The Governing Conception of Laws

Nina Emery
emery@mtholyoke.edu

Abstract: In her paper, "The Non-Governing Conception of Laws," Helen Beebee argues that it is not a conceptual truth that laws of nature govern, and thus that one need not insist on a metaphysical account of laws that makes sense of their governing role. I agree with the first point but not the second. Although it is not a conceptual truth, the fact that laws govern follows straightforwardly from an important (though under-appreciated) principle of scientific theory choice combined with a highly plausible claim about the connection between scientific theory choice and theory choice in metaphysics. I present and defend this argument and then show how the resulting understanding of governance gives rise to an especially strong version of recent explanatory circularity arguments against Humeanism about laws of nature. Finally, I present three options for a further understanding of the governance relation that are compatible with my argument.

Introduction

According to the governing conception of laws, laws of nature are not mere summaries of particular matters of fact. Instead they govern, or determine (in some metaphysically robust sense of 'determine') what the particular matters of fact are. On the governing conception of laws, laws "*do* something—they govern what goes on in the universe" (Beebee 2000, p. 580). Laws that govern are "entities that *produce* or *govern* and thereby *explain* the evolution of events" (Loewer 2012, p. 118); they are "responsible for (i.e., produce, necessitate, etc.) the regularities exhibited in nature" (Hildebrand 2019, p. 3).

In her influential paper, "The Non-Governing Conception of Laws," Helen Beebee (2000) argues that it is not a conceptual truth that laws of nature govern. Therefore, she says, one need not insist on a metaphysical account of laws that makes sense of their governing role. I agree with the first point but not the second. For although it is not a conceptual truth, the fact that laws govern follows straightforwardly from the combination of an important (though under-appreciated) principle of scientific theory choice with the highly plausible claim that the

principles of scientific theory choice ought to constrain theory choice in metaphysics. In what follows, I present and defend this argument and show how it is compatible with several ways of understanding the governance relation itself.

There are two important upshots of this argument for our thinking about laws of nature. The first is that the default position for those philosophers who wish to be scientifically respectable in their metaphysical theorizing should be to endorse the governing conception of laws. The second is that being a Humean about laws of nature is significantly harder than is usually thought. Anyone who wishes to remain a Humean in light of this argument must either (i) accept some fairly surprising claims about the relationship between science and metaphysics, (ii) justify a fairly robust reinterpretation of standard scientific practice and the historical examples that support my claims about that practice, or (iii) accept some fairly unintuitive claims about the nature of explanation. Any of these consequences is surprising and substantive enough that they should move a would-be Humean to revisit the initial motivation for their view—is Humeanism truly so attractive, are its benefits truly so impressive, that they warrant these consequences?

In addition to these domain-specific upshots, the argument demonstrates and defends a more general methodological point, which stands as a challenge not just to Humeans, but to all of us who wish to be scientifically-respectable in our philosophical theorizing. Being scientifically respectable is not just a matter of making sure that the commitments of one's favored philosophical theory do not conflict with the *content* of our best scientific theories. In addition, we need to pay attention to the *principles* that play a role in scientific theory choice. And the way in which those principles impact various philosophical debates is often surprising.

Here is a plan for what follows. In sections 1 and 2, I show how a certain principle constrains theory choice in physics. In section 3, I argue that, given that that principle constrains theory choice in physics, it ought to constrain theory choice in metaphysics as well. In section 4, I show how the principle in question has an important general consequence for one's metaphysics of laws: it requires a governing conception of laws. In section 5, I show how this general consequence affects the debate between Humeans and non-Humeans about laws of nature. In section 6, I lay out several accounts of governance itself that are compatible with the argument in sections 1-4. I close, in section 7, with some thoughts about how this type of argument demonstrates that being scientifically-respectable in our philosophical theorizing is not as straightforward as many philosophers seem to think, and with some suggestions for how all of us, regardless of our particular commitments regarding, for instance, the metaphysics of laws, ought to proceed when evaluating metaphysical theories with an eye toward their coherence with our best science.

1 The pattern-explanation principle

In this section I will argue that a certain principle—I will call it *the pattern-explanation principle*—constrains theory choice in physics. The rough idea behind the pattern-explanation principle is that one of the most serious flaws that a scientific theory can have is to leave a well-established pattern unexplained. Indeed, even if the only way in which one can explain some well-established pattern is to introduce a type of entity that is metaphysically weird or novel, it is worth the cost of introducing such entities.

More formally, here is the initial version of the principle:

> *The pattern-explanation principle — initial version*. We ought not leave a well-established pattern unexplained, even if they only way to explain that pattern is to introduce some type of entity that is metaphysically weird or novel.

I have defended versions of the pattern-explanation principle before (Emery 2017 and Emery 2018), and for my own part I take this principle to be a fairly obvious component of scientific theory choice. But since, as I will show below, the principle has fairly significant consequences for contemporary metaphysics, a more detailed defense is warranted. In what follows, then, I will argue for the pattern-explanation principle by examining three historical cases of scientific theory choice in which metaphysically weird or novel entities were introduced. A natural reading of each of these cases suggests that the reason why these entities were introduced was that otherwise a well-established pattern in the data would go unexplained. At the very least, then, these examples, taken together, put the burden clearly on those who wish to deny the pattern-explanation principle to articulate an alternative story about what is going on in each of these cases.

Here is the first example. In the early 20th century, experimental physicists observed that energy and momentum appeared to be lost during a certain type of radioactive decay, called *beta decay*. The total energy and momentum of the observed particles before the decay was not equal to the total energy and momentum of the observed particles after the decay. This pattern was surprising—it appeared to be a violation of the conservation of energy and of momentum—but by the late 1920s it was well established in the data.

In 1930, Wolfgang Pauli suggested that the explanation for this apparent loss of energy was that the particles that scientists observed after the decay were not in fact all of the particles that were produced.[1] There was, in addition, a theretofore unobserved particle—the *neutrino*—

[1] See Pauli's open letter to the December 1930 group meeting in Tübingen, reprinted in *Physics Today* 31: 9 (1978). In this letter, Pauli referred to the unobserved particle that he postulated as the "neutron". Enrico Fermi later introduced the name "neutrino".

that was produced by beta decay, and the energy and momentum of the neutrino that was produced was such that once it was included, energy and momentum were conserved

Pauli's hypothesis was initially controversial—Pauli himself called it a "desperate remedy." Why was this? For all that has been said so far, several factors may have been at play. For one thing, there was no direct experimental evidence for the existence of neutrinos. For another, neutrinos are strange in several ways. They were thought to be massless,[2] to have no charge, and to barely interact with other particles. As Laurie M. Brown, a physicist and historian of physics writes, when Pauli first proposed the neutrino, "any other elementary constituent [besides the proton and electron] of the atom would have been considered superfluous, and to imagine that another might exist was *abhorrent* to the prevailing natural philosophy" (Brown 1978, my emphasis).

When Pauli first suggested his hypothesis, there was also an alternative explanation of the apparent energy and momentum loss in beta decay. This alternative hypothesis, which had been proposed by Niels Bohr, was that the conservation of energy and the conservation of momentum were probabilistic laws similar to the second law of thermodynamics.[3] Although these principles were very likely to hold in most scenarios, there was at least some probability of their being violated. Bohr's suggestion was that the way in which these violations occurred were such that we should expect the observed energy loss beta decay.

However controversial Pauli's proposal was initially, by the mid-1930s, the neutrino had gained widespread acceptance.[4] What had changed in the intervening years? It was still the case that there was no direct experimental evidence for the existence of neutrinos.[5] And it was still the case that neutrinos were weird and surprising in the ways described above. Instead the key development seems to have been that in 1933 there were new experimental results that showed that Bohr's alternative explanation for the apparent energy loss in beta decay was not viable.[6]

---

[2] Experiments in the late 1990s showed that neutrinos in fact have non-zero mass.

[3] See the discussion in Brown 1978.

[4] Pauli himself seems to wavered with respect to how plausible he found his own hypothesis between 1931 and the fall of 1933. His remarks at the Seventh Solvay Conference in October 1933 seem to mark the turning point at which is fully confident. See Brown 1978, which includes a translation of Pauli's 1933 remarks.

[5] Direct experimental evidence would not be obtained until the Cowen-Reines experiment in 1956.

[6] These experimental results were due to Charles Drummond Ellis and Nevill Mott who showed, in mid-1933, that the beta-ray spectrum has a sharp upper limit. See the description and citations in Brown 1978.

Another important development that happened around this time is that in 1934 Enrico Fermi published a quantitative theory of beta decay built around the neutrino. (See Wilson 1986, which contains an English translation of Fermi's 1934 paper, which was published in German in *Zeitschrift für Physik.)* In conversation I have sometimes had philosophers of science suggest that it was Fermi's development of this theory, as opposed to the ruling out of Bohr's alternative hypothesis, that made the neutrino acceptable to physicists. My reading is that what Fermi's theory did was show that Pauli's hypothesis could in fact do the explanatory work for which it was designed, and thus the suggestion that Fermi's theory was an important step in the acceptability of the neutrino is not in conflict with the pattern explanation principle. For what it is worth, there is also an oft-repeated anecdote about Fermi's paper, according to which it was initially rejected by *Nature* because "it contained speculations too remote from reality to be of interest to the reader" (see Pais 1986 p. 418 and Close 2012, p. 24). This suggests that Fermi's development of the theory itself was not enough to make the neutrino acceptable.

That scientists' attitudes toward the neutrino would change dramatically after these new experimental results ruled out Bohr's alternative explanation (even though little else had changed), would, of course, make perfect sense if the pattern-explanation principle was a constraint on theory choice in fundamental physics. Neutrinos may have been strange, and the evidence for them indirect, but once scientists needed them in order to explain the pattern of apparent energy and momentum loss in beta decay, they were accepted.

In this particular case, one might make the claim that the sort of entity being introduced, however strange, was still in some sense a member of a group of entities that was already accepted by physicists—however unusual a particle, the neutrino was still a particle. But other examples show that when faced with a well-established pattern that would otherwise go unexplained, physicists are also willing to introduce entities that are largely or even wholly novel. The physicists introducing these entities may have hypotheses about what they are, but they admit that these hypotheses are tentative and likely to be overturned. What they seem to be sure of is that there is *something* that explains the pattern in question, whatever sort of thing it turns out to be.

Along these lines, consider a second historical example: the electromagnetic field as introduced by Faraday in 1852 and further developed by Thomson and Maxwell in the later half of the 19th century. Previously, physicists observing various kinds of electromagnetic phenomena had thought that such phenomena had to be explained by some kind of action at a distance, similar to the way that, at the time, gravitational phenomena was thought to be explained. But Faraday had experimental evidence that he thought suggested that electromagnetic phenomena were importantly different than gravitational phenomena, and that showed that the former were not apt for explanation by action at a distance.[7] (In particular Faraday was moved by the observation that electromagnetic forces were exerted along curved lines, and by the fact that at least some electromagnetic forces were affected by the medium between the object exerting the force and the object that the force was acting on.) Instead, Faraday suggested, electromagnetic phenomena must be explained by an electromagnetic field.

What was an electromagnetic field? Faraday himself put forward two different hypotheses about how it might be understood. According to one, the space between the object exerting the magnetic force and the object upon which the force was acting was permeated by an ether of contiguous, unobservable particles which transmitted the force from the acting object to the object being acted upon. According to the other, there were physical lines of force which existed independently of any particles and which connected the acting object to the object being acted upon.[8] Maxwell, meanwhile suggested that the electromagnetic field should be understood as a fluid filled with vortex tubes, where the arrangement of the tubes corresponded to the direction of the lines of the field and the angular momentum of the tubes corresponded to the intensity of

[7] See Faraday 1852, especially pp. 413 - 417; Maxwell 1861; and Hesse 1962, especially chapter 8.
[8] The discussion in Harman 1982, p. 78 is especially helpful in understanding these proposals.

the field.[9]

Both Faraday and Maxwell, however, were insistent that their accounts of the electromagnetic field were tentative at best. And certainly on any of these accounts, the electromagnetic field was a novel entity, and one whose metaphysical nature was not clearly understood. To posit such an entity was surely metaphysically costly—these physicists would have avoided it if they could. Nonetheless Faraday and those who followed him seemed to be convinced that there had to be something that explained electromagnetic phenomena, and given that it could not be accounted for in terms of any other, previously accepted entities, they were, however reluctantly, willing to introduce something wholly novel. Again this would make sense if the pattern explanation principle constrained theory choice in physics.

Nor is the case of the electromagnetic field a historical anomaly. If anything the point is even more vividly illustrated by a final, contemporary example. In the late 1990s, observations from the Hubble Telescope showed that the rate at which the universe is expanding is accelerating. According to the NASA Science website "No one expected this, no one knew how to explain it. But something was causing it." Indeed the site goes on to say,

> "Theorists still don't know what the correct explanation is, but they have given the solution a name. It is called dark energy. What is dark energy? More is unknown than is known. We know how much dark energy there is because we know how it affects the universe's expansion. Other than that, it is a complete mystery."[10]

Here again we have the introduction of an entity that is weird—in this case an entity about which scientists know almost nothing—because without that entity there would be no explanation available for a well-established pattern in the data. In this case, theorists admit that they don't have much of an idea at all as to what dark energy is. They have hypotheses, of course, of one sort or the other. But any such hypotheses are tentative at best. What scientists seem to be convinced of is that there is something that explains the accelerating rate of expansion of the universe, and they use the name 'dark energy' to pick out that thing, whatever it

---

[9] Harman 1982, p. 89. There is some controversy over how serious Maxwell was being when he proposed this account of the electromagnetic field in terms of vortex tubes. He sometimes said explicitly that this account was merely supposed to be illustrative or suggestive. But he was also explicit that the data he had collected required some kind of explanation. See the discussion in Harman ibid, especially p. 92.

[10] "Dark Energy, Dark Matter", *Nasa Science*, https://science.nasa.gov/astrophysics/focus-areas/what-is-dark-energy. See also Carroll 2007, lectures 14 - 17. Note that I am using the term 'dark energy' in an expansive sense that include the possibility that dark energy just is the vacuum energy (or Einstein's cosmological constant). This seems to be relatively standard both in early discussion of dark energy (e.g. Turner 2001; n.b. Turner is often credited with coining the term 'dark energy') and in more recent summary discussions (e.g. Carroll 2007), but note that some may prefer to reserve the term 'dark energy' for those hypotheses that would provide a dynamical explanation that is distinct from the vacuum energy hypothesis. My reading of the literature (supported by the citations above) there is not a consensus regarding the existence of dark energy if the term is being used in this more restrictive, dynamical sense.

is. Yet again, we see here an attitude would make perfect sense if the pattern-explanation principle constrained scientific theory choice.

The thing that all of these examples have in common is that they involve the introduction of entities that are or were (at the time at which they were accepted) metaphysically weird or novel (or both). As such, the acceptance of these entities was a serious cost of the theory in which they appeared. Nonetheless, that cost was considered worth paying. Why? A highly plausible answer, especially when these cases are taken together as a group is: Because without such entities, well-established patterns in the data would go unexplained.

These are, of course, only three examples, and there is far more historical and scientific nuance in each case than I have been able to develop here. I am not claiming, therefore, that these examples prove anything decisive. But taken together these examples are at least highly suggestive. The burden is on those who want to reject the pattern-explanation principle to come up with new examples, or a reinterpretation of these examples, that supports their alternative view.

2 Pattern-explanation as metaphysically robust explanation

The three examples above give us good reason to think that the pattern explanation principle constrains scientific theory choice. The reader will notice, however, that I have said nothing so far about the notion of explanation that is at play in the pattern explanation principle. And given how multi-faceted the notion of explanation is, we need to say at least something more about that notion if the principle is going to have any substance.

Consider, for instance, the following four ways in which we naturally use the word 'explains'.

> We say that A explains B when A provides us with some understanding of B.
>
> We say that A explains B when A shows how B is part of a broader pattern of phenomena.
>
> We say that A explains B when A causes B.
>
> We say that A explains B when A grounds B.[11]

[11] I do not claim that this list is exhaustive. I take the idea that explain involves showing how an event fits into a broader pattern to capture the central idea behind a unification account of explanation, though I'm in principle open to there being a notion of explanation as unification that goes beyond pattern subsumption. See the next footnote for more.

These ways of using the word 'explains' are fairly heterogenous, spanning notions that are relatively metaphysically thin and largely subjective, like the notion of *understanding for creatures like us*, to notions that are metaphysically substantive and seemingly objective, like causal relations and grounding relations.

I think it would be a mistake to argue about which of these ways of talking captures the correct notion of explanation. Certainly in the case at hand we need not engage in anything so contentious. Instead we should focus on the question of what notion of explanation is at play in the pattern explanation principle. Insofar as a well-established pattern gives rise to an explanatory burden, what sort of explanation is required in order to discharge that burden?

In order to answer this question we can look again at the historical examples discussed above. Although these examples don't seem to support a definitive, singular reading of the notion of explanation at play in the pattern explanation principle, they do give us some insight into that notion. Here, for instance, is a fairly obvious point: the key feature of all three of those examples was that the entities that were introduced in order to explain the pattern in question were metaphysically weird or novel or both; as a result, those entities cannot have been said to do much by way of providing us with any further understanding of the phenomena in question. Something other than mere understanding must be required in order to discharge the explanatory burden that these patterns create.

More generally, I claim that the historical examples discussed in the previous section give us good reason to think that when we are faced with a well-established pattern in the data, what we require is what I will call a *metaphysically robust explanation*—an explanation in which the explanans identifies the *reason why* the explanandum occurred. Paradigm cases of metaphysically robust explanations are explanations that identify the cause or the ground of the explanans. Understanding, however, is neither necessary nor sufficient for a metaphysically robust explanation—sometimes the reason why something occurs is beyond our understanding and sometimes our understanding can lead us astray with respect to the reason why something occurs. (I will say something more about the fourth kind of explanation mentioned above—pattern subsumption—in a moment.)

My claim, then, is that the three examples discussed above do more than just support the initial version of the pattern-explanation principle. They also support the following version of that principle:

> *The pattern-explanation principle — final version*. We ought not leave a well-established pattern without a metaphysically robust explanation, even if they only way to give a metaphysically robust explanation of that pattern is to introduce a type of entity that is metaphysically weird or novel.

I find the notion of metaphysically robust explanation to be useful and thus find this way of phrasing the pattern-explanation principle to be illuminating. But I want to emphasize that the role that the metaphysical robustness of an explanation plays in my argument is only the role of a methodological shortcut. The key claim that I am making here is that the notion of explanation at play in the pattern explanation principle should be determined by the examples that give us reason to endorse that principle in the first place. Suppose that we observe some well-established pattern, and someone tries to say that an explanation of type E is sufficient to explain that pattern. What I have suggested above is that a good way of testing whether an explanation of type E is in fact sufficient is to ask whether explanations of type E are metaphysically robust—whether they identify the reason why the explanandum occurred. But insofar as one finds the questions about the metaphysical robustness of an explanation confused or otherwise difficult to adjudicate, one can skip it entirely and instead ask: would an explanation of type E have been sufficient to explain the observed patterns in the examples discussed in section 1? If not, then explanations of type E are not sufficient to explain the pattern in question in the sense of explanation that is at play in the pattern explanation principle.

Here is an example. (One that is relevant to the discussion of Humean accounts of laws of nature in section 4.) Suppose one observes a bunch of Fs, all of which are G, and suppose one tries to explain that pattern by claiming that *all* Fs are G. This corresponds to a pattern subsumption account of explanation according to which if A shows how B fits into a broader pattern then A explains B.[12]

Are pattern subsumption explanations metaphysically robust? If A shows how B fits into a larger pattern, does A thereby identify the reason why B? I think the answer to this question is pretty clearly no. We can show how an event fits into a broader pattern of events without thereby identifying the reason why that even occurred. But we need not rely on this claim. We can consider instead the question of whether pattern subsumption would have been sufficient to explain the sorts of examples that gave us reason for endorsing the pattern explanation constraint to begin with.

Consider, for instance, the fact that in all of our observations the rate of expansion of the universe is accelerating. Here are two ways of trying to explain that pattern. First, one could introduce an entity as strange and poorly understood as dark energy. Second, one could simply claim that the rate of expansion of the universe is *always* accelerating. Surely if the second route had been a viable way of discharging the explanatory burden created by our observations,

[12] The idea that Humean laws might explain by way of pattern subsumption is discussed in Bhogal ms. Sometimes Humeans claim that laws explain by unifying without giving the kind of detailed account that Bhogal gives (see, e.g. Loewer 1996), which of course leaves open the possibility that these other Humeans have some alternative account of explanation as unification in mind. That is fine. I am not arguing here that Humeans laws cannot explain. My argument is just that in order to do so, they need to give an account on which laws provide metaphysically robust explanations in the sense required by the examples in section 1. If the Humean can accomplish this by making use of some version of the unificationist account of explanation, that doesn't undermine my argument. (It will mean, however, that the Humean must face the circularity worries described in section 4.)

scientists would have taken it. But they didn't. This indicates that mere pattern subsumption is not sufficient to discharge the explanatory burden created by a well-established pattern.

Note that nothing that I have said here rules out the possibility that there are genuine explanations that are not metaphysically robust. I am happy to agree that explanations that merely facilitate understanding or subsume some phenomena under a broader pattern are genuine explanations. What I am claiming is that insofar as there are non-metaphysically-robust explanations, they are not sufficient to discharge the explanatory burden created by a well-established pattern. When one observes such a pattern, one is pushed to identify the reason why the pattern occurs. Indeed the explanatory burden generated by such patterns is so substantial that it warrants the introduction of metaphysically weird or novel entities in order to establish that there is *some* reason why that pattern occurs, even if, all else being equal, we would prefer to keep such entities out of our metaphysics.

3 From physics to metaphysics

So far, I have argued that the pattern-explanation principle constrains theory choice in physics. In this section I will argue that if the pattern-explanation principle constrains theory choice in physics, then it ought to be a constraint on theory choice in metaphysics as well.

The argument here is straightforward. Notice first that there is a widespread consensus among contemporary metaphysicians that the *content* of our best scientific theories ought to constrain theory choice in metaphysics. But one can have no good reason for thinking that the *content* of our best scientific theories should constrain theory choice in metaphysics if one does not also think that standard scientific *practice* constrains theory choice in metaphysics as well. Insofar as one thinks that standard scientific practice functions via principles that do not track the facts about the world that metaphysicians are interested in, then why would one think that the content of the scientific theories produced by that methodology should have any bearing on our metaphysical theorizing?

It follows that if one agrees with the widespread consensus that the content of our best scientific theories ought to constrain theory choice in metaphysics, then one ought to think that the principles that constrain theory choice in fundamental physics ought to constrain theory choice in metaphysics as well. This conditional claim is, I think, already strong enough to make the conclusion of my argument substantive. Many if not most philosophers who previously leaned toward Humeanism about laws or expressed skepticism about the notion of governance will agree that one ought not adopt a metaphysical theory if it conflicts with our best scientific theories. So those very philosophers ought to think that the principles that constrain theory choice in physics constrain their own theory of laws, and they cannot avoid the challenge posed by the pattern-explanation principle. Either they find a way of arguing against the principle—

which involves coming up with an alternative account of the examples described in section 1. Or they find a way to accept the consequences discussed below.

But for those philosophers who are less committed in this regard, it is perhaps worth saying a bit more about the sort of background picture that might motivate the consensus that our metaphysical theorizing should be constrained by the content of our best scientific theories. The most natural such background picture is one on which metaphysics and science have the same aim—to accurately describe objective reality—and use the same tools to pursue that aim, but to a different degree. Scientists focus primarily on questions which they suspect will turn on the collection of complex empirical data, and for which the extra-empirical factors at play are relatively straightforward, whereas metaphysicians work primarily on questions where the relevant empirical data is widely accepted, but the extra-empirical factors are controversial.

This sort of background view nicely accounts for a number of facts about the relationship between physics and metaphysics, including the fact that some debates that were once solely investigated by the latter later came under scrutiny from the former (e.g. the nature of time), and the fact that there are many debates that seem to be informed by both physics and metaphysics (e.g. the question of whether there is a fundamental level). It also has the straightforward consequence that the principles that constrain scientific theory choice should constrain metaphysical theory choice as well.[13]

4 What this tells us about laws of nature

So the pattern-explanation principle constrains theory choice in physics. And given that it constrains theory choice in physics it ought to constrain theory choice in metaphysics as well. What does this tell us about laws of nature? I claim that it shows that laws must govern. Here is why.

Suppose we are living in a Newtonian world. It is a law that $f = ma$. In such a world, in every observation that we make, it is always the case that the net force on an object equals the mass times the acceleration. That is a well-established pattern. Here is a question that it is natural to have: what is the *reason why* that pattern occurs? What, in other words, explains that pattern, in a metaphysically robust sense of explanation? A natural response to this question is to say that the reason why the pattern occurs is that it is a law that $f = ma$. To endorse this response is to endorse the governing conception of laws.

Newton's second law as a governing law. The fact that it is a law that $f = ma$ is the

[13] The argument in this section is discussed in detail in Emery ms.

reason why $f = ma$ in all observed cases.[14]

According to the governing conception of laws, laws are the reason why things happen the way that they do. They aren't mere summaries of events. Instead they explain those events, in a metaphysically robust sense. Let P be any well-established pattern. If it is a law that P, then, according to the governing conception of laws, the fact that it is a law that P is the reason why P.[15]

Now, there are many questions that one might have about the governing conception of laws. One might wonder, what is a law anyway? How can we be sure that it is the right kind of thing to play this explanatory role? What if in order to play this explanatory role, laws have to be entities of a sort that we would prefer not to allow into our metaphysics? What if in order to play this explanatory role, laws are such that we cannot give any metaphysical analysis of them at all?

These are all good questions. We would like to be able to answer them in a satisfying way. But according to the pattern explanation principle, regardless of whether and how we end up answering them, none of these questions can give us a good reason for resisting the governing conception of laws, at least not until we can come up with alternative explanations of the patterns in the data that the laws are supposed to explain. One cannot, for instance, reject the governing conception of laws in favor of the following strategy:

> *The no-explanation strategy.* There is no explanation for the fact that $f = ma$ in all observed cases.

Why not? Because this would violate the pattern explanation constraint.

And note that not just any alternative explanation will suffice. In order to satisfy the pattern explanation constraint, one needs an alternative explanation that is *metaphysically robust*. One cannot, for instance, reject the governing conception of laws in favor of:

> *The pattern subsumption strategy.* The explanation of the fact that $f = ma$ in all observed cases is that $f = ma$ in *all* cases.

As argued in section 3, pattern subsumption is not sufficient to satisfy the type of explanation required by the pattern explanation principle.

It may seem surprising that we can arrive at the conclusion that we should accept the governing conception of laws without putting forward any account whatsoever about what laws

---

[14] It is worth noting that nothing important hinges on the 'governing' label. If one has in mind a different notion of governance, one is welcome to use different terminology. All of the consequences discussed in the next section will still follow.

[15] More specifically, they determine patterns of events. Do they do so directly? Or do they determine patterns of event by determining the individual instances that constitute those patterns? I don't take a stand on this here.

are. But it follows from the pattern-explanation principle that if the only way to explain the pattern of instances of a law is by appealing to the law itself, then it doesn't actually matter what sort of entities laws are—it doesn't matter how weird or novel they may turn out to be or how little we understand them—we can be sure nonetheless that they exist and that they provide metaphysically robust explanations of patterns of their instances. If they did not, those patterns would go unexplained and the pattern-explanation principle would be violated.

Of course, nothing that has been said so far forecloses the possibility of giving a reductive, or at least an illuminating, metaphysical account of laws. Surely everyone who is party to the debate should think that, all else being equal, such an account is preferable to an account that takes laws to be primitive or otherwise mysterious. The upshot of the argument in this section is merely that *even if* it turns out that we can't give a reductive or illuminating account of laws, we still must accept their existence and we must still remain committed to at least one aspect of the role that they play—that they provide metaphysically robust explanations of patterns of their instances. Even if laws strike us as just as surprising and strange as the neutrino struck Pauli, even if we know as little about laws as Faraday knew about the electromagnetic field or contemporary cosmologists know about dark energy, we still have to accept laws—the kind of laws that can provide metaphysically robust explanations—into our metaphysics. To do otherwise would be to violate the pattern explanation principle. And that is not something that, as scientifically respectable metaphysicians, we ought to do.

5 The governing conception and Humeanism about laws

In the last section, I argued that laws must provide metaphysically robust explanations of patterns of their instances. In Beebee's terms, I have argued for the governing conception of laws. This argument did not rely on the idea that the governing conception is a conceptual truth. Instead it followed from a straightforward interpretation of standard scientific practice combined with a straightforward understanding of the relationship between science and metaphysics. On my view, this should be the starting point of any metaphysics of laws.

This much, I think, is already substantive. But in this section, I will show how my argument bears on the familiar debate between Humeans and non-Humeans about laws. In particular, I will argue it makes it much more difficult to be a Humean about laws of nature than one might previously have thought, and that it does so in a way that should be especially worrying to those Humeans who like to think of themselves as naturalists—who take scientific theorizing to be a paradigm case of successful inquiry into what the world is like. Those who are disinterested in the many iterations of the Humean/non-Humean debate should feel free to skip to the next section.

Why does my argument make it more difficult to be a Humean? Because it gives rise to an

especially difficult version of the circularity challenge for Humeanism as raised by, e.g. Armstrong 1983 and Maudlin 2007.[16] Versions of the circularity objection have been spelled out in great detail in the recent literature.[17] Here is the version that is made salient by the argument above.

The defining feature of Humean accounts of laws is that laws are in some sense nothing over and above the *Humean mosaic*, where the Humean mosaic is the distribution of categorical (non-nomic) properties throughout spacetime. It is natural to think that it follows from the fact that Humean laws are nothing over and above the mosaic that the following principle is true:

> *Mosaic to Laws*. The reason why the laws are what they are is because the mosaic is what it is.

In other words, the Humean mosaic provides a metaphysically robust explanation of the laws.[18]

But now notice that, given the argument above, we must also agree that the laws provide a metaphysically robust explanation of at least part of the mosaic—the part that corresponds to the pattern of instances of those laws.

> *Laws to Mosaic*. Part of the reason why the mosaic is what it is is because the laws are what they are.

Perhaps there are some parts of the mosaic (the unpatterned parts) that go without explanation or that have explanations that do not involve appeals to the laws. But there are also at least *some* parts of the mosaic that, given the argument in section 5, are what they are because the laws are what they are. The mosaic of a Newtonian world, for instance, consists of many, many instances in which $f = ma$. Why is that? As argued above, it must be because it is a law that $f = ma$.

Thus we have an explanatory circle: the laws provide a metaphysically robust explanation of part of the mosaic and the mosaic provides a metaphysically robust explanation of the laws. And this seems deeply problematic. If A is the reason why B, B cannot be part of the reason why A. At the very least, to accept such a circle is a serious theoretical cost.

What are the prospects for the Human in responding to the circularity challenge? First, they can try to insist that the circularity is not problematic. I won't say anything more about the

---

[16] Beebee 2000 also claims that the governing conception of laws is a key component of the supervenience challenges raised by Carroll 1994, Tooley 1977, and Menzies 1993. I won't discuss those challenges in detail here, but it is worth noting that if Beebee is correct, then this is a second way in which the argument that I have presented for the governing conception of laws will make it harder to be a Humean. One can no longer resist the supervenience objections by resisting the governing conception of laws that (according to Beebee at least) underlies those objections.

[17] In addition to Armstrong and Maudlin, see Lange 2013, Hicks and van Elswyck 2014, Miller 2015, Marshall 2015, and Roski 2017.

[18] If you're skeptical of the idea that Humeanism should be understood in this way, note that I will say more about this assumption below.

plausibility of this move below. If Humeans must take this route, that is surely a surprising and unintuitive cost. Second, they can try to avoid the circle. But notice that given my argument above, the Humean cannot avoid the circle by claiming that laws do not provide metaphysically robust explanations of the mosaic. They must instead claim that laws are not in fact explained by the mosaic. More carefully, given my argument, they must claim that the mosaic is not the reason why the laws are what they are. And while the view that the mosaic is not the reason why the Humean laws are what they are is plausibly compatible with the view that the Humean laws supervene on the mosaic, it is a surprising view nonetheless. If, according to the Humean, the mosaic is not the reason why the laws are what they are, then why *are* the laws what they are? It is unclear how the Humean will answer this question. Third, and finally, the Humean can find some way of avoiding my argument for the governing conception of laws. Doing so will require either a surprising reinterpretation of the examples that I gave in section 1, or a surprising claim about the relationship between science and metaphysics that is at odds with the view that I described in section 4.

One important thing to notice here is that this way of presenting the circularity objection avoids disputes over whether Humeans should frame their account of laws in terms of grounding. The recent trend, especially following Schaffer 2008, and Loewer 2012, has been to understand Humeanism as the view that laws are grounded in the Humean mosaic.[19] As grounding talk started to seem like a promising way of making sense of "nothing over and above" locutions throughout metaphysics, it only made sense to apply it in this case as well. But recently some philosophers, including Miller 2015, have suggested that it may be a mistake to think of Humean laws in this way.[20] These philosophers sometimes suggest that the circularity objection may be avoided simply by returning to an account on which what it is to be a Humean about laws is merely to think that laws supervene on the mosaic. This move may be especially attractive to those who wish to stick close to the views of the most famous proponent of Humeanism, David Lewis, as well as those with Humean inclinations who are skeptical of grounding claims in general.[21]

But what the argument above shows is that we can set discussions of Lewis's intentions and of the plausibility of grounding claims in general, and in this particular case, aside. Regardless of how those discussions turn out, Humeans face a serious challenge to do with

---

[19] Beebee 2000 also includes grounding locutions although it is unclear whether ultimately she thinks that the Humean is committed to thinking that laws are grounded in the mosaic.

[20] See also Hall ms and Kovacs ms. It may be that a non-trivial proportion of metaphysicians interested in laws never endorsed the shift to grounding-talk to begin with. Consider, for instance, the SEP article on laws of nature, authored by John Carroll (2016) which exclusively presents the Humean view in terms of supervenience, and makes no mention of grounding.

[21] Although Lewis occasionally used language suggesting that the Humean was committed to some kind of reduction, he may have thought that in some cases asymmetric supervenience—such as the asymmetric supervenience of Humean laws on the Humean mosaic—was itself sufficient for reduction. The discussion in Miller 2015, especially footnote 8 is helpful here.

explanatory circularity. Either they say that the mosaic is the reason why the laws are what they are, in which case circularity threatens. Or they say that the mosaic is not the reason why the laws are what they are, in which case they face the question: why are the laws what they are? Unless they have some way of answering this question, or some way of convincing us that it need not be answered, we ought not be Humeans.

6 What is governance?

In sections 1 through 4 of this paper I argued that laws govern in the following sense: if P is some well-established pattern and it is a law that P, then the fact that it is a law that P is the reason why P.[22]

The fact that laws provide metaphysically robust explanations in this way is, on my view, the core of the idea that laws govern. But I'm sympathetic to the idea that we should at least attempt to provide a further account of the governance relation, and indeed I think that the argument above suggests several options for such an account.

Start from the fact that the key feature of governance is that the governing relation supports metaphysically robust explanatory relations. One way of putting this is that the governing relation is a *dependence relation*, where a dependence relation is just a relation that supports metaphysically robust explanation. As noted above, two other paradigm examples of dependence relations are causation and grounding. A relatively natural move, then, would be to build an account of governance on these other, already widely accepted, dependence relations. There are three ways of doing this.

The first two ways of building an account of governance on already widely-accepted dependence relations are obvious: we could simply say that governance is just a type of causation or we could say that governance is just a type of grounding.

> *Governance as Causation*. To endorse a governing account of laws is to say that the fact that it is a law that P is the reason why P in the sense that the fact that it is a law that P causes P.

> *Governance as Grounding*. To endorse a governing account of laws is to say that the fact that it is a law that P is the reason why P in the sense that the fact that it is a law that P grounds P.

[22] As noted above, this claim explicitly leaves open whether the governance relation holds directly between the fact that it is a law that P and P, or whether the governance relation instead holds between the fact that it is a law that P and individual instances of P, where the combined individual instances of P are then are the reason why P.

The obvious advantage of endorsing one of these accounts is that many of us are already committed to causation and grounding and to the idea that causation and grounding support metaphysically robust explanations. So if governance just is a type of causation or if governance just is a type of grounding then many of us aren't adding anything new to our metaphysics, and the fact that it governance supports metaphysically robust explanations isn't especially surprising.

But both of these accounts also have a downside: they will require revising widely held beliefs about what causation or grounding consist in. Consider first Governance as Causation. Causation is widely held to be a relation that holds between events, but governance is a relation that takes, as one of its relata a fact about laws. Facts about laws are not events.[23] So if we endorse Governance as Causation, then we have to give up a widely held belief about causation.[24]

The same will be true of Governance as Grounding, although this may not be as immediately obvious. To see why, consider the fact that grounding is widely held to be metaphysically necessitating in the sense that if F grounds G then any metaphysically possible world where F occurs is also a world in which G also occurs. But we shouldn't accept any view of governance that requires governance to be metaphysically necessitating in this sense; many laws, including some of our current best candidates for the fundamental dynamical laws, are indeterministic, and the relation between such laws and their instances (or between such laws and patterns of those instances) is not metaphysically necessitating. Indeed it is not even nomologically necessitating.

Suppose you take a bunch of silver atoms and send them through a set of magnets that creates an inhomogeneous magnetic field (a magnetic field that is stronger in one direction than another). The field will deflect some of the silver atoms in one direction—call it *up*—and the rest of the magnets in another direction—call it *down*. Suppose you then take all and only the silver atoms that were deflected up through the first set of magnets and send them through a second set of magnets, which is rotated slightly with respect to the first. The vast majority of the atoms will go up again through the second set of magnets. Call this pattern *P-M*.

According to several of our current best candidate theories of quantum mechanical phenomena, the only available explanation for P-M is the fact that the fundamental laws assign an very high objective probability to each silver atom going up through the second set of magnets given that it went up through the first set of magnets. Call the laws that assign these objective probabilities *L-M*. According to the pattern explanation principle, then, we have to accept the

[23] See Paul and Hall 2013 and Schaffer 2016b.

[24] Someone who wanted to endorse Governance as Causation might point out that in principle at least it is easy to translate between facts and events—for every fact there is the event of that fact obtaining. One thing to note, however, is that if there is such a thing as the event of the fact that it is a law that P obtaining, then that event is not spatiotemporally localized, which makes it importantly different from most paradigm examples of events that stand in causal relations. In any case, note that if you think there is no issue here for taking governance to be causation, then that is all to the good as far as my argument is concerned.

view that the fact that it is a law that L-M is the reason why P-M. But notice that on any standard view about objective probability, there are metaphysically, and even nomologically possible worlds in which L-M obtains, but P-M does not. These are worlds in which although the objective probability of each silver atom going up through the second set of magnets (given that it went up through the first set of magnets) is very high, but in fact many or even all of the silver atom end up being deflected down through the second set of magnets instead. Such worlds are not very likely, but they are nomologically possible.

What this example shows is that the pattern explanation principle will require a governing account of both deterministic and indeterministic laws.[25] As such, and given the fact that some of our best candidates for the fundamental dynamical laws are indeterministic, one should allow that the governing relation itself is not necessitating. And insofar as one thinks that governance is grounding, one should therefore think that grounding, contrary to widespread belief, is not necessitating either. Many philosophers, especially those steeped in the contemporary literature on grounding, will find the idea that grounding is not even nomologically necessitating to be difficult to accept.[26]

So to say that governance just is causation or just is grounding comes with costs. Are those costs worth paying? I don't want to take a stand on that here.[27] Instead, I want to emphasize that for those unwilling to pay the costs, there is a third way to proceed: to take governance to be a distinct member of the family of dependence relations that also includes causation and grounding. On this view, governance cannot be analyzed in terms of causation or grounding; instead it is a novel type of dependence relation.

This view is especially plausible when one realizes that the key features of governance relations that might in one context seem worrying are also features that it has in common either causation or grounding. Consider, for instance, the fact that governance relations are not necessitating. This might be a reason for thinking that governance is not grounding, but it can't be a reason for thinking that governance is not a member of the family of dependence relations. After all we (or most of us, at least) have already accepted a dependence relation that isn't necessitating—causation. It is widely accepted that F can cause G even if F doesn't necessitate G.

Or consider the fact that governance relations don't hold between events. This might be a reason for thinking that governance is not causation, but it can't be a reason for thinking that governance is not a member of the family of dependence relations. After all we (or most of us, at least) have already accepted a dependence relation that doesn't hold between events—grounding.

---

[25] The argument above follows Emery 2017.

[26] One reason to be especially adamant about holding the line here is if you endorse the view the causation and grounding are very similar and one of the only important differences between the two is that the latter is necessitating, while the former is not. See Schaffer 2016a.

[27] In Emery 2017 I argued for Governance as Grounding, because I thought that Governance as Causation was more costly. Today I am more inclined toward the third view described below, on which governance is a novel dependence relation.

It is widely accepted the grounding relation need not take events as relata.[28]

Taking governance to be a novel dependence relation has the advantage that we need not revise any widely accepted views about causation or grounding. The cost of this view, obviously, is that it involves introducing a novel dependence relation into our metaphysics. All else being equal, we should avoid introducing novel relations into our metaphysics if we can. That said, it is worth emphasizing that there is an important difference between saying that grounding is a *novel* dependence relation, and saying that grounding is a *primitive* dependence relation. Nothing in what I have said here requires that those who take this third option accept that grounding is unanalyzable. The key feature of this approach, rather, is that governance is not analyzed in terms of causation or grounding—that is what makes it novel.

Those are three ways of developing a further account of grounding that builds on already widely-accepted dependence relations. I am not here advocating any one of these views over the others, and in principle, at least, I am open to other options. The key feature of governance that follows from my argument is just that governance is a dependence relation in the following sense: it supports metaphysically robust explanations. The discussion in this section is supposed to illustrate that there are several ways of further fleshing out the notion of governance in a way that is compatible with this claim.

Of course, all three of the options I set out above come with costs. But here is a position that is not viable, given the argument of this paper: one cannot simply refuse to accept a governing account of laws because one does not want to pay these costs. To see why, return to some of the examples presented in section 1. Consider, for instance, the introduction of dark energy to explain the accelerating rate of expansion of the universe. Scientists have little idea what dark energy is. So of course they can have no guarantee that the way in which dark energy explains the accelerating rate of expansion of the universe will be cost-free. Perhaps the only way for dark energy to play the relevant explanatory role will require either revising accepted explanatory relations or even introducing a novel kind of explanatory relation.[29] Hopefully that doesn't turn out to be the case, but the fact that it might doesn't prevent scientists from thinking that dark energy exists. Why not? Because they need there to be *something* to explain accelerating rate of expansion of the universe. Otherwise they would violate the pattern explanation principle.

---

[28] What exactly the grounding relation does take as relata is up for debate. Some philosophers (e.g. Shaffer 2009) are ecumenicists about this and think that grounding relations can hold between a wide range of relata. Other philosophers (e.g. Rosen 2010 or Audi 2012) insist that grounding relations only hold between facts. I know of no one who thinks that grounding holds only between events.

[29] In conversation, I sometimes have heard the following response to this line of reasoning, "but we at least know *something* about how dark energy explains—it explains in the way that energy in general explains." My view is that give the wide range of possibilities for what dark energy is, the claim that dark energy explains in the way that energy explains is far more complicated to evaluate than it first appears. Moreover, a defender of a governing account of laws can also point out that in a similar way, we know *something* about the way in which laws explain—they do so by providing reasons why, just like other less controversial, dependence relations like causation and grounding do.

The same sort of attitude should be adopted in the case of laws. We need governing laws in order to explain patterns in the data. It may be that the way in which governing laws provide these explanations comes with costs. That is perhaps unfortunate, but it isn't a reason not to accept the governing conception of laws—at least not unless one has some alternative explanation available.

Conclusion

The governing conception of laws is the view that laws explain patterns of their instances in a metaphysically robust way. The reason why (in a Newtonian world) net force is always equal to mass times acceleration is that it is a law that net force is equal to mass times acceleration. This fact is not a conceptual truth about laws, but it is a fact—and one that everyone should accept. For the governing conception of laws follows from a important principle of scientific theory choice and the principles of scientific theory choice should also constrain metaphysical theorizing.

If follows from this argument that, in general, when we are doing scientifically-informed metaphysics we ought to pay attention to the principles of scientific practice as well as to the content of our best scientific theories, and insofar as we do so we should be less concerned with our metaphysical scruples regarding certain kinds of entities, and more concerned with the extent to which our metaphysical theories provide adequate explanations. In the particular case of laws, we should be resist being moved, as many prominent Humeans are, by the worry that non-Humean accounts will require "metaphysically heavy-duty and suspect entities".[30] Or at least, we should resist being moved by such worries unless we are confident that laws that don't require such entities can play the explanatory role required of them. In this way, my argument reinvigorates serious issues for Humeanism about laws of nature.

The argument also opens up several relatively straightforward ways of understanding the governance relation by drawing on other, already widely-accepted relations that underwrite metaphysically robust explanations. Governance might be understood as a type of causation, for instance. Or it might be understood as a type of grounding. Or governance might be a novel dependence relation, a member of the same family as causation and grounding, but distinct from each.

Acknowledgements

[30] Loewer 2007, 313. As Beebee puts it, the goal for the Humean is to adopt a "less metaphysically rich account of lawhood" (Beebee 2000, p. 593).

Thanks to Elizabeth Miller, Nick Jones, Henry Taylor, Zee Perry, Alastair Wilson, and to audiences at the FraMEPhys workshop at Birmingham in June 2019, the workshop on Humean Laws at Harvard in May 2019, the Explanation Across the Boundaries Conference at Middlebury College, at the 2019 MARI Graduate Conference at UMass where this was the keynote presentation, and at a MAPS meeting at NYU in April 2019. Thanks also to Boris Kment and Adam Elga and participants in their graduate seminar at Princeton in the fall of 2018.

Works Cited

Armstrong, David. 1983. *What Is a Law of Nature?* Cambridge: Cambridge University Press.

Audi, P. (2012). Grounding: Toward a theory of the in-virtue-of relation. *The Journal of Philosophy*, 109(12), 685–711.

Beebee, Helen 2000, "The Non-governing Conception of Laws of Nature," *Philosophy and Phenomenological Research*, 61: 571–94

Brown, Laurie M. 1978. 'The Idea of the Neutrino', *Physics Today* 31(9): 23.

Carroll, John W. 1994. *Laws of Nature*. Cambridge: Cambridge University Press.

Carroll, John W. 2016. "Laws of Nature", *The Stanford Encyclopedia of Philosophy*, Edward N. Zalta (ed.), https://plato.stanford.edu/archives/fall2016/entries/laws-of-nature/>.

Carroll, Sean. 2007. *Dark Matter, Dark Energy: The Dark Side of the Universe.* Virginia: The Teaching Company.

Close, Frank. 2012. *Neutrino*. Oxford: Oxford University Press.

"Dark Energy, Dark Matter". *Nasa Science*. https://science.nasa.gov/astrophysics/focus-areas/what-is-dark-energy, accessed November 5, 2018.

Durrer, Ruth. 2011. 'What do we really know about dark energy?' *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 369 (1957), pp. 5102-5114.

Emery, Nina. 2017. 'A Naturalist's Guide to Objective Chance'. *Philosophy of Science*.

Emery, Nina. 2018. 'Laws and Their Instances'. *Philosophical Studies.* https://doi.org/10.1007/s11098-018-1077-8

Emery, Nina. ms. 'Mooreanism in Metaphysics from Mooreanism in Physics.'

Faraday, Michael. 1852. "On the physical character of the lines of magnetic force." *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* 3 (20), pp. 401-428.

Hall, Edward. ms. "Humean Reductionism about Laws of Nature".

Harman, P. M. 1982. *Energy, Force, and Matter.* Cambridge: Cambridge University Press.

Hesse, Mary. 1962. *Forces and Fields: On the Concept of Action at a Distance in the History of Physics.* New York: Dover Publications.

Hicks, Michael Townsen, and Peter van Elswyk. 2014. "Humean Laws and Circular Explanation." *Philosophical Studies* 172 (2): 433–43.

Kovacs, D. ms. "There is no Circularity Problem for Humeanism about the Laws of Nature"

Lange, Mark. 2013. "Grounding, Scientific Explanation, and Humean Laws." *Philosophical Studies* 164 (1): 255–261.

Loewer, Barry. 1996. "Humean supervenience." *Philosophical Topics*, 24(1), 101–127.

Loewer, Barry. 2007. "Laws and Natural Properties". *Philosophical Topics*, 35 (1 & 2): 313 - 328

Loewer, Barry. 2012. “Two Accounts of Laws and Time.” *Philosophical Studies* 160 (1): 115–137.

Marshall, Dan. 2015. “Humean Laws and Explanation,” *Philosophical Studies*, 172: 3145–65.

Maxwell, James Clark. 1861. "On physical lines of force. Part I." *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, 4: pp. 161 -175

Miller, Elizabeth. 2015. “Humean Scientific Explanation,” *Philosophical Studies*, 172: 1311–1332

Maudlin, Tim. 2007. *The Metaphysics within Physics*, New York: Oxford University Press.

Paul, L. A., & Hall, E. J. (2013). Causation: A user’s guide. Oxford: Oxford University Press.

Rosen, G. (2010). Metaphysical dependence: Grounding and reduction. In B. Hal & A. Hoffman (Eds.) *Modality: Metaphysics, Logic, and Epistemology* (pp. 109–136). Oxford: Oxford University Press.

Roski, Stefan. 2017. Grounding and the explanatory role of generalizations. *Philosophical Studies*. https://doi.org/10.1007/s11098-017-0946-x.

Schaffer, Jonathan, 2008, “Causation and Laws of Nature: Reductionism,” in *Contemporary Debates in Metaphysics*, J. Hawthorne, T. Sider, and D. Zimmerman, (eds.), Oxford: Basil Blackwell.

Schaffer, J. (2009). On what grounds what. In D. Manley, D. J. Chalmers, & R. Wasserman (Eds.), *Metametaphysics: New essays on the foundations of ontology* (pp. 347–383). Oxford: Oxford University Press.

Schaffer, J. (2016a). Grounding in the image of causation. *Philosophical Studies*, 173(1), 49–100.

Schaffer, J. (2016b). The metaphysics of causation. In E. N. Zalta (Ed.) *The Stanford encyclopedia of philosophy*. https://plato.stanford.edu/archives/fall2016/entries/causation-metaphysics/.

Tooley, Michael. 1977. "The Nature of Laws," *Canadian Journal of Philosophy*, 7: 667–98.

Turner, Michael S. 2001. "Dark matter and dark energy in the universe." *Particle Physics And The Universe*. 2001. 210-220.

Wilson, Fred L. 1968. 'Fermi's Theory of Beta Decay'. *American Journal of Physics* 36 (12), 1150.