirically equivalent density-matrix realist theory. Their ontology and nomology are different, but no experiment can determine which is correct.

wrong. They can be regarded as open research problems. There is, however, a more urgent problem, because it seems to suggest that PoS is false or incoherent. That is the problem of nested theories, or sometimes called the problem of logical constraints.[11]

The most straightforward formulation of PoS is that it is a fundamental epistemic guide to *truth*. In probabilistic terms, it means that, for two propositions $L_1$ and $L_2$, if $L_1$ is simpler than $L_2$ then $L_1$ is more likely to be true than $L_2$. But this leads to probabilistic incoherence.

Whenever two theories have nested sets of models, say $\Omega^{L_1} \subset \Omega^{L_2}$, the probability that $L_1$ is true cannot be higher than the probability that $L_2$ is true. For example, let $\Omega^{GR}$ denote the set of models compatible with the fundamental law in general relativity—the Einstein equation, and let $\Omega^{GR^+}$ denote the union of $\Omega^{GR}$ and a few random spacetime models that do not satisfy the Einstein equation. Suppose there is no simple law that generates $\Omega^{GR^+}$. While the law of $GR$ (the Einstein equation) is presumably simpler than that of $GR^+$, the former cannot be more likely to be true than the latter, since every model of $GR$ is a model of $GR^+$, and not every model of $GR^+$ is a model of $GR$. This is an instance of the problem of nested theories, as $\Omega^{GR}$ is a subclass of and nested within $\Omega^{GR^+}$.

Hence, it is probabilistic incoherent to maintain that simpler laws are more likely to be true. We may summarize the puzzle:

**Puzzle about Simplicity:** If simplicity is not a guide to truth, what is it a guide to?

That question shall be a clue for a new principle of simplicity.

## 3 Simplicity as a Fundamental Epistemic Guide to Lawhood

I propose that *simplicity is a fundamental epistemic guide to lawhood*. Roughly speaking, simpler candidates are more likely to be laws, all else being equal. This principle solves the problem of nested theories in a straightforward way. It also secures epistemic realism in cases of empirical equivalence where simplicity is the deciding factor.

The principle is to be contrasted from the simplicity criterion in the Humean best-system account of lawhood. They are different kinds of principles: the latter is a metaphysical definition of what laws are, while the former is an epistemic principle concerning ampliative inferences based on our total evidence. Even if a Humean expects that the best system is no more complex than the mosaic, it does not follow that she should expect that the best system is relatively simple, since there is no metaphysical guarantee that the mosaic is "cooperative." Both Humeans and non-Humeans can be uncertain about the laws, and both need a new principle to justify epistemic realism. If Humeans are epistemically warranted in making such a posit, non-Humeans are too.

I clarify the key terms below.

[11]This was first raised by Popper (2005) against the Bayesian proposal of Wrinch and Jeffreys (1921). For recent discussions, see Sober (2015) and Henderson (2022).

## 3.1 *Simplicity*

What is the measure of simplicity invoked here? It is unrealistic to insist that there is a single measure of simplicity regarding physical laws. There are many aspects of simplicity, as shown by recent works in computational complexity, statistical testing, and philosophy of science. Among them are: number of adjustable parameters, lengths of axioms, algorithmic simplicity, and conceptual simplicity.[12] Certain laws may employ more unified concepts, better achieving one dimension of simplicity, but require longer statements and hence do less well in other dimensions of simplicity. There need not be any precise way of trading off one over the other. Moreover, not all laws must take the form of differential equations; there can be boundary-condition laws and conservation laws. It is unreasonable to expect a single principle can be applied to all different forms of laws. I suggest that we take simplicity to be measured in a holistic (albeit vague) way, taking into account these different aspects of simplicity.[13]

The vagueness of simplicity might seems like as a problem for nomic realists. However, what matters to a realist who believes in simplicity is that there is enough consensus around the paradigm cases. There are hard cases of simplicity comparisons, but there are also clearcut cases, such as $T_{M1}$ and its empirical equivalents generated by Algorithm A, or general relativity and its empirical equivalents generated by Algorithms B and C. This is similar to Lewis's assumption that Nature is kind to us and the borderline cases do not show up in realistic comparisons. The vagueness of simplicity here is no worse than the problem in the BSA account of lawhood.

The vagueness of simplicity does not imply that there are no facts about simplicity comparisons. Let us think about an analogy with moral philosophy. Judgments about moral values are also holistic and vague. While there are moral disagreements about hard cases, there can still be facts about whether helping a neighbor in need is morally better than beating the neighbor out of the blue. Moral realists maintain that we have robust moral intuition in the paradigm cases, which need not be threatened by the existence of borderline cases. Sometimes different moral considerations conflict. In such cases, we may need to trade-off one factor against another.

Given the vagueness of the simplicity postulate, we should not expect there be a total order that ranks theories from the most to the least simple. Instead, there may be multiple chains of partial orders, where each is connected by a "simpler than" relation $>_S$.[14]

## 3.2 *Guide*

What does it mean for simplicity to be a guide? A guide is not a guarantee. Inferences in the context of uncertainty, even when epistemically justified, are fallible. We can make mistakes when relying on the principle of simplicity. Perhaps the actual physical laws

[12]For an overview of these different measures, see Baker (2022) and Fitzpatrick (2022).

[13]Alternatively, we may take simplicity as a family of concepts, and the principle of simplicity as a family of principles.

[14]Hence, there may be pairs of theories that cannot be compared with respect to simplicity. If $A$ and $B$ are such a pair, then none of "$>_S$," "$<_S$," and "$=_S$" applies to them. We should allow cases of incommensurability or incomparability regarding simplicity. This relation can be denoted by $A \circledast B$.

appear less simple than the ones we regard as laws, based on the principle of simplicity. I think a realist should admit this possibility. Indeed it is a hallmark of realism that we can be wrong, even when we follow scientific methodology. This uncertainty can be formulated in terms of comparative probability (where higher probability does not guarantee certainty):

**Simplicity Comparison:** Other factors being equal, if $A >_S B$, then $L[A] >_P L[B]$, where $>_S$ represents the comparative simplicity relation, $>_P$ represents the comparative probability relation, $L[\cdot]$ denotes *is a law*, which is an operator that maps a proposition to one about lawhood.[15]

But often other factors are not held equal, and we need to consider overall comparisons of theoretical virtues (epistemic guides). Other theoretical virtues can also serve as epistemic guides for lawhood. For example, informativeness and naturalness are two such virtues. A simple equation that does not describe much or describe things in too gruesome manners is less likely to be a law. How to trade off simplicity against other virtues can be another source of vagueness.

We can formulate a more general principle:

**Overall Comparison:** If $A >_O B$, then $L[A] >_P L[B]$, where $>_O$ represents the relation of overall comparison, of which $>_S$ is a contributing factor.

Since $>_O$ need not induce a total order of all possible candidate laws, the corresponding $>_P$ need not induce a total order either.[16] What is overall better is a holistic matter, and it can involve trade-offs among the theoretical virtues such as simplicity, informativeness, and naturalness.

The formulation in terms of comparative probability is much more modest than earlier objective Bayesian accounts that insist on a single simplicity measure, a single probability distribution, and the condition of normalizability.[17] The problem of non-normalizability does not arise, since we do not require a single probability distribution on the space of possible laws.

### 3.3 *Lawhood*

What is the difference between Guide-to-Truth and Guide-to-Lawhood? The latter but not the former solves the problem of nested theories. Recall the earlier example of $GR$ and $GR^+$. Even though we think that the Einstein equation is more likely to be a law, it is less likely to be true than the law of $GR^+$. I suggest that what simplicity selects here is not truth in general, but truth about lawhood, i.e. whether a certain proposition has the property of being a fundamental law.

[15]For example, $L[F = ma]$ expresses the proposition that *F=ma is a law*. The proposition *F=ma* is what Lange (2009) calls a "sub-nomic proposition."

[16]There are theories that are related by $\circledast$. However, in the cases of empirical equivalence discussed in §2, there are clear winners in terms of overall comparison.

[17]For example, Wrinch and Jeffreys (1921) insist on normalization of a single probability distribution, which involves somewhat arbitrary assignments of probabilities to candidate laws. For a discussion, see Sober (2015).

Let us assume that fundamental lawhood is factive, which is granted on both BSA and MinP. Hence, lawhood implies truth: $L[p] \Rightarrow p$. However, truth does not imply lawhood: $p \nRightarrow L[p]$. This shows that $L[p]$ is logically inequivalent to $p$. This is the key to solve the problem of nested theories.

On Guide-to-Truth, in the case of nested theories, we have probabilistic incoherence. If $L_1$ is simpler than $L_2$, applying the principle that simpler laws are more likely to be true, we have $L_1 >_P L_2$. However, if $L_1$ and $L_2$ are nested with $\Omega^{L_1} \subset \Omega^{L_2}$, the axioms of probability entail that $L_1 \leq_P L_2$. Contradiction!

On Guide-to-Lawhood, the contradiction is removed, because *more likely to be a law* does not entail *more likely to be true*. If $L_1$ and $L_2$ are nested, where $L_1$ is simpler than $L_2$ but $\Omega^{L_1} \subset \Omega^{L_2}$, then $L_1 \leq_P L_2$. It is compatible with the fact that $L[L_1] >_P L[L_2]$. What we have is an inequality chain:

$$L[L_2] <_P L[L_1] \leq_P L_1 \leq_P L_2 \tag{2}$$

This is a new solution to the problem of nested theories. It is compatible with but less demanding and perhaps more general than the recent proposal of Henderson (2022). Unlike Henderson's approach, my proposal works even when candidate laws are not structured in a hierarchy.

### 3.4 *Epistemic*

Why should we regard the Guide-to-Lawhood principle as an epistemic principle? Like many substantive (not merely structural) epistemic principles, it does not follow from self-evident premises. However, we may consider an argument from reflective equilibrium. There are many cases of empirical equivalence where the salient difference between the empirical equivalents is their relative complexity. For example, if we are epistemically justified in accepting $T_{M1}$ over $T_{M2}$ because the former has simpler laws, or in accepting $GR$ over $GR^+$ because the former has simpler laws, simplicity has to be an epistemic guide.[18]

Reflecting on our judgments over those cases, we may conclude that simplicity as a guide to lawhood is one posit we should make to justify epistemic realism about laws. It is what we presuppose when we set aside (or give less credence to) those empirical equivalents as epistemically irrelevant. For our preferences in the cases of empirical equivalence to be epistemically justified, the principle of simplicity should be an epistemic guide. As such, it is not merely a pragmatic principle, although it may have pragmatic benefits. Simpler laws may be easier to conceive, manipulate, falsify, and the like. But if it is an epistemic guide, it is ultimately aiming at certain truths about lawhood and providing epistemic justifications for our believing in such truths. There is, to be sure, the option of retreating from epistemic realism. But it is not open to nomic realists.

[18]For a similar argument, see Lycan (2002).

## 3.5 *Fundamental*

Why should we regard Guide-to-Lawhood as a *fundamental* epistemic principle? The reason is that in the cases of empirical equivalence discussed above, the principle cannot be reduced to other epistemic principles that are more closely connected to lawhood or truth. I suggest that it is a rock-bottom principle that need not be justified further; it is an assumption we ought to adopt prior to empirical investigation. The reductive approaches to simplicity in the literature do not apply in the case of empirical equivalence. For example, the AIC model-selection criterion advocated by Forster and Sober (1994) is designed for predictively inequivalent theories. In the absence of any successful reduction of simplicity to resolve cases of empirical equivalence, it is warranted to regard it as a fundamental epistemic guide. Admittedly, if someone presents a proof that simplicity can be reduced to something else, we should be open to the idea and regard the principle of simplicity as derivative of some deeper principle. However, the existence of reasonable algorithms that generate empirical equivalents should cast doubt on the existence of such proofs.

Does Guide-to-Lawhood follow from the metaphysical postulates of BSA? The answer is no. To see this, let us recall the comparison between $T_{M1}$ and $T_{M2}$. Following Guide-to-Lawhood, a Humean scientist living in a world with Maxwellian data would (and should) prefer $T_{M1}$ to $T_{M2}$ because the laws of $T_{M1}$ are simpler. However, it is metaphysically possible that the actual ontology does not include fields. If that is the actual mosaic, the best system may in fact correspond to the enormously complicated laws of $T_{M2}$. It follows that what counts as the actual best system on the BSA may differ from what we should accept as the best system according to Guide-to-Lawhood.

There is no inconsistency, because *what the laws are* can differ from *what we should believe about what the laws are*. Hence, defenders of BSA are in a similar epistemic situation as defenders of MinP. Even if the nomology of $T_{M2}$ represents the actual governing laws, a defender of MinP would and should regard $T_{M1}$ as more likely than $T_{M2}$. Humeans and non-Humeans can be mistaken about the physical reality, even if they are completely rational. That is a feature and not a bug, because nomic realists should be fallible.

This has ramifications for debates between Humeanism and non-Humeanism. According to an influential argument,[19] Humeanism has an epistemic advantage over non-Humeanism, because the former offers better epistemic access to the laws. The argument is that the Humean mosaic is all that we can empirically access, on which laws are supervenient, but non-Humeans postulate facts about laws that are empirically undecidable. But if the analysis in this paper is correct, such arguments are epistemically irrelevant. We never, in fact, occupy a position to observe everything in the mosaic. Our total evidence $E$ will never exhaust the entire mosaic $\xi$. But if both Humeans and non-Humeans need to accept an independent substantive epistemic posit in order to ensure epistemic access to the laws, there is no real advantage on Humeanism. The reason we have epistemic access to laws is by appeal to this new principle of simplicity, which does not follow from the metaphysical posits of either Humeanism or non-Humeanism. Humeanism and non-Humeanism are epistemically on a par, with respect to the discovery and the evaluation of laws.

[19]For example, see Earman and Roberts (2005) and Roberts (2008).

## 4 Conclusion

Nomic realism can be epistemically risky, since it requires ampliative inferences to go beyond what the empirical evidence guarantees. However, the risk is no smaller on Humeanism than on non-Humeanism. We need to decide what the physical laws are, in the vast space of possible candidates, based on our finite and limited evidence about the universe. The principle of simplicity, as a fundamental epistemic guide to lawhood, encourages us to look in the direction of simpler laws. It vindicates nomic realism when there is empirical equivalence (at least in those cases discussed in the paper) and avoids probabilistic incoherence when there are nested theories. Simplicity is not a simple thing, but from this analysis we can conclude that its connection to lawhood is much tighter than its connection to mere truth. Rather than being the seal of the true, simplicity should be regarded as an epistemic guide to the laws.


## Acknowledgement

I thank Emily Adlam, James Brown, Weixin Cai, Craig Callender, Eugene Chua, Maaneli Derakhshani, Frederick Eberhardt, Sheldon Goldstein, Bill Harper, Christopher Hitchcock, Mahmoud Jalloh, Mario Hubert, Kerry McKenzie, Wayne Myrvold, Francisco Pipa, Carlo Rovelli, Charles Sebens, Chris Smeenk, Kyle Stanford, Elliott Sober, Anncy Thresher, Shimin Zhao, and audiences at Western Ontario and CalTech for helpful discussions, and especially Shelly Yiran Shi for her insightful suggestions and research assistance. This project is supported by an Academic Senate Grant from the University of California San Diego.


## References


Adlam, E. (2021). Determinism beyond time evolution. *arXiv preprint arXiv:2110.07656*.

Albert, D. (2021). Physical laws and physical things (manuscript).

Baker, A. (2022). Simplicity. In Zalta, E. N., editor, *The Stanford Encyclopedia of Philosophy*. Metaphysics Research Lab, Stanford University, Summer 2022 edition.

Bell, J. S. (2004). *Speakable and Unspeakable in Quantum Physics: Collected Papers on Quantum Philosophy*. Cambridge University Press.

Bhogal, H. and Perry, Z. (2017). What the humean should say about entanglement. *Noûs*, 51(1):74–94.

Callender, C. (2015). One world, one beable. *Synthese*, 192(10):3153–3177.

Chen, E. K. (2022a). From time asymmetry to quantum entanglement: The Humean unification. *Noûs*, 56:227–255.

Chen, E. K. (2022b). Fundamental nomic vagueness. *The Philosophical Review*, 131(1).

Chen, E. K. (2022c). Strong determinism. *arXiv preprint arXiv:2203.02886*.

Chen, E. K. and Goldstein, S. (2022). Governing without a fundamental direction of time:

Minimal primitivism about laws of nature. In Ben-Menahem, Y., editor, *Rethinking The Concept of Law of Nature*. Springer.

Earman, J. and Roberts, J. T. (2005). Contact with the nomic: A challenge for deniers of humean supervenience about laws of nature part ii: The epistemological argument for humean supervenience. *Philosophy and Phenomenological Research*, 71(2):253–286.

Esfeld, M. (2014). Quantum humeanism, or: physicalism without properties. *The Philosophical Quarterly*, 64(256):453–470.

Fitzpatrick, S. (2022). Simplicity in the Philosophy of Science. In *The Internet Encyclopedia of Philosophy*.

Forster, M. and Sober, E. (1994). How to tell when simpler, more unified, or less ad hoc theories will provide more accurate predictions. *The British Journal for the Philosophy of Science*, 45(1):1–35.

Henderson, L. (2022). Inference to the best explanation, bayesianism and the problem of logical constraints.

Hildebrand, T. (2013). Can primitive laws explain? *Philosophers' Imprint*.

Hildebrand, T. (2022). *The Metaphysics of Laws of Nature (forthcoming)*. Cambridge University Press.

Kukla, A. (1998). *Studies in scientific realism*. Oxford University Press.

Lange, M. (2009). *Laws and lawmakers: Science, metaphysics, and the laws of nature*. Oxford University Press.

Lewis, D. (1973). *Counterfactuals*. Blackwell, Oxford.

Lewis, D. (1983). New work for a theory of universals. *Australasian Journal of Philosophy*, 61:343–77.

Lewis, D. (1986). *Philosophical papers II*. Oxford: Oxford University Press.

Lewis, D. (1994). Humean supervenience debugged. *Mind*, 103:473–90.

Lycan, W. G. (2002). Explanation and epistemology. In Moser, P. K., editor, *The Oxford handbook of epistemology*, pages 408–433. Oxford University Press.

Manchak, J. (2020). *Global spacetime structure*. Cambridge University Press.

Manchak, J. B. (2009). Can we know the global structure of spacetime? *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics*, 40(1):53–56.

Miller, E. (2014). Quantum entanglement, bohmian mechanics, and humean supervenience. *Australasian Journal of Philosophy*, 92(3):567–583.

Norton, J. D. (2019). The Hole Argument. In Zalta, E. N., editor, *The Stanford Encyclopedia of Philosophy*. Metaphysics Research Lab, Stanford University, Summer 2019 edition.

Popper, K. (2005). *The logic of scientific discovery*. Routledge.

Roberts, J. T. (2008). *The law-governed universe*. Oxford University Press.

Sober, E. (2015). *Ockham's razors: a user's manual*. Cambridge University Press.

Stanford, P. K. (2006). *Exceeding our grasp: Science, history, and the problem of unconceived alternatives*. Oxford University Press.

Wrinch, D. and Jeffreys, H. (1921). Xlii. on certain fundamental principles of scientific inquiry. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, 42(249):369–390.