**Physical Modality, Laws, and Counterfactuals**

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**1. Introduction**

Physical modality and related notions (“law”, “cause”, counterfactual dependence etc.) seem philosophically puzzling in part because (we think) it is unclear how to “locate” them—unclear what if anything in the world “corresponds” to these notions or “makes true” claims involving them. One approach attempts to resolve the problem by invoking special metaphysical entities and relationships (“relations between universals”, “powers”, “dispositions” and other “non- Humean what-nots”, as David Lewis calls them) to serve as worldly correspondents for modal claims. Opposing such approaches, we have “Humean” views such as the Best Systems Analysis that attempt to connect physical modality to the organization of our knowledge. This paper defends an alternative to both these approaches in which *invariance* and various *independence* conditions play a central role. I claim that this provides incorporates some of the strengths of both approaches while avoiding some of their limitations.

**2. Preliminaries**

I begin with some general remarks by way of background and orientation. Although some (e.g. Cartwright and Ward, 2016) favor an image of science that moves “beyond laws” or that replaces law –talk with something else, such as claims about powers or capacities (Mumford, 2004), this paper is organized around the assumption that laws play a central role in some areas of science, principally physics. But I also think (and have argued elsewhere—see Woodward, 2003) that it is important not to exaggerate this role. Much science, including large portions of biology and the social and behavioral sciences, gets along fine without making any very extensive use of generalizations naturally described as laws. Laws are just one kind of invariant generalization and the more general notion of invariance is better suited than the notion of a law for capturing the distinctive features of many special science generalizations. Moreover, as I shall argue below, even in areas of science in which laws figure importantly, not all information having to do with physical modality is well captured by a purely law-centered framework. For example, modal features having to do with the physical independence or independent variability of initial conditions are not captured in a natural way just by talk of laws. Similarly for various assumptions about constraints and boundary conditions, as when one assumes that a bead is constrained to move along a wire—here the constraint has a modal or causal character but it is not naturally regarded as a law (although its presence may reflect laws that are undescribed or unknown). In these and other respects, those who complain that standard philosophical image of science is too “law-centric” are correct.

Second, a methodological remark: As I see it, one of the primary tasks of philosophers of science is to elucidate features of “actually existing” science. In the present context, this means that our target should be conceptions of law and physical modality that figure in current and past science. This contrasts with the project of envisioning a fully completed or final ideal science that might exist if we “knew everything” and had unlimited computational problems and then trying to elucidate notions of law and modality that (the philosopher imagines) would figure in that science. I don’t want to foreclose at the outset the possibility that this is the best way to understand actual science, but we should also bear in mind that actual science reasons, often successfully, about law and physical modality in contexts in which we are very far from having unlimited information and God-like computational powers. We need to understand how this is possible and we also need to be sensitive to the possibility that our notions of law and physical possibility are influenced and partially structured by our epistemic limitations and not understandable in abstraction from these[[1]](#footnote-1).

Finally, terminology: The word “law” is used by philosophers to mean both (i) generalizations in some representational format (usually mathematical) as when one says that that the Schrodinger equation is a law of nature and (ii) whatever in nature is described by such generalizations or “corresponds” to them. I will generally use “law” to mean (i), in part because, for reasons that will emerge below, I think it far from clear what in nature “corresponds” to the generalizations we call laws and I wish to avoid begging questions about this. In my view it is particularly problematic to identify the correspondents in question with “regularities”.

**3. Laws, Invariance, and Initial Conditions**

Part of the inspiration for the account that follows can be found in the remarks about laws, invariance, and initial conditions in Wigner (1967). I acknowledge at the outset that Wigner’s discussion does not fully fit all the different physical situations we may wish to model (See Section 5) [[2]](#footnote-2). In particular, it fits cases in which we are dealing with a well-formulated initial value problem and with laws that take the form of hyperbolic differential equations as well as certain other examples discussed below. It arguably fits less well with certain boundary value problems, and situations involving non-hyperbolic differential equations. However, the cases in which the framework applies most naturally turn out to a fruitful point of departure, and complications can be added later.

Wigner is interested in situations in which the results of physical theorizing can be divided into two different sorts of information, having to do with, on the one hand, *laws* and, on the other, *initial conditions*. Roughly what the theorist tries to do is to separate each of these from the other, insofar as possible. This separation is tied to the idea that laws and initial conditions should satisfy different sorts of constraints. One such constraint is that (in the kind of situation we are presently considering) initial conditions should be “free” to vary independently of each other—they should be “freely assignable”. Of course, given some particular kind of system we wish to model, the empirical facts about that system will dictate which initial conditions are appropriate but the idea is that the laws employed should not themselves provide constraints concerning what combinations are possible among the initial conditions—if it looks as though there are such constraints we should either re-conceptualize what counts as an initial condition to remove the constraints or else we should reformulate the laws so that the constraints are incorporated into the laws. To take a familiar example, if we have a classical mechanical system of consisting of a single particle, then the values of each of the three variables specifying its position in a three-dimensional coordinate system should be capable of independent variation – any value for the x coordinate should be co-possible with any values for the y and z co-ordinates and so on. Similarly for the three variables specifying the momentum of the particle—they should be independent of each other and of the position co-ordinates. Similarly for systems of N particles: any combination of values for each of the 6N variables characterizing the system should specify initial conditions for a possible system. Furthermore, ideally, information concerning the values of the full set F of such variables should be all of the information that is required, in connection with the dynamical laws associated with the system, to describe its subsequent behavior: additional information about initial conditions should be redundant and less than the set F should be insufficient. F then gives us the *degrees of freedom* possessed by the system and what is required for the specification of its *state* or *phase* *space*. The degrees of freedom of the system thus constitute a maximal set of variables capable of independent variation. Such state space representations are one way in which physical theories encode (some kinds) of modal information – in this case information about “possible” states of the system.

It is important that, as an epistemic matter, it is often possible, either by observation or experiment or some combination of these, to discover empirically (at least to some considerable extent) which variables are capable of independent variation (and some or all of the degrees of freedom possessed by a system) without having any very detailed knowledge of the laws governing the system. If there is doubt about whether, say, values of X can vary independently of values of Y, one can observe the system to see whether there are combinations of values that never seem to co-occur or alternatively, one can attempt to experimentally create various combinations of values and see whether this is possible. Of course conclusions based on such considerations are subject to ordinary inductive fallibility but they are often fairly reliable.

Observational and experimental exploration can thus serve as an source of access to when independence conditions concerning relations among variables are satisfied that does not require prior knowledge of or understanding of the laws governing the system. Relatedly, as a semantic matter, claims of independent variability also seem understandable or graspable independently of the adoption of detailed commitments about laws. (When I told you that the position and momentum variables characterizing a system of particles were capable of independent variation, you understood what was meant without knowing the dynamical laws governing the system.) This suggests a picture according to which such notions of independence can have to some degree, both conceptually and epistemically, a “life of their own” apart from the notion of law. I will return to this observation below[[3]](#footnote-3).

Given this conception of initial conditions, I turn next to how it can be connected to the notion of law. I suggest that a necessary (not sufficient) condition for a generalization to count as a law is that it describe a repeatable relationship that would continue to hold under some appropriate range of variations in initial conditions, where these include variations in the values of the variables figuring in the generalization. “Continue to hold” here means that the generalization continues to accurately describe (perhaps up to some reasonable approximation) what happens under the variations just described[[4]](#footnote-4). When this feature is present, I will say the generalization is *invariant* (or *stable*) under the variations in question, with these constituting the “domain” or “regime” of the law. For example, given a system consisting of only two gravitating masses *m1*, *m2*, the Newtonian gravitational law *F= Gm1m2/r2* would continue to hold under some considerable range of variations in the values of the masses and the distance between them, as long as the masses are not too large, the distance not too small, and certain other conditions are met. Note that when understood in this way claims of invariance are always *relative* to a set of variations in initial and perhaps other conditions (see below)—a generalization like the Newtonian inverse square law can be invariant within a certain range of variations but not under other variations (e.g., in the presence of sufficiently large masses). Note also that on this account, the notion of an initial condition, understood as above, is required to characterize the notion of law.

Now for some additional unpacking: According to the proposed account, the claim that L is a law (or that L is invariant ) requires that counterfactuals of form (C) be true:

(**C**) For some range of initial conditions reflecting possible values of the variables figuring in L, L would continue to hold under the realization of those initial conditions.

How should such counterfactuals be understood? Without attempting a full treatment (that would be a paper in itself), the intuitive picture is that we should think of the antecedents of the counterfactuals in **C** (“if such and such initial conditions were to occur, then…”) as realized by intervention-like processes, in the sense of intervention described in Woodward, 2003. Roughly what this means is that we are to think in terms of these antecedents having an “independent” causal history, so that if the law holds under the realization of these antecedents, it will hold only as a consequence of the relationship that the law describes between the antecedents and what according to the law, follows from them, and not for some other reason. This excludes, for example, cases in which there is an association between variables *F* and *G*, but only because they are effects of a common cause.

Sometimes counterfactuals of form (**C**) can be assessed experimentally— an experimenter (as Coulomb claimed to have done) may be able to vary the charges *q1, q2* on two small balls and the distance *d* between them in such a way that the values of *q1, q2*, and *d* have the appropriate sort of independent history in virtue of being set by the experimenter and then, by measuring the electrostatic force between the balls, determine whether the relationship *F=k q1 q2/r2* continues to hold under such manipulations. In other cases, such direct experimental manipulation will not be possible, but the appropriate counterfactuals may be assessable in other ways[[5]](#footnote-5) and in any case (since our main concern here is not epistemic), it is whether such counterfactuals hold that is relevant to whether the generalization in question is a law.

Several other features of the counterfactuals associated with C are worth underscoring. Because (**C)** makes use of counterfactuals (indeed so-called interventionist counterfactuals) to help elucidate laws, it is of course non-reductive, in the sense that these counterfactuals themselves carry modal commitments. Nonetheless it is arguable that no vicious circularity is present. In the example above, the experimenter can identify candidate initial conditions like *q1*, *q2* and *r* and determine that these can be varied independently of each other—the experimenter does not have to already know that Coulomb’s law is a law in order to do this. Moreover, whether the relation *F=k q1 q2/r2* continues to hold under such variations is also something that can be ascertained empirically, again without presupposing the truth of Coulomb’s law. So in this case no *epistemically* vicious circularity appears to be present

What about other sorts of circularity? It is often claimed that (legitimate) counterfactuals must be “grounded” in laws, where in the case under discussion, these must presumably include Coulomb’s law itself. Perhaps this is one consideration that induces people to think that one cannot appeal to counterfactuals to help to elucidate laws. But what does such grounding involve and why is it thought to be necessary? For reasons described above, the need for grounding does not seem to arise for epistemic or semantic reasons: It does not seem plausible to claim that one cannot know whether counterfactuals along the lines of (**C**) are true or that one cannot understand such counterfactuals or that they are vague or unclear or in some way semantically defective or incomplete unless one knows the laws that ground them. It seems that our envisioned experimenter can understand or grasp the counterfactuals in (**C**) perfectly well and assess their truth without having settled whether L is a law—rather, whether L is a law can be determined (in part) by assessing these counterfactuals. Presumably then the demand for grounding in laws arises from some other (non-epistemic, non-semantic) source. Even if this demand is thought appropriate, it is hard to see how it undermines the legitimacy of using (**C**) to elucidate the notion of law, which is all that I wish to claim.

There is a second feature of the counterfactuals in C that deserves emphasis. This is that they are to be understood as claims about whether, if we or nature were to make it the case that their antecedents are realized, doing so would make it the case that their consequents hold. They are *not* to be understood merely as claims about what it would be justifiable to infer or believe under some arbitrary counterfactual supposition including suppositions not about initial conditions. For example, it might be reasonable to accept the following counterfactual **S**, construed as a claim about what it would be reasonable to believe:

**S**: If virtually all 22nd century physicists were to come believe that special relativity (SR) is false on the basis of experimental evidence, then SR would be false.

However, this is not a counterfactual that is relevant to assessing the invariance or law-like status of SR—it does not count as an application of the schema (**C**) and the truth of this counterfactual under this inferential, reasonable-to-believe interpretation does not show that SR is non-invariant. Under the present interpretation, the antecedent of (**S**) does not describe the realization of an initial condition for SR and its consequent follows from its antecedent only in the sense that it is reasonable to believe the consequent, given the antecedent. (**S**) is of course not true if instead it is interpreted as claiming that making it the case that physicists have the beliefs described would make it the case that special relativity false or that the truth or falsity of SR depends on what physicists believe. The truth of SR will be unaffected by such variations in beliefs and it is this interventionist, what- would- happen –if- it were-made-the-case interpretation that is relevant to assessing its invariance and lawfulness [[6]](#footnote-6). Several other writers (including Carroll, 1994 and Lange, 2009), connect laws to counterfactuals in something like the manner of **C**, but they do not restrict the relevant class of counterfactuals as I have—something which seems necessary if **C** is to give sensible results[[7]](#footnote-7).

(**C**) focuses on the stability of laws under changes in initial conditions, realized by interventions. But we expect (and find) that laws are invariant under many other sorts of changes as well. One such class is changes in *boundary* conditions – that is conditions at more than one point on a spatial or temporal boundary characterizing some system. I postpone discussion of these until Section 5. Another set of changes relevant to assessments of invariance have to do with what I will call *background* conditions. These are conditions that do not figure in the laws themselves—roughly because variations in them are irrelevant to the relationship described by the law. For example, the gravitational inverse square law is stable under changes in such background conditions as the colors of the attracting masses, the materials out of which they are composed, variations of the price of tea in China and so on. This sort of invariance (invariance under a broad range of background conditions) is also an important feature of laws.

Another aspect of the invariance possessed by laws has to do with their continuing to hold and to correctly describe how the factors in their antecedents contribute to their consequents in contexts in which other causally or nomologically relevant factors are operative. Consider a charged object *m1* subject to both gravitational force *Fg* and an electrostatic force *Fe*. A number of writers suggest that the gravitational inverse square law fails to hold in this case since it does not correctly describe the total force on the object which also includes *Fe*. In my view, this conclusion is misguided—instead, the gravitational inverse square law should be understood as describing the gravitational component of the force on *m1* and similarly for *Fe*. When understood in this way, the gravitational force law is invariant under variations in the magnitude of *Fe*.[[8]](#footnote-8). Indeed, one of the attractions of understanding laws as invariant relationships is that it leads us to think in terms of decompositions of forces - it is the component forces, not the total force, that are invariant (under variations in background and the presence of other forces).

Yet another aspect of the invariance-based account is that it nicely captures a feature possessed by all or virtually all known candidates for fundamental laws—the fact they are merely “effective” (or are components of effective theories). “Effective” in this context means that these generalizations hold to a high degree of approximation within a certain range of circumstances or within a certain “domain” or “regime” and break down or have exceptions outside of these. Moreover, rather than the deviations from exceptionlessness being small, in many cases they may take the form of major, qualitative, even catastrophic failures, which suggest the need for new physics. Thus, for example, General Relativity is widely believed to break down at very small distances—the so-called Planck length, where quantum gravitational effects become important. Current descriptions of the strong, weak and electromagnetic force are expected to break down at higher energy scales, where completely new theories may be required. Since, as explained above, the notion of invariance is relativized to a set of variations, it is a framework that is well-adapted for capturing this feature of laws—a generalization can be sufficiently invariant to count as a law, even if it is not exceptionless[[9]](#footnote-9).

A standard philosophical reaction to the examples just described is that true or genuine laws *must* be exceptionless; hence that merely effective generalizations are not real laws. The task of the philosopher is to analyze real laws. As explained above, I hold that an important part of the task of the philosopher of science is to elucidate actually existing science. Science as it currently exists employs effective theories and laws and the philosopher of science should try to understand these and how they figure in scientific reasoning. My account of the connection between laws and invariance is advanced in the service of this project.

A related possible response to this emphasis on the effective status of known laws is that, contrary to what I have suggested, these can only be understood by reference to exceptionless laws: underlying every effective law there “must” be an exceptionless law that grounds the former and accounts for its status as a law. Thus (it might be argued) a preoccupation with exceptionless laws is warranted after all.

One might wonder what warrants the “must” in this claim. But even putting that aside, there is another difficulty. This is that as nearly we can tell it is wrong that the currently known effective laws “depend” on any particular deeper law or candidate for such a law. Instead, currently known effective laws are thought to be “decoupled” from or independent of whatever deeper, higher energy physics underlies them—this is why, for example, one cannot use information about known effective laws or experimental evidence from the energy scales at which they hold to infer anything very specific about the laws that describe physics at higher energy scales. Put differently, there are many different candidates for the correct unknown underlying laws all of which satisfy the empirical and theoretical constraints available at lower energy scales and all of which yield current effective theories at lower energy scales. Thus insofar as current effective generalizations are grounded in more fundamental theories, this “ground” seems to be something more like what the various plausible candidates for the fundamental theory have in common (certain generic features they possess) such that they yield the effective generalizations at lower energies—it is this that explains or accounts for the invariance of the effective generalizations insofar as anything does[[10]](#footnote-10). The decoupling results highlight the need to understand the features of effective generalizations that make for their lawlike status on their own terms[[11]](#footnote-11).

I said above that satisfaction of (**C**) is a necessary but not a sufficient condition for a generalization to count as a law; the set of laws is a proper subset of the set of invariant generalizations. Roughly speaking, laws are those invariant generalizations whose range of invariance is sufficiently large or substantial (including invariance over a large range of background conditions) and which (at least in many cases) are integrated with other laws as part of a coherent theory. One consequence of this picture is that the boundaries of the notion of law become vague and there is a sort of continuum between laws and generalizations that are invariant over some range of interventions and other conditions but where these are narrow enough that the generalizations are not regarded as laws. As I have argued elsewhere ( Woodward, 2003), this fits well with most science outside of physics. There one finds generalizations that are invariant but only relatively locally so—generalizations describing how, e.g., synaptic weights change in response to neural activity, how companies in a competitive market change supply in response to price changes and so on. For that matter, much theorizing in physics about the behavior of particular kinds of systems—waves moving on a string, fluid moving through a pipe etc.-- also makes use of locally invariant generalizations (e.g., constitutive equations such as versions of Hooke’s law) that are far from paradigmatic laws but which are crucial for physical modeling.

This “graded” picture of generalizations differing in degree of invariance contrasts with the more standard philosophical picture according to which there is a sharp dichotomy or discontinuity between true laws and all other sorts of generalizations, including those that are only locally invariant, with the former possessing some (non-graded) distinguishing feature not shared by the latter. Indeed, part of the appeal (to many philosophers) of the “true laws must be exceptionless” doctrine is that it implies such a dichotomy (exceptionlessness being an all-or-nothing matter). I suggest, however, that empirical facts about the kinds of generalizations actually found in science instead support the more graded invariance-based picture.

**4. Independence and Additional Constraints on the Law/Initial condition Contrast.**

So far I have emphasized the role of independence in the form of independent variability of initial conditions. However, one may also think about invariance (and in particular the wide-range invariance possessed by fundamental laws) in terms of an independence condition—different from but not unrelated to the independence that characterizes initial conditions. Here the idea is that, ideally, the “cut” between laws and initial conditions should be made in such a way that these are “independent” of each other (or as “separate”) as possible, where this means, roughly, that insofar as this is possible, the laws should not incorporate non- generic information about initial conditions and conversely—these two kinds of information (law information and initial condition information) should be kept distinct and not mixed together. Metaphorically, we should, insofar as possible, represent nature as choosing its laws independently of any specific choice of initial conditions and conversely. Theories that satisfy this requirement of separating laws and initial condition information have, I will suggest below, a number of virtues – it is no accident that modern science looks for such theories, although (I will also acknowledge below) it does not always find them.

I remarked above that the separation of law/initial condition information is reflected in the fact each is treated as subject to very different constraints. One such constraint is that laws are expected to satisfy various symmetry conditions— physical laws should remain the same under spatial and temporal translations and so on. We may think of these as special cases of invariance conditions in the general sense described above—laws must return the same behavior under transformations corresponding to these symmetries, so that, for example, a pendulum will behave the same way if the only change to which it is subject is a spatial translation. This is a particular kind of independence condition – independence of behavior from spatial location. Note that to even describe such symmetry requirements, we require a contrast between laws and initial conditions— it is the laws that remain the same and return the same behavior as certain initial conditions (e.g. having to do with spatial location) change. By contrast, initial conditions or patterns in initial conditions themselves are not required to satisfy any such symmetry conditions—arguably it is not even clear what such a requirement would mean.

A second contrast has to do with the different role played by considerations having to do with simplicity (and related virtues having to do with unification and generality) in connection with laws and initial conditions. Roughly speaking, to the extent simplicity matters in theory-choice (and however in detail it is understood), it is laws that we want to be simple, unified, and general. By contrast, at least in many cases, there are no corresponding demands imposed on initial conditions. When the systems we are interested in demand it, the initial conditions used in their characterization can be highly complex—indeed, basically what one tries to do, ceteris paribus, is to off-load whatever complexity is required for the characterization of the system’s behavior onto its initial conditions as far as this is possible, while keeping the laws describing the system’s behavior of the system as simple and general as possible. For example, one tries to capture any complexity and variability in the behavior of projectiles and planets by appealing to differences in the initial conditions they face while accounting for the similarity of their behavior in terms of the same laws. In effect, one tries to separate out the disorderly elements in their behavior, putting this in the initial conditions while keeping as much order as possible in the laws. This is reflected in the way in which we think about simplicity and unification: a theory according to which, e.g., the behavior of projectiles on the surface of the earth and the orbits of the planets follow entirely different laws is seen as less simple and less unified than one according to which both are governed by the same set of laws and this is so even if this theory makes use of very different initial conditions in explaining planetary and terrestrial behavior—the latter is not seen as detracting from the simplicity and generality of the explanations provided. By contrast, there is no corresponding virtue associated with explaining these two sets of behaviors in terms of the same initial conditions but different laws—this does not count as a simplification or unification in the same way. So laws and initial conditions are treated very differently from the point of view of assessments of unification and simplicity[[12]](#footnote-12).

**5. Complications: Laws and differential equations**

So far I have been following the tradition of most philosophical discussion by neglecting the fact that most or all known laws are stated in the form of differential equations. This requires some important complications in the picture described above. Some of these (e.g., the observations about the relationship between laws and their “instances”) lend further support to the invariance-based picture while other considerations suggest that the idealized account in previous sections needs to be complicated in important respects.

A time-honored schema for laws, deriving from the logical empiricists but remarkably influential even among those who have moved far away from this tradition[[13]](#footnote-13), is that they can be represented by universally quantified conditionals like (i) (x) (Fx🡪 Gx), where the connective 🡪 may be either the material conditional or something with more modal force. There are many respects in which this schema misleads and distorts but I want to focus on one consequence in particular— the way that it leads us to think about the relationship between laws and the systems to which they “apply”. Basically, the schema (i) encourages us to model this relationship as a matter of universal instantiation or perhaps universal instantiation followed by modus ponens. We have a system *a* which is *F* and applying (i) we deduce that *Ga.* This picture embodies several assumptions. First, it is assumed (i) can be applied to any object *x* in the domain of quantification and for any such object if it is *F*, we can derive that it is *G*, so that the application of this schema and the derivations it involves are, if not trivial, rather mechanical and always possible in principle. Second, the results of these various instantiations of (i) are, so to speak, qualitatively the same— *F*ness always yields *G*ness. Relatedly each of the “instances” of (i) is mirrored or reflected directly in the law (i), so that (i) seems to describe a “regularity” among these instances in a very straightforward sense. This encourages the use of certain toy examples-- for example, the “law” that (ii) all ravens are black which seems to describe a regularity among its instances.

Differential equations work very differently from this. First, rather than the first- order logic picture of instantiation, we look for *solutions* to differential equations and this is a matter of finding *functions* that satisfy the equations and whatever additional constraints (in the form of initial and other sorts of conditions) we have imposed. Such solutions are not (and do not represent) “instances” of laws in the way in which some particular raven might be regarded as an instance of (ii). Moreover, many differential equations will not have any solutions or will have no unique solution for many imposed conditions. Or they may have solutions within a certain interval but not outside of it. (Compare this with instantiation of (i) which is always possible and yields a unique result for any object in the domain of quantification.) In addition, differential equations (including differential equations representing scientific laws) are remarkably unconstraining in the absence of specific information about initial and boundary conditions and solutions to them can be qualitatively very different depending on which such conditions are imposed. For example, the general solution to the one-dimensional wave equation which takes the form ∂2u/∂t2 = c2∂2u /∂x2 is consistent with all sorts of quite different behaviors in the systems to which it applies[[14]](#footnote-14). The equation yields more specific behavior only when combined with much more specific assumptions about initial and boundary conditions—for example, imposition of the boundary condition that the end points of a string or fluid are fixed leads to solutions involving periodic behavior, behavior which is not present in other solutions. To put the point slightly differently, the same differential equation can have solutions that are qualitatively quite different, depending on the additional conditions that are imposed. (Compare this with the qualitative similarity of the instances of (i)). Thus laws, insofar as they are represented by differential equations, have very little strength (in the BSA sense of permitting the derivation of many specific behaviors) taken in themselves—they get the kinds of strength that allows them to describe the behavior of particular kinds of systems only when combined with other sorts of information (about initial and boundary conditions etc.).

One immediate consequence of these observations is that the “regularity” described by the wave equation (and even more so for more fundamental laws like the Schrodinger equation or the Einstein Field equations) is different in important respects from regularities of the “all ravens are black” variety. Regularities of the latter sort are, so to speak, concrete and overt—they may be inducible from their instances in the sense that the instances (black ravens) are recognizable prior to the formulation of the generalization of which they are instances. Typically, they (or their representations) incorporate lots of non-lawful information about initial and boundary conditions. The properties (or whatever) such generalizations relate can often be specified in ways that do not implicate modal assumptions (or at least they are as good candidates for such non-modal specification as we are likely to find). In short such regularities conform in at least some respects to the philosopher’s paradigm of a “Humean” regularity . To the extent that regularities of this sort correspond to anything in the world of differential equations, they are more like particular solutions to those equations than the equations themselves. By contrast, the differential equations that are regarded as laws (the Field equations, the Schrodinger equation etc.) are very abstract and do not incorporate information about initial and boundary conditions in the way that more concrete regularities do. It is often not obvious how to interpret the terms figuring in these equations – e.g. the Hamiltonian operator in the case of the Schrodinger equation -- in ways that avoid all commitment to anything modal. The word “regularity” is sufficiently vague and flexible that we can, if we wish, say that the Field Equations and the Schrodinger equations describe regularities but if we do so, we should be mindful of how different these regularities are from “all ravens are black” paradigms.

The features of genuine laws like the Field Equations just described fall naturally into place if one takes the separation of laws and initial conditions seriously as a methodological ideal at which portions of science aim. Generalizations like “All ravens are black” do not satisfy the separation requirement. Generalizations that come closer to satisfying that requirement—those we think of as laws—must, insofar as they satisfy the requirement, be far more general and abstract in order to avoid incorporating information about initial and boundary conditions[[15]](#footnote-15).

With these observations about differential equations in mind, let us now turn to their implications for understanding invariance. I spoke above of the free assignability of initial conditions and the possible of combinability of different initial conditions with the same law to describe the behavior of different systems One immediate qualification that is required (once we attend to the fact that laws take the form of differential equations) is that not all initial conditions that we might envision for a system will be combinable with laws to yield solutions or unique solutions for the behavior of the system. This point applies even more strongly when we consider the role of boundary conditions which will be required for the solution of many partial differential equations. There are many cases in which the combination of a differential equation representing a law and boundary conditions will yield no unique solution. Among other considerations, arbitrary boundary conditions imposed at different spatial and temporal locations may fail to be consistent, given the governing equations. In addition, taken together, some systems of equations representing laws of nature impose consistency constraints (roughly because there are more equations than unknowns) that restrict free variability in the assignment of initial and boundary conditions. For example, althoughMaxwell's equations admit an initial value formulation, the initial conditions one can assign are not completely unconstrained. This is because the equations (∇⋅**B=0,**∇⋅**E=0)** specifying the vanishing of the divergence of magnetic and electric fields *B* and *E* (in the source free case) place restrictions on which initial conditions are possible. Similarly, in General Relativity, the initial value problem requires that initial conditions satisfy a set of partial differential equations (the Einstein constraint equations) which are distinct from the equations specifying the temporal evolution of the system.

While these considerations complicate the picture described above, they do not fatally undermine it. We still have a conception according to which laws of nature are expected to remain stable or invariant over some substantial range of changes in initial conditions and over other sorts of conditions including boundary conditions. Variation in the behavior of systems governed by the same laws is still accounted for in terms of variations in initial and boundary conditions that, even if not completely unconstrained, are still thought of as capable of exhibiting a great deal of variation.

Next let me briefly comment on another issue which has likely occurred to the reader, having to do with the “absoluteness” of the law/initial condition distinction. In his (1967), Wigner says both that the distinction “is probably one of the most fruitful ones the human mind has made” *and* that it is “probable” that “the possibility of such a division has its own limits”. More recently, several philosophers have pointed to contexts and examples in which the distinction may break down or become unclear. Sklar (1991) suggests (among other examples) that cosmological models in which there are closed timelike curves may be cases in point: consistency in such models requires restrictions on the free assignability of initial conditions and if such models are claimed to be “impossible”, it is unclear whether this should be regarded as a lawlike restriction, a restriction on initial conditions, or whether the boundary between the two collapses.

Without getting drawn into a discussion of this (and other) specific example(s), I’m happy to endorse Wigner’s (and Sklar’s) general claim. Whether the behavior of some set of systems can be fruitfully decomposed into claims about initial (and boundary) conditions and claims about laws meeting the criteria described above is in my view a contingent, empirical matter—nothing assures us that it will always be possible to do this. It may well be that there are situations in which the law vs. initial/boundary conditions distinction breaks down or fails to apply. I would add, however, two further points. First, echoing Wigner, the fact the distinction may break down under some conditions, does not undermine its utility in those (apparently widespread) circumstances in which we can fruitfully employ it. Second, the philosophical task I have set myself in this paper is to provide an account of physical modality and laws of nature. If I am correct, the notion of law only applies or makes sense in contexts in which we can draw a law/initial condition contrast. The moral we ought to draw from examples like Sklar’s is not that there is no difference between laws and claims about initial conditions (or regularities in initial conditions) or that the latter should sometimes be regarded as lawlike or “nomological” but rather that, as I said above, there may be contexts in which the contrasts assumed by these words do not apply[[16]](#footnote-16). In such cases we should withhold characterizations like “law” and “initial condition”, rather than thinking in terms of initial conditions that are lawful or nomological. Such cases do not show that we need to revise our notion of law in a way that ignores the law/initial condition distinction.

**6. More on the Separation of Laws and Initial (and other) Conditions**

My discussion so far has repeatedly invoked the notion of “separating” laws from initial (and boundary and background) conditions. I have tried to provide some illustrations of what this might involve. Here I would like to add to these and make some additional connections with aspects of my earlier discussion.

**6.1. Independence of the Frequency with which Initial Conditions Occur**.

One way in which one might fail to adequately separate laws and initial conditions is by making one’s candidates for laws (or at least those laws deemed important or interesting) too dependent on the frequency with which various patterns occur in nature. Separation requires that whether a generalization counts as a law should not depend on the frequency with which initial conditions occur. Consider Newton’s first law, which describes the motion of a particle subject to zero total force. It is plausible that particles are rarely found in this condition, but even if there are no examples of such particles, the first law remains a law-- and an important one. Of course the frequency with which inertial motion occurs reflects not just Newton’s first law, but also the prevailing distribution of initial conditions. It was an important insight on Newton’s part to recognize the lawful status of the first law even though it rarely describes the actual motions of many of the particles around us.

**6.2. Independence from Other Causal and Nomological Influences**.

When a body moves on a surface it is typically subject to a number of causal influences, including friction. When a body falls freely near the surface of the earth it is subject to other forces besides gravity (e.g. a velocity dependent force, approximately described by Stokes’ law, due to air resistance). As a result the net or overall behavior of such objects is often very complex and the upshot of a number of different applicable laws, the import of which will reflect prevailing initial conditions—e.g., in the case of friction the nature of the surface across which the body moves. Again, understanding requires separating out the role of the different forces incident on the body and, along with this, how these interact with (separable) initial conditions.

**6.3. The BSA**.

A frequently noted feature (e.g., Hicks, forthcoming) of the BSA is that which generalizations are counted as laws seems to depend on the actual distribution of initial and boundary conditions. The latter affect which possibilities are realized and hence whether these possibilities need to be accommodate in the BSA. For example, in a case in which there are two competing law claims *L1* and *L2*, both consistent with what has been observed so far, but which can be distinguished by a crucial experiment producing result *E*, it is a arguable (cf. Woodward, 2003) that whether either *L1* or *L2* count as laws may depend on whether the experiment is performed. (We assume that if the experiment is not performed *E* does not occur “naturally”.) If the experiment is not performed, *E* will not be part of the Humean mosaic, and accommodating it will not contribute to the strength of either *L1* or *L1* [[17]](#footnote-17) This is one of a number of examples that suggests that the BSA does not separate laws and initial conditions in the way it should.

**6.4. Regularities and Dispositions.**

I noted above that many of the most obvious overt regularities in nature reflect an interaction between laws and initial and boundary conditions—to this extent, if we focus too much on such overt regularities, taking them to be central to science, this will reflect a failure to separate these two kinds of information. A similar observation seem to holds for many examples of dispositions that are assigned the role of grounding or replacing laws in the philosophical literature. This is because the manifestation or effect associated with a disposition possessed by some system will typically reflect both the laws applying to the system and the initial and boundary conditions that characterize it. For example, as noted above, the disposition of a plucked violin string to produce a particular sound will reflect both the laws describing the behavior of the string and the fact that it is subject to certain boundary conditions—e.g., the ends are largely but not completely fixed etc. In the absence of the imposition of some set of initial and boundary conditions, the laws governing the string will predict no very specific manifestations at all (and the string will not have any very distinct disposition.) One reason why dispositions seem like problematic candidates for “grounding” laws is that they mix lawful and non-lawful information in this way.

More generally, the cognitive architecture associated with dispositions and powers seems rather different from the architecture associated with the laws and initial conditions framework—the former is a different way of organizing our knowledge from the latter, rather than any kind of basis for it. First, dispositions seem to require kinds of things or systems that “have” them (e.g., salt has the disposition to dissolve in water) and such “things” require initial/boundary conditions for their specification, which violates the ideal of separating laws and initial/ boundary conditions. Second, most standard accounts of dispositions require the occurrence of some stimulus to “trigger” them (and do not manifest themselves in the absence of such a stimulus), but fundamental laws do not have this feature—whatever disposition might be associated with Schrodinger’s equation is always manifest and requires no stimulus. In addition, plausible candidates for stimuli typically do not capture all of the initial and boundary condition information relevant to the disposition’s manifestation. (The stimulus that triggers the disposition of the glass to break is something like a sharp impact, but the initial and boundary conditions relevant to the breaking include the composition and micro and meso-organization of the glass.)

This raises the general question of the benefits and limitations of thinking about nature in terms of laws and initial/boundary conditions, rather than in some other way (e.g., in terms of dispositions). On my view, the law/ initial condition framework provides important benefits, at least when nature cooperates — it allows us to deal with a complicated set of appearances whose overt behavior (because it reflects the combined influence of many causal factors, and the vagaries of the distribution of initial conditions) is often not particularly simple, regular or generalizable. The separation allows us to distinguish those relationships that are stable and generalizable from aspects of nature that do not have these features. From this perspective the common perception that the rise of modern science was accompanied by a shift away from the disposition-talk that characterized scholastic philosophy is no accident-- it reflects a judgment that the law/initial condition framework has certain advantages over alternatives[[18]](#footnote-18).

**7. Humean vs non- Humean Conceptions of Laws**.

I conclude with some remarks about the implications of the invariance-based account for the standard dichotomy between “Humean” and “non- Humean” views of laws. These labels are attached to packages of claims that are commonly grouped together but which are more independent and separable than is often supposed. In particular, Humeans about laws are often taken to be committed to the following:

(**7.1**) *Reducibility*. Claims about laws (and other claims about physical modality) are, to the extent that these are scientifically or metaphysically legitimate, reducible to claims that do not involve physical modality —typically the latter are taken to be claims about the existence of regularities meeting further conditions for Humean acceptability.

(**7.2**) *Necessary connections*: There are no necessary connections “in” nature.

(**7.3**) *Non-governance*: Laws do not “govern” what happens; rather they are or describe patterns in what happens.

(**7.4**) *No non – Humean stuff*. Appeals to “non-Humean” entities or properties —dispositions, powers, relations of necessitation between universals and so on-- cannot be legitimately used to explicate the notion of law or other modal notions.

Invariance-based accounts are non- Humean in rejecting (7.1) but agree with Humeans about (7.4). (See below) The invariance-based position regarding (7.2) and (7.3) depends on what is meant by “necessary connection” and “governance”. On some interpretations of these notions the invariance-based account rejects both (7.2) and (7.3). However, there are other construals of (7. 2) and (7.3) which are supported by the invariance-based account. Thus, as claimed in Section 1, the invariance-based account thus combines elements from both Humean and anti-Humean treatments of laws, while (as I see it) departing from both in refusing to provide a metaphysics of laws

*Necessary Connections*. With respect to (7.2) the invariance account makes no use of metaphysically ambitious notions of “necessary connections” located “in” nature—relations of nomic necessitation between universals instantiated in particular objects, dispositions possessed essentially whose characteristic behavior is metaphysically necessary and so on. Nonetheless, there is, according to the invariance based account, a naturalized non-metaphysical notion of necessitation that is legitimate. All that necessitation amounts to is invariance: within some domain there are no initial and background conditions that might be realized—nothing that might be done by nature or an experimenter—under which the law will fail to hold. This sort of necessity contrasts with the contingency or non-necessary character of accidentally true generalizations like “all the coins in my pocket are quarters”, which can readily be made false by e.g., the introduction of a dime into my pocket. This is all that the necessity of laws can legitimately amount to. This as an unmysterious empirically testable notion of necessity.

*Governance*. This is often understood as the idea that, as Maudlin (2007, p. 15), an advocate, puts it, laws “produce” or “generate” what happens or that as, Beebee (2000) , a critic of the notion puts it, laws “do” things or “bring about” outcomes. A number of writers take this version of governance to be central to the very idea of a law of nature but Humeans reject this contention, often suggesting that various arguments for non-Humean conceptions of laws rest, illegitimately, on indefensible assumptions about governance. If governance is understood as described above, I think that Humeans are right to reject it[[19]](#footnote-19) . To employ an old-fashioned diagnosis, the idea that laws make things happen or are productive seems like a category mistake; laws (or what they describe or correspond to “in the world”) are not factors or entities that play a causal or productive role in nature. It is not the case that in addition to the role played by two masses separated by some distance in exerting a mutual gravitational force on each other, some further factor – the gravitational inverse square law -- is at work in producing this force. Similarly for invariance—to say that a relationship is invariant is to say that it exhibits features captured by claims like **C**, but this is not to say that these invariance features are productive forces that make things happen.

On the version of governance presently under discussion, laws are regarded as both “external” to the things they govern and yet as somehow “acting” on particular systems to guide their behavior. This conception makes the “location” problem particularly vivid— one immediately wonders “where” these laws are situated (in some Platonic realm separate from ordinary things?) and how they get into contact with the particular systems on which they act. This concern suggests an alternative for those who wish to retain the governance idea—why not locate the laws (or at least something that functions in many ways like laws) “in” the particular systems on which they act? This is one route to accounts that invoke dispositions and powers as sources of physical modality—these are properties of systems that “govern” their behavior, but are not “external” to them. One consequence, accepted by some (e.g. Mumford, 2004) but not all fans of dispositions, is that laws, conceived as external governors, now seem superfluous—it looks as though whatever work can be done by laws can be done by powers and dispositions alone. Although I lack the space for detailed discussion, it is worth noting that if thinking of laws as producers or generators is objectionable, it is not clear it helps to merely relocate them (or their surrogates in the form of powers and dispositions) in the objects they govern. When salt dissolves in water, there is a familiar story to be told about the dissociation of Na and Cl ions, the polarity of water molecules etc. However, the disposition of salt to dissolve is not an additional actor in this process that contributes to or helps to generate the dissolving, anymore than the inverse square law plays a similar role in connection with gravity.

Although this seems right, it is easy to slide from this legitimate rejection of governance as production to a stronger position that rejects much of what is distinctive about laws and other modal claims. An illustration is provided by Beebee (2000) in the context of her discussion of the following principle, which is advocated by Carroll (1994):

**(SC\***) If P is possible and Q is a law, then if P were the case, Q would still be a law.

(**SC\***) (and related other principles Carroll discusses) are broadly similar to (**C**) above, when the counterfactuals that figure in them are given an interventionist interpretation, and when P is appropriately restricted to claims about initial (or boundary or background) conditions that are within the domain of invariance of Q. When understood in this way **SC\*** seems basically correct, and to amount to the claim that laws satisfy an invariance condition. However, Beebee rejects (**SC\***), associating it with illegitimate versions of the governance idea. She observes that (**SC\***) will be false on Lewis’s account of counterfactuals and their relation to laws. This is because, as is well-known, within Lewis’ framework the realization of the antecedent of a counterfactual in deterministic worlds will require a small miracle, with the result that some law will no longer hold. For example, if in actuality I do not strike a match, the supposition that I do will require a small miracle. Carroll contends that this has the absurd consequence that the laws counterfactually depend on whether I strike the match. Beebee responds that in fact the laws *do* depend counterfactually on whether I strike the match, in contravention of (**SC\***). She thinks our tendency to suppose otherwise and to accept (**SC\***) relies on the illicit assumptions about governance.

Even if we accept Lewis’ claims about the need to postulate miracles, we need not accept Beebee’s conclusions. As emphasized above, **C** (and **SC\***) are only true when the counterfactuals in them are given an interventionist and not an inferential interpretation. If Lewis’s claims about the analysis of counterfactuals are correct, then when I make a counterfactual supposition about striking a match, this assumes a law violation. But this just concerns what I can infer from this supposition and not what I can make the case—the latter being the interpretation that is appropriate for (**C**) and (**SC\***). The contention that the laws of nature counterfactually depend on whether I strike a match seems so obviously absurd (just as Carroll claims) because (or to the extent that) we give the counterfactuals in question an interventionist or “would make it the case” interpretation. So Lewisian miracles provide no ground for denying (**C**) and (**SC\***), although such miracles may of course be objectionable on other grounds. Moreover, rejecting principles like (**C**) and (**SC\***) collapses the distinction between those generalizations that can be made false by the realization of initial conditions within their domain and those that do not have this feature and consequently (I would argue) amounts to an abandonment of what is distinctive about laws.

Note also that when understood in the way described (**C**) and (**SC\*)** do not require an objectionable interpretation of governance as generation—neither carries any commitment about laws producing things. What is correct in the governance idea is simply the claim that laws have the kind of independence from initial conditions described by (**C**) -- that realizing initial conditions within the domain of invariance of a law does not make the law false but rather implies that the system in question will conform to the law**.**

*No Non-Humean Stuff*. The invariance-based account does not invoke dispositions, relations of necessitation between universals and the like. Many readers may have the reaction, however, that in eschewing these, as well as standard Humean accounts, the invariance-based account leaves physical modality mysterious: no explanation is offered for what makes invariance claims true. I have tried to say more about this issue elsewhere (Woodward, Forthcoming) and confine myself here to a few brief remarks, which are entirely directed at non- Humean accounts[[20]](#footnote-20). First invariance claims (except perhaps the most fundamental) have ordinary *scientific* explanations—for example, General Relativity can be thought of as providing an explanation of why the generalizations of Newtonian gravitational theory are invariant (or have the domain of invariance that they do). So the complaint of non-explanation really amounts to the contention that such scientific explanations are not enough, and that in addition the kind of *metaphysical* explanation that the proponent of non-Humean stuff claims to provide is also required. I see no reason to accept this contention, especially since it is not clear to me that the alleged metaphysical explanations are really *explanations* of anything. (At the very least we need a better understanding of the criteria for successful metaphysical explanation than we currently have.) For one thing, as argued above, the currently available metaphysical explanations seem to fail to capture important aspects of the phenomena (features of nature or of science) which they target. Second, to the extent that these accounts don’t misrepresent their targets, they often seem to be nothing more than re-descriptions in metaphysical language of whatever it is we are trying to understand, with no real illumination provided. (As when one says that the truth-maker for the Schrodinger equation is the disposition of quantum –mechanical systems to behave in accord with that equation). Perhaps it is possible to produce metaphysical explanations of modal claims that are genuinely illuminating but the track record of existing attempts is not encouraging. Until we have better reasons to think that such explanations are possible it seems unmotivated to fault the invariance-based account for failing to provide them. [[21]](#footnote-21)

**8. Conclusion**

It is a common although not uncontroversial view that (i) the Scholastic vocabulary of powers and dispositions was gradually abandoned in modern science. Approvingly noting (i) and associating modal claims with these, Hume and many of his descendants drew (ii) the moral that there was something problematic about the use of modal claims in general in science, at least when interpreted in a non-subjective way, and that these should be reduced to or replaced with non-modal claims – claims about regularities or regularities occupying a certain role within a deductive systemization. I think that Humeans are right about (i) but wrong about (ii). Modern science continues to make modal claims (and distinguishes these from claims about mere regularities) but it has found ways of representing modality by means of devices that are clearer and more perspicuous than talk of dispositions, essences and similar stuff – these include the use of state and phase spaces to represent possibilities, and equations (differential and otherwise) to represent laws and other invariant relations, assumptions about various sorts of independence and so on. Philosophers of science should focus on understanding these representations, rather than trying to reinterpret them either in terms of dispositions or non-Humean regularities, frameworks into which they do not fit naturally.

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1. I do *not* mean that our notions of law and physical modality contain some covert reference to or relativization to epistemic factors. Rather the idea is that these notions are engineered for contexts and beings with epistemic and calculational limitations and this is reflected in the character of those concepts. In the same manner, an insect wing might be “designed” for performance in air currents with certain characteristics without its being the case that we need to think of the wing as somehow “relativized” to those currents. [↑](#footnote-ref-1)
2. I also acknowledge that what follows is my gloss on Wigner. I’m not concerned with whether it is in every respect an accurate report of his views. Rather I treat Wigner as an inspiration for a certain picture of laws. [↑](#footnote-ref-2)
3. If one thinks of the notion of “law” as the sole basic element in understanding of physical modality, then one will presumably think of the independent variability of initial conditions in purely negative terms— it is just a matter of the absence of any law according to which values of *X1* constrain values of *X2.* An alternative approach might include physical independence as among the basic elements needed to understand physical modality. I regret that I lack the space to explore this idea here. [↑](#footnote-ref-3)
4. Note that this is not just a matter of the generalization failing to be false for those variations over which it is invariant; the requirement is rather that the generalization must “apply to” systems exhibiting the variations in question and accurately describe the nomological relationship holding under the variations. For example, although a version of the Newtonian gravitational inverse square law that is explicitly restricted to phenomena near the surface of the earth does not make false claims about celestial phenomena, it does not count as invariant under changes in initial conditions describing celestial phenomena. [↑](#footnote-ref-4)
5. See Woodward, 2013. [↑](#footnote-ref-5)
6. A similar observation holds for so-called backtracking counterfactuals. Suppose that in the actual world the cat is on the mat a time t. Then it is certainly arguable that the counterfactual, “If the cat had not been on the mat at t, something about the past would have been different” has an interpretation under which it is true—either some prior initial condition would have been different or, as Lewis claims, a prior miracle would have occurred. This again is an interpretation of the counterfactual under which we consider whether it is reasonable to infer the truth of the consequent given the supposition of the antecedent. However, although some philosophers seem to dispute this, I take it to be uncontroversial that it is not true that making it the case that that the cat is not on the mat at t, would make the past different. Again it is the latter (interventionist) interpretation that is relevant to the assessment of invariance claims. [↑](#footnote-ref-6)
7. Lange (2009, xiii) takes subjunctive facts, expressed by counterfactuals, to be “ontologically primitive and responsible for laws”. My view differs in several important respects. First, I make no claims about what is most primitive or fundamental. My view is that laws and counterfactuals are so entangled that there is no basis for claiming one of these is more fundamental than the other. Second, Lange does not distinguish among kinds of counterfactuals in elucidating laws in the way that I do. Roughly, Lange requires that laws hold under *all* (allowable) counterfactual suppositions consistent with them. I require that this be true only for a specific subclass of counterfactuals,-- those that have an interventionist or at least manipulationist interpretation in the manner described above. As a result, Lange’s account is (I believe) subject to counterexamples along the lines of (**S**)—that is, on Lange’s account, the truth of a counterfactual like (**S**) means that SR fails to be invariant or counterfactually stable, which I take to be the wrong result. (See Woodward, 2011.) Finally, my notion of invariance is graded, as explained below, while Lange’s analogous notion is an all or nothing matter. [↑](#footnote-ref-7)
8. I suspect that the temptation to think of the gravitational force law as a claim about the total force derives in part from thinking of laws as straightforward descriptions of “Humean” regularities relating properties that do not carry any modal commitments. If we think instead of the law as describing the *component* of the gravitational force on *m1*which is *due to* mass *m2 ,* we have a much more accurate description of the content of the law. Note, however, that this is no longer a description of a “Humean” regularity characterized in non-modal terms, since “due to” and perhaps “component” are not properly Humean. [↑](#footnote-ref-8)
9. This relativization to a domain is not just the triviality that laws hold when they hold; it rather involves the claim that laws would continue to hold if non-actual conditions (and non-actual processes leading to these conditions) within their domain of invariance were to be realized, where (at least often) this domain can be given an independent specification—in physics this is often done by specifying length or energy scales in which the law holds. [↑](#footnote-ref-9)
10. Perhaps one might think of the relationship between current effective theories and the deeper theories that underlie them is in terms of a kind of robustness or invariance of the former under variations in the latter, but where the invariance is conceptual or mathematical in nature, having to do with the fact the effective theory continues to hold under variations in some mathematical space of possible deeper theories. This sort of invariance is different from the more “empirical” variety considered in the body of this paper. I lack the space to explore it here. In any case, this sort of grounding is very different from what metaphysicians of science have in mind when they talk about “grounding”. [↑](#footnote-ref-10)
11. Note also that effective laws (obviously) can be recognized as having that status (on the basis of features F they possess) in the absence of information about the more fundamental laws that underlie them. So we can ask the question of what those features F are. Relative invariance is my candidate for such a feature. [↑](#footnote-ref-11)
12. Contrast this with philosophical accounts of laws that, like the BSA, do not begin with a distinction between laws and initial conditions but instead impose a general simplicity constraint that operates on an undifferentiated Humean mosaic. On such conceptions simplicity in connection with laws and simplicity in connection with initial conditions are treated in the same uniform way. See Woodward, 2013 for some difficulties to which this leads. Note also that philosophical accounts of unification that do not begin with a distinction between laws and initial conditions and instead assess degree of unification just by counting the number of independently acceptable premises (or something similar) will fail to capture the different role played by unification considerations with respect to laws and initial conditions. [↑](#footnote-ref-12)
13. For example, philosophers who wish to ground laws in dispositions typically retain something very like this picture of laws. [↑](#footnote-ref-13)
14. This is a point that is emphasized in Wilson, forthcoming. [↑](#footnote-ref-14)
15. Cartwright (e.g., 1999) has repeatedly observed that (i) a great deal of specific structure (which she calls a nomological machine) must be present in a system before it generates (what I would describe as concrete and specific) regularities. Apparently influenced by the philosophical tradition that associates laws with such regularities, she concludes that laws themselves require such structure in order to hold. Laws thus have a sort of derivative status—derivative on the machines that generate them, whose behavior is due to capacities that are assembled in a particular way. I agree with the initial observation (i) but for exactly that reason would resist the association of laws with highly concrete regularities. [↑](#footnote-ref-15)
16. At the conference at which I presented this paper, it was noted that several recent accounts of laws treat the Past Hypothesis (PH) as having nomological status (and as central to an acceptable account of lawhood), despite the fact that PH looks in some respects as a claim about initial conditions. It was suggested that this showed I was wrong to attach any great importance to the contrast between laws and initial conditions. Without commenting on PH, I think this is the wrong moral, for the reasons described above. Assuming for the sake of argument that PH is defensible science, if it blurs the line between lawful and non-lawful in the way described, the conclusion we should draw is that this is a context in which the notion of law no longer fruitfully applies, not one in which we are dealing with something that is both a law (or nomological) and a claim about initial conditions. [↑](#footnote-ref-16)
17. An anonymous referee suggests that the use of this example to criticize the BSA assumes that there is a fact of the matter about whether *L1* or *L2* (or neither) is a law even if the experiment is never done. I agree. The referee infers from this that, on my view, “the actual pattern of physical facts does not alone fix what the laws are, since nothing about the world without the experiment determines which law is correct” and that, consequently, which law is correct “must depend on some non-Humean fact”. I lack the space to respond in detail, but let me make the following remarks (See Woodward, 2013 for more discussion.) First, the notion of “fixing” here is metaphysically loaded (and in my opinion unclear). If we instead ask the clearer question of what sorts of information is used to discover or infer to laws, the answer is that in actual practice this involves a mix of claims that may be “Humean” and non-modal and other claims that carry modal or causal or nomological commitments. (I assume for the sake of argument that the contrast between “modal” and “non-modal” is clear, even though I think this is not always the case.) The pattern of inference is: Non-modal information N+ modal information M1-🡪 new modal information M2. As far as inference goes, it is indeed true that the non-modal information N is not sufficient to fix (or as econometricians would say) “identify” M2. But this does not mean that the nomological facts in M2 are independent of “everything” in the world or all “the physical facts”, unless we simply identify the expressions in quotes with N, which seems arbitrary. When I do an experiment and use the result to (reliably and correctly) support a claim about a law, this use of the experiment requires that certain modal (or causal or nomological) claims about the processes generating the experimental result be true—for example, claims about the absence of confounders, that the experimental result has been produced in certain ways and so on. I see no reason to deny that these are “physical facts”, having to do with how matters stand in the world. Nor do I see any reason to suppose it must be possible to fully translate these modal claims into non-modal claims, in the absence of the actual exhibition of such a translation.

    The second thing to be said is that the criticism makes assumptions about modal claims needing truth-makers of the sorts postulated by metaphysicians-- assumptions that I would reject, for reasons described in Section 7.

    [↑](#footnote-ref-17)
18. It is worth underscoring that these sorts of considerations contrast with the metaphysical arguments usually offered for and against a grounding role for dispositions. The argument described above is instead methodological— the law framework is methodologically superior for the reasons described. [↑](#footnote-ref-18)
19. The idea that the laws govern is also connected by some to the notion that they have their source in a divine lawmaker who prescribes rules that nature must obey. Contrary to what some have suggested, I don’t think that any such theological connection is really assumed in discussions of law in modern science. [↑](#footnote-ref-19)
20. I thus put aside, for reasons of space, any discussion of whether the BSA and similar accounts provide a “metaphysical explanation” of some kind for laws and physical modality, as claimed by, e.g. Loewer, 2012. For a variety of reasons I don’t think that they do, but this is a matter for another paper. [↑](#footnote-ref-20)
21. A further remark: We should distinguish the idea that claims about physical modality, invariance and so on should be responsible to how matters stand in the world, which I endorse, from the idea that we can illuminate modal claims by postulating special metaphysical entities or relationships to serve as truth-makers for them, which is what the advocate of non-Humean stuff claims. On my view, modal claims can be true because of how matters stand in the world without having the simple discrete truth-makers or correspondents envisioned in talk of relations of necessitation between universals and so on. And one can be a non-Humean about modal claims, in the sense that they are not reducible to claims about Humean regularities, without postulating non-Humean stuff as truth-makers for such claims. (It’s the “stuff” part of “non-Humean stuff “ that the invariance-based account rejects.) Analogously, claims about the probability of red on spins of a roulette wheel can be true even though there is no metaphysical item, chance, present in the machine to serve as truth-maker. [↑](#footnote-ref-21)