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Derivative Properties in Fundamental Laws

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ABSTRACT

Orthodoxy has it that only metaphysically elite properties can be invoked in scientifically elite laws. We argue that this claim does not fit scientific practice. An examination of candidate scientifically elite laws like Newton's $F=ma$ reveals properties invoked that are irreversibly defined and thus metaphysically non-elite by the lights of the surrounding theory: Newtonian acceleration is irreversibly defined as the second derivative of position, and Newtonian resultant force is irreversibly defined as the sum of the component forces. We think that scientists are happy to invoke metaphysically non-elite properties in scientifically elite laws for reasons of convenience, such as to simplify the equations and to make them more modular. On this basis, we draw a deflationary moral about laws themselves, as being merely convenient summaries.

1 *Introduction*
2 *Orthodoxy*
  2.1 *Orthodoxy stated*
  2.2 *Orthodoxy explained*
  2.3 *A worrisome commitment: Term objectivism*
3 *The Loose View*
  3.1 *The argument from practice*
  3.2 *Finding the scientifically elite equations*
  3.3 *Diagnosing the metaphysically non-elite properties*
  3.4 *Situating our challenge*
4 *Newtonian Mechanics*
  4.1 *Newtonian acceleration*
  4.2 *Newtonian resultant force*
  4.3 *A metaphysical discovery?*
5 *Objections*
  5.1 *Metaphysically elite after all?*
  5.2 *Scientifically non-elite after all?*
  5.3 *But our world is not Newtonian!*

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6 *Consequences*
6.1 *Consequences for the motivations for link*
6.2 *Consequences for metaphysically elite properties*
6.3 *Consequences for lawhood*

1 Introduction

> This brings me to a very general principle that guides our physical theorizing, from which the other principles I use all extend: the dynamical laws are about what's fundamental to a world. The dynamical laws relate what's fundamental to what's fundamental, where what's fundamental includes the fundamental space and its structure, and the fundamental ontology. The dynamical laws govern the fundamental level of reality; that is why they are a guide to the fundamental nature of the world. (North [2013], p. 186)

> Colette said angrily, 'It's not that I don't believe in you. Well I do. I have to believe in what you do, because I see you doing it, I see and hear you, but how can I believe it, when it's against the laws of nature?'
> 'Oh, those', Al said. 'Are you sure we have them anymore? I think it's a bit of a free-for-all these days'. (Mantel [2005], p. 123)

Orthodoxy in the metaphysics of science claims a link between properties and laws. It is thought that there are 'metaphysically elite properties': fundamental, wholly natural sparse properties that carve nature at the joints, such as perhaps mass and charge. It is also thought that there are 'scientifically elite laws': the ultimate equations that govern the workings of nature, such as (one might once have thought) Newton's $F=ma$ or (one might now think) Schrödinger's equation. Orthodoxy then has it that these metaphysical and scientific ideas are linked as follows:

> Link: Only metaphysically elite properties can be invoked in scientifically elite laws.

We argue against Link—and in favour of the contrary view that metaphysically non-elite properties can be invoked in scientifically elite laws—by appeal to scientific practice. We examine paradigm historical candidates for scientifically elite laws like Newton's $F=ma$, and find properties invoked that are metaphysically non-elite by the lights of the surrounding theory. Thus within Newtonian mechanics, acceleration is irreversibly defined as the second derivative of position, and resultant force is irreversibly defined as the sum of the component forces. We also offer an explanation as to how metaphysically non-elite properties can earn their way into the scientifically elite laws, by improving the equations in various practical ways (such as by simplifying

them or rendering them more modular). We conclude by drawing a deflationary moral about laws themselves as merely convenient summaries.

We are not rejecting the notion of a metaphysically elite property or the notion of a scientifically elite law, but saying that these notions are not as tightly connected as orthodoxy presumes (in ways that matter to the nature of lawhood). Indeed, we claim that the main rationale for Link—which is to provide a naturalistic constraint on the metaphysical posit of elite properties—can still be retained while positing a looser and more plausible connection. So in that respect, we claim to liberate the metaphysical posit of elite properties from the false image of science to which it has been chained.

2 Orthodoxy

2.1 Orthodoxy stated

Orthodoxy in the metaphysics of science claims that only metaphysically elite properties can be invoked in scientifically elite laws, as per Link. This claim arises from the work of Armstrong and Lewis, who each posit metaphysically elite properties in direct connection to the scientifically elite laws. For Armstrong ([1978], Chapter 24, [1983]) the metaphysically elite properties are the universals, and the scientifically elite laws involve a second-order necessitation universal ('Nec') connecting first-order universals ('*F*', '*G*') with the laws taking the form 'Nec(*F*, *G*)' (which may be read as '*F*-ness necessitates *G*-ness'). Only universals can be connected by such necessitation.

For Lewis ([1986], p. 64), the metaphysically elite properties may be understood in terms of Armstrong's universals, exact resemblance classes of tropes, or sets of possibilia that have the primitive status of being perfectly natural (he remains neutral over these options). The scientifically elite laws are the best systematization of the pattern of events, which is the summary that optimally balances simplicity and strength in the language of the metaphysically elite properties. As Lewis ([1983], p. 368) makes explicit: 'Fundamental laws, those that the ideal system takes as axiomatic, must concern perfectly natural properties'.

It is not hard to understand why Armstrong and Lewis were both drawn to Link. Each is making a substantive metaphysical posit (metaphysically elite properties), and wants to bring this posit 'down to earth' by connecting it with real science. So Link is a natural and very direct way to provide a scientific basis for the metaphysics. And for this reason it is not hard to understand why Link has become orthodoxy. In this vein, Bird ([2007], p. 13) says that the fundamental powers 'participate in (or generate) the laws of nature'. Maudlin ([2007a], p. 35) speaks of laws and fundamental physical magnitudes as 'to some extent mutually determining'. Sider notes that 'Many connect laws of nature with fundamentality' ([2011], p. 21), then generalizing this

requirement to scientific theorizing: 'The core insight of Lewis's account of laws can be generalized beyond the case of laws: good scientific theories, whether or not they cite laws, must be cast in joint-carving terms' ([2011], p. 23). Link is now orthodoxy in the metaphysics of science, to the point where North ([2013], p. 186) invokes it as 'a very general principle that guides our physical theorizing, from which the other principles I use all extend'.[1]

The picture that emerges is something like this: The physicists can be expected, or at least reasonably hoped, to deliver the basic equations of nature. The metaphysician can then examine these equations, read off the predicates, consider which properties these predicates denote (these are the properties 'invoked' in the laws), and conclude that those properties must be metaphysically elite.

That said, we emphasize that—even given metaphysically elite properties and scientifically elite laws—it is a substantive posit that they are connected so directly, and in such a way as to allow real science to guide metaphysical theorizing so directly. As will emerge, there are ways to 'defend' Link that rob it of much of its substance, either by refusing to give independent content to 'metaphysically elite properties', or by refusing to give independent content to 'scientifically elite laws' beyond those in which the metaphysically elite properties are invoked (in which case the idea of a scientifically guided metaphysics is lost). There is even a use of 'fundamental' that can make Link look almost truistic. Call a metaphysically elite property a 'fundamental property', and a scientifically elite law a 'fundamental law'. Then one can express Link as:

> Link, Rewired: Only fundamental properties can be invoked in fundamental laws.

But it must be understood that 'fundamental' is being used equivocally in Link, Rewired, first to mark a metaphysical status, and then to mark a scientific status. It is a substantive claim—which we think does not bear scrutiny—that scientists are so metaphysically scrupulous as to the terms they allow in their equations.

[1] The extent to which Link is now orthodoxy is perhaps best seen by how readily it is now taken for granted. As an illustrative example, Bird ([2005], p. 354)—pursuing an account of laws in terms of fundamental powers—introduces the topic as follows: 'The dispositionalist takes the properties with which science is concerned, the properties that appear in laws of nature (Lewis's "sparse properties") to be essentially dispositional'. Here it is simply presupposed that the scientifically elite properties ('the properties that appear in the laws of nature') just are the metaphysically elite properties ('Lewis's "sparse properties"'). This is not intended as a criticism of Bird of course, but just as an indicator of the extent to which Link is now taken for granted by almost everyone in the field.

2.2 Orthodoxy explained

Not for nothing is Link orthodoxy. Indeed, Link can claim at least three lines of support, the first of which (as mentioned) is to allow for a naturalistically acceptable epistemology for the metaphysics. Armstrong, Lewis, and their followers are making a metaphysical posit, and so there is an obvious concern about epistemic accessibility. In this vein, Sider ([2011], p. 11; see also Dorr and Hawthorne [2013], p. 18) poses the question: 'How are we supposed to *know*—or even, reasonably believe—anything about structure?'. Given that one has some independent grip (from the practice of physics) on what the scientifically elite laws are, Link allows one to use this grip on the laws to gain a grip on the metaphysically elite properties (Lewis [1986], p. 60).

Indeed, Link can look like a plausible extension of a naturalistic Quinean methodology for metaphysics, albeit one dealing in properties and targeted to the fundamental. The methodology is this: one is committed to treating a given property as metaphysically elite when one is committed to treating a given theory as scientifically elite, whose most basic laws invoke the property. This principle is made fully explicit by North ([2013], p. 186), who writes: 'The dynamical laws govern the fundamental level of reality; that is why they are a guide to the fundamental nature of a world'. She then adds the general methodological principle: 'We posit, at the fundamental level, whatever the dynamical laws presuppose—whatever there must be in the world for these laws to be true of it'.

As a second line of support, Link can also help explain why 'gruesome' properties have no place in the scientifically elite laws. Any candidate law system S permits a radically simple and strong axiomatization: let 'F' apply to all and only things at worlds whose laws are exactly as S says, and axiomatize via '$(\forall x)Fx$' (Lewis [1983], p. 367). The question is why this single gruesome summary should not automatically count as the one true scientific 'theory of everything', given its simplicity and strength.[2] Is it just because scientists haven't yet seen the trick, that they imagine that the true laws of nature might be more complicated in form?

Link provides a plausible reply to this threat of trivialization. As Lewis ([1983], p. 367) explains: 'The remedy, of course, is not to tolerate such a

[2] This question might seem especially pressing for Lewis, whose starting point notion of a fundamental law just is the notion of an axiom of the simplest and strongest summary of the occurrences. But it equally arises for anyone (including many of Lewis's opponents) who thinks that Lewis's approach at least captures something right about the epistemology of lawhood. For instance, Armstrong ([1983], p. 73) charges that 'the Systematic approach mistakes good methodology about laws for analytic truths about lawhood'. But as a result Armstrong equally needs to explain why it would be bad methodology to treat this single gruesome summary as the one and only fundamental law. Likewise, Carroll ([1994], p. 45)—defending primitivism about the scientific laws—describes the Lewisian approach as 'shaped by the epistemology of lawhood' and using concepts 'of the appropriate nature to be part of the epistemology of lawhood'. As a result, Carroll equally needs to explain why it would be poor reasoning to infer that this single gruesome summary is the one and only fundamental law.

perverse choice of primitive vocabulary'. The single gruesome summary does not automatically count as the one and only fundamental law for the friend of Link, since the predicate involved (F) will almost certainly fail to denote a metaphysically elite property. Link thus can help explain certain aspects of scientific practice.

Third, Link can help explain still another feature of scientific practice, namely, why positing new (and potentially underlying) scientific laws can point towards new (and potentially deeper) metaphysical joints in nature. Thus Lewis ([1983], p. 368) says that both his account of laws and Armstrong's can explain:

> [. . .] why the scientific investigation of laws and of properties is a package deal; why physicists posit natural properties such as the quark colors in order to posit the laws in which those properties figure, so that laws and natural properties get discovered together.

For instance, imagine that physicists succeed in explaining the standard model of particle theory by invoking laws that treat particles as composed of oscillating strings. It would seem perverse to refuse to take this as a deeper insight into metaphysical joints of nature than those articulated in the particle model, and perverse to still view the fundamental realm as a realm of particles.

Putting this together, Link is orthodoxy for at least the following three reasons:

- Link helps provide a naturalist epistemology for the metaphysically elite properties;
- Link keeps gruesome properties out of the scientifically elite laws; and
- Link explains why new scientific laws can point towards new metaphysical joints in nature.

We think that Link is false, but we think that there is also something insightful in these three points, and so we owe a story about how to preserve these insights without Link (Section 6.1). We also note that much of the rationale for Link consists of its fit with certain aspects of scientific practice and naturalistic methodology. Insofar as the friend of Link was seeking a metaphysics guided by science, a lack of fit with scientific practice should be especially concerning.

2.3 A worrisome commitment: term objectivism

So much for the content of, and rationale behind, Link. We note that Link is neutral on many metaphysical controversies. For instance, while Link is committal towards the existence of metaphysically elite properties, Link is neutral as to their nature. Thus Link is neutral as to whether these elite properties are to be understood as sparse universals (Armstrong [1978]), exact resemblance

classes of sparse tropes (Campbell [1990]), or privileged classes of possibilia (Lewis [1986], p. 64). And Link is neutral as to whether fundamental properties are categorical or dispositional, or perhaps both at once (see Shoemaker [1980]; Bird [2007]).

And while Link is committal towards the existence of scientifically elite laws, Link is also neutral as to their nature. By a 'scientifically elite law' we just mean a familiar sort of scientific posit, of which Newton's second law $F = ma$ and Schrödinger's equation are paradigm historical candidates.[3] The friend of Link thinks we have some independent grasp on these laws from the practice of scientific theorizing, insofar as these laws can then inform her metaphysical theorizing. But Link is neutral as to whether these equations are best metaphysically understood in terms of second-order necessitation universals (Dretske [1977]; Tooley [1977]; Armstrong [1978], Chapter 24), primitive and *sui generis* aspects of the fundamental fabric of reality (Carroll [1994]; Maudlin [2007a]), or axioms of the best systematization of nature (Lewis [1983], p. 369; Earman [1984]; Loewer [1996]).[4] We ultimately prefer the deflationary views of scientific laws as having the nature of systemizations (Section 6.3); but this is not in any way presupposed by Link, rather it is a moral we draw from our argument against Link.

Link is also neutral as to which laws turn out to be scientifically elite. We generally assume that the elite laws are physical laws, as befits a background physicalist worldview. But nothing in our argument turns on this. Perhaps there are also scientifically elite psychological laws as the dualist supposes; or perhaps there are even scientifically elite biological laws as a vitalist might suppose. We only say that a claim about the connection between metaphysically elite properties and scientifically elite laws, which is supposed to yield a scientifically informed metaphysics, should at least fit such historical paradigm laws as $F = ma$.

That said, Link does have a worrisome commitment to what we will label 'term objectivism', concerning the terms involved in the scientifically elite equations. Term objectivism is the view that there is a fact of the matter as to the right terms to use, even when the choices are mathematically equivalent.

[3] One diagnostic feature of elite laws is that, while they may be used (possibly in conjunction with boundary conditions or typicality assumptions) to prove other laws, no attempt is made to prove them from more basic principles. So Newton used his laws plus assumptions about the solar system to prove Kepler's three laws, and Boltzmann used Hamiltonian mechanics plus typicality assumptions to try to prove the laws of thermodynamics.

[4] This only scratches the surface of the options with respect to the metaphysics of lawhood. Perhaps laws instead reflect the metaphysically elite powers (Bird [2007], p. 13), or reflect the essential properties of the natural kind to which our world belongs (Bigelow *et al.* [1992]), or best systematize the possible distributions of powers (Demarest [forthcoming]). Or perhaps laws instead reflect the counterfactually stable generalizations found at a certain strata of the subnomically counterfactually stable hierarchy of truths (Lange [2009], p. 41). Link is neutral across all of these and other options.

For instance, in Newtonian mechanics it is usually thought that $F = ma$ and $F = m(dv/dt)$—being mathematically equivalent—are just notationally variant expressions of Newton's second law. But the term objectivist thinks that it is one thing to claim that $F = ma$ is a law, but another thing to claim that $F = m(dv/dt)$ is a law, and so views these equations as rival candidates for lawhood. Link brings in a commitment to term objectivism, since Link treats equations with different terms as making different claims about which properties are metaphysically elite. For instance, by the lights of Link, if $F = ma$ is a law then acceleration is metaphysically elite, while if $F = m(dv/dt)$ is a law then velocity and time are metaphysically elite instead. In other words, Link draws a tight connection between the terms invoked in the scientifically elite laws and the metaphysically elite properties, such that objectivism about the latter requires objectivism about the former.[5]

Term objectivism is problematic insofar as it already deviates from scientific practice, in which equations such as $F = ma$ and $F = m(dv/dt)$ are usually thought of as mere notational variants and not as metaphysically distinct images of fundamental reality.[6] Term objectivism is also problematic insofar as it makes the hope of a scientifically informed metaphysical posit seem elusive. If one goes to the physicists to ask after the scientifically elite laws, one should only expect to come back with a class of mathematically equivalent expressions with varying terms, rather than a single equation with fixed terms that one can simply read off. (The picture on which the physicists can be expected to deliver the basic equations of nature looks oversimplified.) But term objectivism is especially problematic with respect to any attempt to assess Link, including our own attempt. For if we want to challenge Link by arguing that 'a' denotes a metaphysically non-elite property, mustn't we first argue that the scientifically elite equation is $F = ma$, or something else that actually involves 'a'?

We propose to proceed as follows: First, although we are suspicious of term objectivism, we propose to grant the matter to the friend of Link (see also our

[5] North ([2009]) is very clear about this implication with respect to Newtonian mechanics as opposed to both Lagrangian and Hamiltonian mechanics. These too are often thought to be notational variant expressions of an underlying classical mechanics, but North takes them to invoke distinct pictures of reality. She goes on to argue that Lagrangian and Hamiltonian mechanics are more objective and description-independent than Newtonian mechanics in virtue of being coordinate-independent, and that Hamiltonian mechanics is more parsimonious than Lagrangian mechanics in virtue of only having a volume structure without any surplus metric structure. So by her lights, these are not only subtly different rivals, but there is even a discernible fact as to their relative merits (with Hamiltonian mechanics coming out best). We are sympathetic to North on this point, but in this paper are pointing out that the friend of Link is equally committed to drawing further and far more troubling distinctions, including distinguishing between $F = ma$ and $F = m(dv/dt)$ as rival law claims rather than mere notational variants.

[6] We thank an anonymous BJPS referee for the following further example: 'I can write the Einstein field equations out the usual 'long' way, via the Ricci tensor and scalar curvature, or the 'short' way, via the Einstein tensor. I see both expressions about equally often. Why it's written one way rather than the other seems entirely conventional.'

claim Loose, Conditional in Section 3.4), if only for the sake of discussion.[7] But how then can Link even be assessed, one way or another? Fortunately, we can proceed along two converging lines. First, we can test Link with respect to $F = ma$. It is fair play to consider whether Link fits paradigm historical candidates for the scientifically elite laws, since any friend of a scientifically informed metaphysics should at least want her view to be compatible with the prospect of $F = ma$ being scientifically elite. It would be a result if we showed Link to be incompatible with even the prospect of $F = ma$ being scientifically elite. Indeed, we think that this would be a new and surprising result, and one that should, moreover, make Link seem deeply questionable to those seeking a naturalistic metaphysics.

Second, we can also proceed by looking beyond $F = ma$, towards a range of mathematically equivalent expressions of Newton's second law (and also examining the central equations in standard formulations of Lagrangian mechanics, Hamiltonian mechanics, and Schrödingerian quantum mechanics) to find a pattern. For the phenomenon we are interested in—namely, the invocation of metaphysically non-elite properties for practical gains—is not just an artefact of one particular equation, but arises through a wide range of real historical candidates for the scientifically elite laws. So we say that to the extent that Link can be used and assessed at all, that assessment should be negative. Putting these two ways of proceeding together, we can then conclude that $F = ma$ is both a paradigm case and a representative example, with respect to the invocation of metaphysically non-elite properties in candidate scientifically elite laws.

In summary, the core commitment of Link is the idea that one can provide a viable naturalistically respectable constraint on the metaphysical posit of elite properties, by holding that only metaphysically elite properties can appear in candidate scientifically elite laws like $F = ma$.

3 The Loose View

3.1 The argument from practice

We think that scientific practice does not support Link but instead supports the following contrary claim:

> Loose: Metaphysically non-elite properties can be invoked in scientifically elite laws.

[7] Our ultimate view is that term choice is highly pragmatic. Indeed—though we cannot pursue the issue further in this space—there is a natural progression from our concluding view that laws are merely convenient summaries (Section 6.3) to the thought that different equations may be more convenient in different explanatory contexts, in a way that would explain the practice of scientists who shift back and forth between broadly mathematically equivalent equations and frameworks as explanatory convenience demands.

Or to put things in the nearly paradoxical-sounding terms of our title:

> Loose, Rewired: Derivative properties can be invoked in fundamental laws.

Our main case for preferring Loose comes from looking into candidate scientifically elite laws like $F = ma$, and finding properties invoked that are metaphysically non-elite by the lights of the theories in which they figure.

Our strategy is thus to go to plausible candidates for being the elite equations of a given scientific theory (we mainly work with Newtonian mechanics but also consider Lagrangian mechanics, Hamiltonian mechanics, and Schrödinger-style quantum mechanics), and hunt for properties with the following features:

- the properties are invoked in the scientifically elite equations, but
- the properties are metaphysically non-elite by the lights of the theory itself.

Of course this strategy requires us to provide some independent grip on plausible candidate scientifically elite equations for a given theory (Section 3.2), and on whether a property is metaphysically non-elite by the lights of a given theory (Section 3.3).[8]

This strategy feeds into an argument from scientific practice for Loose with the following form:

(1) Scientific practice allows metaphysically non-elite properties to be invoked in scientifically elite laws.

(2) If scientific practice allows metaphysically non-elite properties to be invoked in scientifically elite laws, then metaphysically non-elite properties can be invoked in scientifically elite laws.

(3) Thus metaphysically non-elite properties can be invoked in scientifically elite laws.

This argument is evidently formally valid, and its conclusion is Loose (a contrary of Link). We think that almost all of the action is in premise 1, and so we focus (Sections 4 and 5) on the defence of this premise. We doubt that many would challenge premise 2 (which is essentially just a 'respect scientific practice' premise), or insist that the scientist must be mis-describing the laws for failing to fit some metaphysical preconception, but we return to this issue near the close (Section 6), when we explain how one can accept Loose while still respecting the core insights about scientific practice that motivated Link (Section 2.2).

[8] We thank an anonymous BJPS referee for encouraging us to be explicit from the start about what our strategy requires.

3.2 Finding the scientifically elite equations

Our general strategy requires us to provide some independent grip on which properties are invoked in the scientifically elite equations of a given theory. Given a particular equation like $F=ma$ of Newtonian mechanics, it is fairly straightforward to say what properties are invoked, at least to the point required for our argument. For instance, it is straightforward that '*a*' denotes acceleration, and while there may be residual controversy over what exactly that is, all that matters for our purposes is that we can show that acceleration—whatever exactly it is—counts as metaphysically non-elite by the lights of Newtonian mechanics.

But what is not at all straightforward is to say which equations count as scientifically elite for a given theory, especially given Link's commitment to term objectivism (Section 2.3). For instance, is the equation $F=ma$ scientifically elite by the lights of Newtonian mechanics, or is it rather $F=m(dv/dt)$, or perhaps some other mathematically equivalent expression (for example, $F=m(d^2x/dt^2)$)? There seems to be no way to decide.

Fortunately—as explained in Section 2.3—we may skirt these concerns in two ways. First, even though it is not obvious that $F=ma$ should count as scientifically elite, Link should still at least be compatible with the prospect of $F=ma$ being scientifically elite, to the extent that one wants to preserve anything like the spirit of a scientifically guided metaphysics. The metaphysician should not dictate to the physicist that $F=ma$ must be scientifically non-elite. Second, insofar as the phenomenon of interest (the invocation of metaphysically non-elite properties for practical gains) arises through a wide range of real historical candidates for the scientifically elite laws, it should be clear that the problem with Link is systematic and not a mere artefact of having picked the wrong equation to study.

Accordingly, we start (in Section 4) from the assumption that $F=ma$ is in fact a scientifically elite equation in Newtonian mechanics. This allows us to discuss the metaphysical status of both resultant force and acceleration in Newtonian mechanics. We then (Sections 4.3 and 5) consider alternative equations, as well as further scientific theories. This allows us to show how Link's failure is predictable and systematic.

Of course, the stubborn defender of Link could just reject $F=ma$ and the other equations we consider as candidate scientifically elite equations, and simply stipulate that it is part of being a scientifically elite law that the properties it invokes must be metaphysically elite. But that is just to rob Link of substance, and moreover to abandon the vision of getting an independent empirical handle on the metaphysics.

3.3 Diagnosing metaphysically non-elite properties

Our general strategy also requires us to provide some independent grip on what the metaphysically non-elite properties are, by the lights of a given theory. This might seem even more difficult than saying which equations count as scientifically elite, both insofar as this requires deciding a metaphysical matter, and insofar as this needs to be decided independently of Link, which was supposed to be what provides our main empirical grip on the metaphysical status of properties in the first place (Section 2.2). So how can we argue that acceleration is metaphysically non-elite by the lights of Newtonian mechanics, while at the same time assuming that $F = ma$ is allowed as a scientifically elite equation? By what independent means can we claim that acceleration is metaphysically non-elite?

Fortunately, we do not need a full decision procedure for sorting the metaphysically elite from the non-elite properties by the lights of a given theory, or even necessary and sufficient conditions for being metaphysically elite by the lights of a given theory. We only need some Link-independent sufficient conditions for being metaphysically non-elite by the lights of a given theory. And such conditions, as it happens, are not hard to come by. For the friends of metaphysically elite properties have not stopped at Link. They have invested the notion of a metaphysically elite property with further content, sufficient at least to independently determine that certain properties are metaphysically non-elite by the lights of a given theory.[9]

We focus on the connection between metaphysical eliteness and definition. For metaphysical eliteness is also associated with a background picture on which properties are connected by chains of definition, with the metaphysically elite properties as the undefined primitives at the bottom (Lewis [1984], p. 228; Sider [2011], p. 129). This picture plays various crucial roles for friends of metaphysically elite properties, including helping to rule out disjunctive properties from the ranks of the elite (see especially Lewis [1983], pp. 345–7). Indeed Lewis ([1984], p. 228, also [1986], p. 61; see also Dorr and Hawthorne [2013], p. 19) goes further, and suggests that the degree of non-eliteness ('the imperfect naturalness') of a given property can be identified with the length of its shortest definition in elite terms. We are neutral here on Lewis's further suggestion, but just noting that it presupposes that defined properties are thereby non-elite.

One must exercise some caution with the notion of a defined property, in large part because definitions can hold symmetrically (terms can be inter-definable).

[9] It is no accident that the friends of metaphysically elite properties have not stopped at Link. Indeed, their primary strategy for convincing people to posit metaphysically elite properties—perhaps most explicitly stated in (Lewis [1983])—is to show that the posit helps one do systematic work not just on the single topic of lawhood, but across many topics.

But to address this concern we only need to show that the definition in question does not in fact hold symmetrically, so that the chains of definition can only possibly run in one direction. An irreversibly defined term cannot be treated as an undefined primitive, and so cannot be understood as a metaphysically elite property. This gives us the following Link-independent sufficient condition for being metaphysically non-elite by the lights of a given theory:

> Irreversibly Defined: If a given property is Irreversibly Defined in a given theory, then that property is metaphysically non-elite by the lights of that theory.

So one may subject Link to independent scrutiny.[10] (While we focus on Irreversibly Defined as our primary test for metaphysical non-eliteness, other tests drawing on free recombination and intrinsicness will come up in a buttressing way; see Section 5.1.)

Of course the stubborn defender of Link could reject Irreversibly Defined and any further independent test for metaphysical non-eliteness, and simply stipulate that it suffices for being metaphysically elite that a property is invoked in a scientifically elite equation. But that is just another way to rob Link of substance. Such a person should take our argument to show that some properties that are 'metaphysical elite' in her sense are not 'metaphysically elite' in Armstrong's or Lewis's sense, and that her notion of 'metaphysical eliteness' cannot do the work that Armstrong's or Lewis's notion arguably can. (For all that she may still be able to show that her notion of 'metaphysical eliteness' can do further work. But the burden would be on her to show this.)

3.4 Situating our challenge

Before proceeding to our argument proper, it may help to distinguish it from, and situate it with respect to, three extant challenges to Link. One extant challenge is a radical 'challenge from the outside' that rejects the very terms in which Link is cast, either by rejecting metaphysically elite properties altogether (Hirsch [2009]), or by rejecting scientifically elite laws altogether (Cartwright [1983]; van Fraassen [1989]; Mumford [2004]). We are not disputing the terms in which Link is cast, but merely denying the claim of a tight connection that Link makes with these terms. Loose uses the same terms but merely makes a contrary claim. Our challenge via Loose is thus a more moderate 'challenge from the inside'. Obviously we cannot defend the use of these terms in this space, and so for present purposes we may be read as making a conditional claim:

> Loose, Conditional: Given that there is a distinction between metaphysically elite and non-elite properties, and a distinction between

[10] Our thanks to Jill North for helping us clarify these issues.

> scientifically elite and non-elite laws, metaphysically non-elite properties can be invoked in scientifically elite laws.

We think that Loose, Conditional should be of interest even to those who would deny the antecedent, insofar as they might be interested to see how some notions they would reject are interwoven.

A second sort of challenge to Link—discussed by Hawthorne ([2006], pp. 236–7)—concerns the metaphysics of quantity. Candidate fundamental laws like $F = ma$ record relations between determinable quantities, and it is not clear that determinable quantities belong to the fundamental structure of reality; one might worry that the fundamental properties need to be maximally determinate and/or scale-invariant. Indeed, on standard views about quantity one starts from a pattern of relations—either second-order relations between the properties (Mundy [1987]) or first-order relations between the objects involved (Field [1980])—and then proves a representation theorem authorizing the use of numbers. It is then natural to think that the quantities appearing in the laws (for example, mass) derive from these relations (for example, mass-betweenness and mass-congruence). These views about the metaphysics of quantity can thus provide an independent argument against Link.

We take no stand on the metaphysics of quantity in this space. For present purposes we just note that our argument against Link is independent and arguably stronger in two respects. First, the metaphysics of quantity are an abstruse and difficult matter, to the extent that many practicing scientists have a 'don't know and don't care' towards these issues. An argument from scientific practice that proceeded via the metaphysics of quantity would be open to the rebuttal that such issues simply do not impact actual scientific practice. In contrast, the Newtonian definition of acceleration as the second derivative of position is an elementary textbook matter that all practicing scientists know full well. So only our challenge can claim to be transparent to actual scientific practice. Second, on the standard metaphysical views about quantity, the underlying metaphysically elite properties are still in the vicinity of the quantities appearing in the laws (for example, they are all massy), while we don't think that anything 'acceleration-y' is a metaphysically elite property in Newtonian mechanics. So in that sense our challenge is also more radical.[11]

The third main extant challenge to Link—due primarily to van Fraassen ([1989]) and Loewer ([2007])—concerns lack of epistemic access to

[11] Though our challenge and the challenge from the metaphysics of quantity may ultimately converge. Perhaps the reason why scientists use determinable quantities like mass rather than patterns of relations (and might continue to do so even if aware of the metaphysical concerns) is that it is simpler to use determinable quantities, and extremely fruitful for directly connecting to mathematics. If so, then there is an underlying common theme that could emerge from these two issues: considerations of simplicity and utility can call for the use of both metaphysically non-elite properties and quantities in fundamental laws. We thank Marco Dees for this insightful perspective.

metaphysically elite properties. Thus Loewer ([2007], p. 322)—drawing on van Fraassen's ([1989], pp. 55–9) charge that Lewisian laws fail to fit scientific practice—imagines that the scientifically elite laws might prove more cumbersome stated in terms that invoke metaphysically elite properties than stated in terms invoking metaphysically non-elite properties, and suggests that in such a case scientific practice would favour choosing the simpler formulation in terms invoking metaphysically non-elite properties. As Loewer ([2007], pp. 323–4) clarifies, he is not denying that there are metaphysically elite properties in nature, but only claiming that such properties 'do not play the constitutive role that Lewis claims for them in characterizing the [best systems account] of laws'.

Our worry is in the vicinity of van Fraassen's and Loewer's, but distinct and arguably stronger in two main respects. First, their worry is presented purely hypothetically, in terms of an imagined mismatch between two ways of stating the laws. Their verdict that scientific practice would favour the simpler formulation invoking metaphysically non-elite properties is an imagined verdict. (We find their imagined verdict plausible; our point is just that it is imaginary.) In contrast, our claim is based on actual physics, involving a pattern of candidate scientifically elite laws invoking metaphysically non-elite properties, extending from classical mechanics all the way through to quantum mechanics. Our verdict about scientific practice is thus not imaginary but rooted in actual practice.

The second main difference between van Fraassen's and Loewer's worry and our own is that their worry is primarily epistemic, rooted in the concern that Lewisian perfectly natural properties are a brute metaphysical posit inaccessible to us. Our claim is instead based on the idea that within a given system (for example, Newtonian mechanics) one can actually determine that certain properties are metaphysically non-elite (through their irreversibly defined status; see Section 3.3). We thus replace a general scepticism about discriminating metaphysically elite from non-elite properties, with positive tests for deciding that certain properties are metaphysically non-elite. Putting these two points of difference together: We are not worried about an imaginary scenario (as per van Fraassen and Loewer) in which the scientists have come to a best system which, unbeknownst to them, happens not to invoke metaphysically elite properties. Rather, we are pointing to actual cases in which scientists have proposed a system already known to them to invoke metaphysically non-elite properties.

4 Newtonian Mechanics

So far we have stated and motivated Link, and outlined and situated our argument from scientific practice for the contrary principle Loose. We are now in position to turn to actual science, with the aim of identifying paradigm

historical candidates for the office of the scientifically elite laws, which invoke properties that are irreversibly defined and thus metaphysically non-elite by the lights of the very theory involved. This is all in order to support our first premise:

(1) Scientific practice allows metaphysically non-elite properties to be invoked in scientifically elite laws.

So we begin with Newtonian mechanics, as expressed via the classic equation $F = ma$, because it is a paradigm case (if not the paradigm case) of a law that has been taken as scientifically elite by practicing scientists, and because of its likely familiarity to most readers. We argue that both 'F' and 'a' denote irreversibly defined and thus metaphysically non-elite properties by the lights of Newtonian mechanics ('m' is perhaps the only term in the equation that invokes a metaphysically elite property by the lights of Newtonian mechanics). We thus think that Link gets even the most central historical paradigm cases badly wrong.

4.1 Newtonian acceleration

We begin with the equation $F = ma$, and specifically with the property of Newtonian acceleration: the determinable quantity denoted by 'a'. As per our general strategy (Sections 3.1–3.3), we need to establish that acceleration has the following two features in Newtonian mechanics:

- acceleration is invoked in the scientifically elite equations of Newtonian mechanics, and
- acceleration is irreversibly defined in Newtonian mechanics.

That will suffice to show that acceleration is a metaphysically non-elite property invoked in a scientifically elite law (by the lights of Newtonian mechanics).

That acceleration is invoked in the scientifically elite equations of Newtonian mechanics follows immediately from the following two claims:

- $F = ma$ is a scientifically elite equation in Newtonian mechanics, and
- in '$F = ma$' the predicate 'a' denotes acceleration.

The first of these claims follows immediately from our plausible provisional assumption about Newtonian mechanics (alternatives are to be considered later), and the second of these claims is self-evident.

So it remains to show that acceleration is irreversibly defined in Newtonian mechanics. This follows from the following two claims:

- acceleration is a defined quantity within Newtonian mechanics, defined as the second derivative of position, and

- the definition of acceleration as the second derivative of position is irreversible.

That acceleration is a defined quantity within Newtonian mechanics, defined as the second derivative of position, is uncontroversial. One finds this definition near the start of most introductory textbooks. That is, if one starts with the idea of a body having a position, one can define velocity as the first derivative of position: velocity is the rate of change of position. Then one can define acceleration as the second derivative: acceleration is the rate of change of velocity, $a =_{df} dv/dt$; or equivalently, the rate of change of the rate of change of position, $a =_{df} d^2x/dt^2$. (Thus the mathematical equivalence of the expressions $F = ma$, $F = m(dv/dt)$, and $F = m(d^2x/dt^2)$, as guaranteed by the definitions of 'a' and 'v' in terms of position and time.)

It remains to show that the definition of acceleration in terms of position is irreversible. To begin with, Newtonian position is a notion of place in absolute Newtonian space. Thus Newton ([1999], p. 409) says: 'Absolute motion is the change of position of a body from one absolute place to another' and 'true rest is the continuance of a body in the same part of that unmoving space'. Now from acceleration one cannot recover place in absolute Newtonian space. Indeed, from the accelerations of any number of bodies over time, the most that could be mathematically recovered would be their positions relative to their initial positions and velocities. Accelerations (and relative positions) are compatible with arbitrary displacements in absolute space, such as shifting everything ten meters over to the left. The definition is thus irreversible in Newtonian mechanics with its absolute positions.

Indeed, position looks to be the best candidate for the relevant metaphysically elite property within Newtonian mechanics. The basic metaphysical picture of Newtonian mechanics, which is largely explicit in the *Principia*, is a picture of enduring bodies moving through absolute positions in Newtonian space. In this respect, Irreversibly Defined looks to be getting things right, in seeing position rather than acceleration as metaphysically elite within Newtonian mechanics.

Of course the idea of operating in Newtonian absolute space turns out to be problematic (in ways that lead on to alternative forms of 'classical mechanics'; see Section 5.2), since absolute position turns out to be 'surplus structure' within the Newtonian lawbook. If one moves from a fully Newtonian space–time to a neo-Newtonian space-time, the proper physical notion becomes that of the intrinsic curvature of a worldline, and so in a neo-Newtonian setting it becomes more plausible that acceleration is a metaphysically elite property after all.[12] We acknowledge this point, but reply that

[12] Our thanks to Tim Maudlin for discussion of this issue.

physicists were still perfectly happy to formulate equations invoking terms like '*a*' within a Newtonian space–time. $F = ma$ was a perfectly viable candidate fundamental law as initially stated against the background of a Newtonian space–time. Its viability did not await the later discovery of the neo-Newtonian alternative (Section 4.1).

So we conclude that acceleration is a metaphysically non-elite property invoked in a scientifically elite law, by the lights of Newtonian mechanics. Why then write '$F = ma$' with '*a*', or even permit a scientifically elite law to be expressed in such terms? We see two rationales, the first of which is simplicity. One could insist on writing '$F = m(dv/dt)$' to get down to velocity, or even writing '$F = m(d^2x/dt^2)$' to finally get down all the way to position. But it would seem perverse to insist on always writing the equation in the last way, when one has to hand the defined quantity $a =_{df} (dv/dt)$, $a =_{df} (d^2x/dt^2)$.

A second independent rationale is transparency, in the sense that acceleration is actually what is dynamically relevant in Newtonian mechanics (a point Newton himself made explicit). Acceleration, unlike position, is invariant under symmetry transformations in Newtonian mechanics. By invoking acceleration rather than position, the equation manages to wear its dynamical symmetries on its sleeve (as it were).

We emphasize that the status of Newtonian acceleration as defined is an elementary matter. All physicists realize that acceleration is a defined notion in Newtonian mechanics, but happily allow this notion in formulating the elite equations of Newtonian mechanics nonetheless, because it is useful. The point of defining the notion of acceleration is to simplify the equations and to render the dynamically relevant aspects of position more transparent.

We also emphasize that simplicity and transparency are in a sense pragmatic. Our point is that the conditions for being a scientifically elite equation are partly pragmatic. (This is in contrast to the conditions for being a metaphysically elite property, which are usually taken to be fully realistic and objective matters.) We think that the real lesson of Newtonian acceleration is that, in contrast to the idea in Link that physicists always insist on metaphysically elite terms, physicists are in practice happy to trade some metaphysical non-eliteness for sufficient practical gains in matters such as mathematical simplicity and dynamical transparency. To the extent that we can expect the physicists to deliver certain basic equations at all, we can expect that their choice of equations will be partly guided by pragmatic constraints. That is why metaphysically non-elite properties can be invoked in scientifically elite equations (as per Loose). And that is also why Link is broken: it tries to forge a tight connection between the real and objective structure of nature (metaphysically elite properties) and what turns out to be a partly pragmatic matter of convenience (term choice in the scientifically elite equations).

And so we conclude that $F = ma$—perhaps the central historical paradigm of a candidate scientifically elite law—invokes the metaphysically non-elite property of acceleration. By our lights, this suffices to show that scientific practice favours Loose, as per the crucial premise 1 of our argument from scientific practice. The reader who is already convinced may skip to Section 6. But it will also prove useful to examine Newtonian resultant force (Section 4.2), and also to consider alternative equations and theories, as well as likely objections (Sections 4.3–5).

4.2 Newtonian resultant force

We turn now to Newtonian resultant force, the determinable quantity denoted by 'F'. As per our general strategy (Sections 3.1–3.3), we need to establish that resultant force has the following two features in Newtonian mechanics:

- resultant force is invoked in the scientifically elite equations of Newtonian mechanics, but
- resultant force is irreversibly defined in Newtonian mechanics.

That will suffice to show that resultant force is a metaphysically non-elite property invoked in a scientifically elite law, by the lights of Newtonian mechanics.

That resultant force is denoted by predicates appearing in the scientifically elite equations of Newtonian mechanics follows immediately from the following two claims:

- $F = ma$ is a scientifically elite equation in Newtonian mechanics, and
- in '$F = ma$' the predicate 'F' denotes resultant force.

The first of these claims follows immediately from our provisional assumption about Newtonian mechanics (alternatives are to be considered later), and the second of these claims is self-evident.

So it remains to show that resultant force is irreversibly defined in Newtonian mechanics, in order to independently establish its status as a metaphysically non-elite property by the lights of the theory. Such irreversible definability follows from the following two claims:

- resultant force is a defined quantity within Newtonian mechanics, defined as the vector sum of the component forces, and
- the definition of resultant force as the vector sum of the component force is irreversible.

That resultant force is a defined quantity within Newtonian mechanics, defined as the vector sum of the component forces, is uncontroversial. One finds this definition near the start of most introductory textbooks.

For instance, if one starts with a body, o, subject to exactly three component forces, f_1, f_2, and f_3, then $F(o) = f_{o,1} + f_{o,2} + f_{o,3}$.[13]

That the definition is irreversible follows from the mathematical fact that it is impossible to recover the specific component forces just from the resultant (resultant force is a vector that is multiply decomposable). Indeed, if one starts with the idea that a given body is subject to a given resultant force, one cannot recover (1) which total component forces there are (in terms of the total force from one body on another), (2) which directional components of the resultant are due to which specific directional component forces, and (3) which specific type component forces went into a total specific resultant force from some body. (So, for example, if one knows that the resultant force on a marble is $5N$ in the y direction on some coordinatization, one cannot from that recover (1) how many other bodies are exerting a force on the marble, (2) whether there are any components acting in the x or z direction, or the value of any component forces in the y direction, or (3) how much of the total resultant force is due to gravity and how much is due to charge or any other component force.) From a mathematical perspective, it seems that the specific component forces must come first. Anything else represents a loss of information.

Indeed, the specific component forces look to be the best candidate for the relevant metaphysically elite properties within Newtonian mechanics. In this respect, Irreversibly Defined looks to be getting things right, in seeing specific component forces rather than resultant force as metaphysically elite within Newtonian mechanics.

So we conclude that resultant force is a second metaphysically non-elite property invoked in a scientifically elite law, by the lights of Newtonian mechanics. (Moreover, the case of resultant force does not require conceiving of position as absolute position, and holds equally within neo-Newtonian space.) Why then write '$F = ma$' with 'F', or even permit a scientifically elite law to be expressed in such terms? We see two rationales, the first of which is simplicity. One could insist on writing '$\sum_1^n \vec{f}_{o,n} = ma$' (summing the component forces), or even—supposing one is working with gravitational and electrical forces—'$\sum_1^n \vec{f}_{G:o,n} + \sum_1^n \vec{f}_{C:o,n} = ma$' (summing the gravitational and the electrical forces). But it would seem perverse to insist on always writing the equation in one of these two latter ways, since one has to hand the defined quantity $F =_{df} \sum_1^n \vec{f}_{o,n}$; $F = \sum_1^n \vec{f}_{G:o,n} + \sum_1^n \vec{f}_{C:o,n}$.

A second rationale is modularity. To begin with, the alternatives to 'F' are problematic in their own ways. Writing '$\sum_1^n \vec{f}_{o,n}$' would be invoking the

[13] Notation: Component forces require subscripts indicating their source. We write '$f_{o,n}$' for the force on object o from object n. Our notation is only apt for the case of finitely many objects (indexed from 1 to n). If there are infinitely many objects—and nothing in Newtonian mechanics prevents this—more complicated notation is required. But this simple notation is sufficient for our purposes.

generic notion of a component force, which is presumably disjunctive (and thereby non-elite) in Newtonian mechanics, since it collapses distinct specific component forces (for example, gravitational and electrical forces). Indeed the same irreversible definition argument would apply in the relation between $\sum_1^n \vec{f}_{o,n}$ and $\sum_1^n \vec{f}_{G:o,n} + \sum_1^n \vec{f}_{C:o,n}$. If one starts with the idea that a given body is subject to a given number of generic component forces, one cannot recover (1) which specific component forces there are, and (2) which generic component forces are due to which specific component forces. Again from a mathematical perspective it seems that the specific component forces must come first, and that anything else represents a loss of information.

Writing '$\sum_1^n \vec{f}_{G:o,n} + \sum_1^n \vec{f}_{C:o,n}$' may get down to metaphysically elite terms, but it is also unhelpfully over-committal as to which specific component forces exist, in ways that make it much less useful. Writing '$F = ma$' with 'F' rather than '$\sum_1^n \vec{f}_{G:o,n} + \sum_1^n \vec{f}_{C:o,n}$' preserves neutrality as to which component forces there are, thereby allowing physicists to use $F = ma$ in models with different hypothetical component force law packages. In point of fact, a crucial part of the historical development of Newtonian mechanics consisted of using $F = ma$ as a way to test various hypotheses about component forces: Newton's original lawbook from 1687 only posits f_G, to which Coulomb's law positing f_C was a later addition, in 1785.[14] Moreover, a major aspect of the practical application of Newtonian mechanics consists of using $F = ma$ in contexts where one only has an approximate force law (for example, friction), non-fundamental forces (for example, Hooke's spring law), or even fictitious forces (for example, centrifugal force). Thus with 'F' the resulting system of laws is not just simpler but also more modular, and hence both more resilient to future discovery and more useful to the practicing scientist.

We emphasize that the status of Newtonian resultant force as defined is an elementary matter. All physicists realize that resultant force is a defined notion in Newtonian mechanics, but happily allow this notion in formulating the elite equations of Newtonian mechanics nonetheless, because it is useful. The point of defining resultant force is to simplify the equations and to render them more modular and thereby more useful. We also emphasize that simplicity and modularity are in a sense pragmatic. Our point (again) is that the conditions for being a scientifically elite equation are partly pragmatic.

And so we conclude that two out of the three terms in '$F = ma$' denote properties that are metaphysically non-elite by the lights of

[14] Two other notable examples: Airy paired $F = ma$ with various hypothetical forces to establish conditions under which perpetual motion would be possible, and Ehrenfest paired $F = ma$ in conjunction with alternative hypotheses about gravitation to establish conditions under which solar systems would be stable (Lange [2009], p. 39).

Newtonian mechanics![15] In general, we think that scientists are not so single-mindedly focused on the metaphysical status of the properties they invoke, but are also, to at least some extent, mathematically and practically oriented, interested also in improving the simplicity, transparency, and modularity of the equations. This is why scientists routinely define metaphysically non-elite properties and happily invoke them even in candidate scientifically elite equations.

4.3 A metaphysical discovery?

For all we have said, some readers may think that the friend of Link can still escape the critique so far, just by insisting that the true scientifically elite expression of Newton's second law cannot be $F=ma$ as we are supposing, but must instead be $\sum_1^n \vec{f}_{G:o,n} + \sum_1^n \vec{f}_{C:o,n} = m(d^2x/dt^2)$. For that equation invokes neither acceleration nor resultant force, and moreover neither velocity nor generic component force, but only specific component forces, absolute positions, and times, which by our own lights (Sections 4.1 and 4.2) are more plausible candidates for being metaphysically elite properties within Newtonian mechanics. So perhaps instead of delivering a criticism of Link, we have accidentally stumbled onto a metaphysical discovery as to the 'true' scientifically elite expression of Newton's second law?![16]

The idea readily generalizes: for any seeming candidate for a scientifically elite equation, the friend of Link can simply replace whatever metaphysically non-elite properties are invoked with their translations into metaphysically elite terms (assuming the background picture on which the metaphysically non-elite properties are connected to the metaphysically elite properties by chains of definition; see Section 3.3). Many further 'metaphysical discoveries' loom!

In one respect we agree: the friend of Link can make this response, both to the case of $F=ma$ and generally. But in another respect we disagree: no friend of Link should make this response, since it robs Link of substance, and it abandons the goal of finding an independent empirical handle on the metaphysics. Indeed, this is just an example of the move we warned against at the close of Section 3.2, of rejecting equations like $F=ma$ as candidate scientifically elite equations on metaphysical grounds, and simply stipulating that the true scientifically elite equations can only invoke metaphysically elite properties.

[15] And what about 'm'? There are two causes for concern: One stems from the metaphysics of quantity (Section 3.4), but another—more connected to our concerns—is that Newton himself ([1999], p. 403) introduces mass as defined via volume and density. But—unlike with acceleration and resultant force—we don't see a barrier to reversing the definition and thinking that mass is overall best treated as an undefined primitive (for further discussion of the status of mass in the *Principia,* see (Cohen [1999], pp. 89–95)).

[16] We thank an anonymous BJPS referee for pushing this point.

We emphasize that scientific practice in no way favours $\sum_1^n \vec{f}_{G:o,n} + \sum_1^n \vec{f}_{C:o,n} = m(d^2x/dt^2)$ over the more familiar $F = ma$. By our lights we see a trade-off, and a practice that is subject to conflicting considerations. There may well be some metaphysical pressure not to use overly non-elite notions. But there is also some countervailing mathematical and practical pressure towards using simpler, more transparent, and more modular equations. It is because of this countervailing pressure that scientific practice allows metaphysically non-elite properties to show up in scientifically elite laws, when there is sufficient gain.

But we can even be neutral on this response: perhaps the most interesting moral to take away from this discussion is just that Link looks to require that the scientifically elite expression of Newton's second law be $\sum_1^n \vec{f}_{G:o,n} + \sum_1^n \vec{f}_{C:o,n} = m(d^2x/dt^2)$. We see in that moral an objection to Link, since we hold that Link should still at least be compatible with the prospect of $F = ma$ being scientifically elite (Section 3.2). But the reader who would rather preserve Link and instead see an objection to the scientific eliteness of $F = ma$ should still take interest in this moral, and indeed should regard it as a shining example of metaphysical insight!

5 Objections

Drawing on an examination of both a and F in $F = ma$, we have argued that metaphysically non-elite properties can be invoked in scientifically elite laws when it improves the mathematical or practical utility of the equations, and thereby made the case that scientific practice allows metaphysically non-elite properties to be invoked in scientifically elite laws (the crucial premise 1 of our argument from scientific practice). We now turn to considering the following three forms of objection:

- a and F are metaphysically elite properties by the lights of Newtonian mechanics after all (Section 5.1);
- a and F are not invoked in the scientifically elite laws of Newtonian mechanics after all (Section 5.2); and
- Newtonian mechanics is a false theory and so may be ignored when evaluating Link (Section 5.3).

By our lights, the third form of objection is confused, but discussion of it gives us the opportunity to show how metaphysically non-elite properties resurface all the way through to quantum mechanics.

5.1 Metaphysically elite after all?

First, one might reply that acceleration and resultant force are candidate fundamental properties in Newtonian mechanics after all. But we argued

that both are irreversibly defined and thus metaphysically non-elite properties in Newtonian mechanics (Sections 4.1 and 4.2). So, barring a response to our argument, we see little further prospect in this line of reply.

Still, it may help to add some buttressing considerations, drawing on two further aspects of the Armstrong–Lewis notion of a metaphysically elite property. One further aspect starts from the idea that the metaphysically elite properties are all intrinsic (Lewis [1983], pp. 356–7; Sider [2011], p. 10), which entails that any extrinsic property must thereby be non-elite. This idea plays various crucial roles for friends of metaphysically elite properties, including helping to characterize the difference between real change and mere 'Cambridge' change, and helping to characterize objective similarity and dissimilarity (Lewis [1983], pp. 345–7; see also Dorr and Hawthorne [2013], pp. 21–7). So if we can show that acceleration and resultant force are not just irreversibly defined but extrinsic to boot, this should buttress our case for their being metaphysically non-elite.

The case for acceleration and resultant force both being extrinsic to boot can be made in two ways. The first way draws on the connection between extrinsicness and duplication:

- duplicates can only differ over extrinsic properties;
- any two electrons are duplicates; and
- two electrons can differ over their accelerations and/or the resultant forces they are subjected to.

The second way draws on the connection between extrinsicness and relations:

- if something has a given property only in virtue of its relations to other things (beyond its parts), the property is extrinsic;
- something has acceleration (by the lights of Newtonian mechanics) only in virtue of its occupation relations to positions in space; and
- something is subject to a certain resultant force only in virtue its external physical surroundings.

So this is a further sign that Irreversibly Defined is getting things right as far as classifying acceleration and resultant force as metaphysically non-elite by the lights of Newtonian mechanics.[17]

A second buttressing consideration—albeit one that applies only to resultant force and not to acceleration—draws on the idea that the metaphysically elite properties should all be freely recombinable (Lewis [1986], pp. 87–9;

[17] That said, the extrinsicness test seems to push for the even more radical conclusion that even position and specific component forces are extrinsic (and thus metaphysically non-elite) by the lights of Newtonian mechanics. We are not sure what to make of this matter, beyond registering the thought that the idea of perfectly natural properties as both undefined and intrinsic is showing strain.

Dorr and Hawthorne [2013], pp. 13–5). The total Newtonian lawbook also includes Newton's law of gravitation: $f_G = Gm_1m_2/r^2$, and thus invokes both resultant force (F) and specific component forces (f_G—also f_C if one casts an eye to Coulomb's law). But resultant force and specific component forces are not freely recombinable. (Otherwise it would be metaphysically possible for something to be subject to any combination of component forces but no resultant at all, or some other resultant that differs arbitrarily from the sum of the components. But this is mathematically and hence metaphysically impossible.) So it follows, contrary to Link, that at least one of these two properties invoked in the total Newtonian lawbook is metaphysically non-elite (though the free recombination test leaves open which).[18]

5.2 Scientifically non-elite after all?

Second, one might reply that acceleration and resultant force are not invoked in the scientifically elite equations of Newtonian mechanics after all. This reply certainly flies in the face of many standard textbook presentations.[19] But this itself may not be such a problem, especially because many textbooks present Newton's second law in multiple mathematically equivalent forms (Section 2.3), and also because it is standard pedagogical practice to introduce simpler equations first, and ramp up the complexity later as needed.

Indeed, a quite plausible version of this reply begins by noting that $F = ma$—and equally $F = m\left(\frac{dv}{dt}\right)$ as well as $F = m\left(\frac{d^2x}{dt^2}\right)$—are only applicable to systems with a constant amount of mass. It turns out there is a more general (and therefore more useful) statement of Newton's second law, applicable even to systems with a non-constant amount of mass, which replaces talk of mass and talk of acceleration with talk of linear momentum (p): $F = \frac{dp}{dt}$. Notice that the reason for shifting from $F = ma$ to $F = \frac{dp}{dt}$ has nothing to with the metaphysical eliteness of the terms, but everything to do with the wider applicability and thus the greater practical utility of the equation.[20]

Indeed, it should be evident that shifting to $F = \frac{dp}{dt}$ offers no help for fixing Link. Our point is not merely that 'F' is still there (though of course it is), but also that a new term 'p' for linear momentum is introduced, which itself has a textbook—and irreversible—definition as the product of velocity (itself the first derivative of position) and mass: $p =_{df} mv$.[21] So linear momentum is also a

[18] Wilson ([2010]) provides a further argument that resultant force and specific component forces cannot both be fundamental, on the grounds that positing both would lead to a problematic over-determination of fundamental powers.

[19] Endless examples could be given, but the reader may consult (Kleppner and Kolenkow [2010], pp. 2, 59; Morin [2007] p. 52, from a chapter entitled 'Using $F = ma$'; Taylor [2005], p. 13).

[20] Our thanks to F. A. Muller for discussion of this issue.

[21] This is all often made completely explicit. For instance, Goldstein *et al.* ([2013], pp. 1–2) begin by stating that linear momentum is defined from mass and velocity ($p = mv$) and then immediately state the law $F = \frac{dp}{dt}$.

metaphysically non-elite property, as shown by its being irreversibly defined as well as extrinsic. Thus, if anything, one sees further evidence from scientific practice that Link must be broken: linear momentum is yet another example of a metaphysically non-elite property that scientists are perfectly willing to invoke in scientifically elite laws. Again, the point of using the metaphysically non-elite property of linear momentum is to improve the utility of the equations, in this case by generalizing them to cover systems with non-constant mass.

Perhaps the most interesting version of this reply is to note that it proves preferable within classical mechanics (broadly construed) to move beyond Newtonian formulations altogether, and to move towards essentially mathematically equivalent Lagrangian or Hamiltonian reformulations, which possess the crucial added virtue of being coordinate-independent. At this point, the terms 'F' and 'a' do at last disappear from the elite equations. Can the friend of Link find any solace in this fact?

There are two major problems with this move. First, recall that the friend of Link is committed to term objectivism (Section 2.3). So she cannot accept the usual view that Newtonian, Lagrangian, and Hamiltonian mechanics are mere notational variants of some underlying classical mechanics, but must instead view these as subtly different rival theories, positing rival metaphysical pictures of fundamental reality (as is completely explicit in North [2009]). We are not objecting to this perspective. We are just noting that, on this perspective, for around one hundred years between the publication of Newton's *Principia* (in 1687) and Lagrange's *Mécanique Analytique* (in 1788), in the era when Newtonian mechanics reigned, scientific practice allowed terms such as 'F' and 'a' (or 'p') to appear in the scientifically elite laws, despite the clear metaphysical non-eliteness of the properties they denote. On our view, whatever happens once the rival approaches of Lagrangian and Hamiltonian mechanics come into view is irrelevant, insofar as it remains the case that in the Newtonian era, scientific practice allowed for metaphysically non-elite properties to be invoked in scientifically elite laws.

The second major problem with this move—which is perhaps more intellectually interesting in the end—is that there are other metaphysically non-elite properties invoked in the standard formulations of the scientifically elite equations of Lagrangian mechanics as well as Hamiltonian mechanics. In Lagrangian mechanics, the central dynamical law is usually formulated as: $\frac{d}{dt}\frac{\partial L}{\partial \dot{x}} = \frac{\partial L}{\partial x}$.[22] Here L (the Lagrangian) represents a metaphysically non-elite property of a system, defined as $L =_{df} K - V$, which is the total kinetic energy of the system, K, minus the total potential energy of the system, V.

[22] Typical formulations of Lagrangian and Hamiltonian mechanics use generalized coordinate q; we use x for simplicity and notational continuity.

And indeed K itself is a defined notion in Lagrangian mechanics (defined from velocity and mass), as is V (defined—in ways partly reminiscent of the definition of resultant force in Newtonian mechanics—as the vector sum of the gravitational potentials and the electrical potentials). There is no plausible way that we can see to think that the Lagrangian of a system (the difference between the total kinetic energy of a system and its total potential energy) is a metaphysically elite property.[23]

Likewise in Hamiltonian mechanics, the central dynamical law is usually formulated in terms of the Hamiltonian, H, defined as $H =_{df} K + V$.[24] The Hamiltonian is just as much a non-elite property as the Lagrangian, differing only slightly in its definition ($H =_{df} K + V$ instead of $L =_{df} K - V$, where K and V are themselves defined notions). So, if anything, one sees from the developments of classical mechanics from Newtonian mechanics with $F = ma$, through to Lagrangian and Hamiltonian mechanics, that various metaphysically non-elite properties are earning their keep in the scientifically elite laws at every stage. Why are Lagrangian and Hamiltonian mechanics worth working with, despite their invocation of metaphysically non-elite notions? Because their equations are beautiful and coordinate-independent, and because the scientist can use them to solve problems. Part of the reason why scientists bother to define notions like the Lagrangian and the Hamiltonian in the first place is to formulate simpler and more useful laws.

(Both the Hamiltonian and the Lagrangian take values at points in the state-space of the system, which has a dimension for each particle's position and momentum; typically, they can be defined in terms of the intrinsic properties (such as the mass or charge) and configuration of the particles in the system, but this isn't an essential feature of either. Taking the Hamiltonian or Lagrangian to be metaphysically elite properties would then require us to take the state-space of the system as fundamental; although some authors

[23] Yet another respect in which the Lagrangian may look to many like a non-elite property (which also applies to the Hamiltonian) is that it is a property of whole systems, and ultimately of the whole cosmos. We have been taking classical mechanics to be a theory that is fundamentally about the positions of particles, though it is possible to revise the 'positions of particles' picture by adding in a new fundamental external relation among the particles, namely, that of being part of a system with Lagrangian L (or Hamiltonian H), or to revise that picture even more radically to view the theory as fundamentally about the Lagrangian (or Hamiltonian) of the cosmos and not about particles at all. In the main text we remain neutral on these matters.

[24] Alternatively, H is sometimes defined as $H = p^2/2m + V(x)$, which explicitly represents the total energy of the system as a function of position and momentum, or just as the Legendre transform of the Lagrangian L. What is interesting about the case of H in Hamiltonian mechanics is that it is not only an explicitly defined notion, but it is also a notion that lacks a unique canonical definition. Instead, one finds H defined in different ways depending on the explanatory context. (For instance, the definition of H as the Legendre transform of L is—perhaps unsurprisingly—especially useful when showing how to derive Hamiltonian mechanics from Lagrangian mechanics.)

advocate state-space fundamentality for quantum mechanics (Albert [1996]; Loewer [1996]), to our knowledge no one has defended state-space fundamentality for classical mechanics. But this too would be a consequence of Link.)

And so, as we pass from Newtonian mechanics, through to Lagrangian mechanics and on to Hamiltonian mechanics, we find at least three different historical candidate scientifically elite laws within classical mechanics broadly construed, not a single one of which fits Link. With Newtonian mechanics, one finds that a plausible candidate for the central dynamical law invokes the metaphysically non-elite properties of acceleration and resultant force. And the others—the usual central dynamical law of Lagrangian mechanics and the usual central dynamical law of Hamiltonian mechanics—invoke the respective metaphysically non-elite terms 'L' (defined as $K - V$) and 'H' (defined as $K + V$, or as $p^2/2m + V(x)$, or as the Legendre transform of L). Every one of these three rivals provides a core example of scientific practice contrary to Link.

5.3 But our world is not Newtonian!

We think that these first two replies (Sections 5.1 and 5.2) to our case for our crucial first premise about scientific practice are the only serious replies. For if $F = ma$ is a candidate scientifically elite law (*pace* the second reply), and if acceleration and resultant force are not candidate metaphysically elite properties (*pace* the first reply), then our premise is vindicated. But we mention a third reply that we have encountered on several occasions, if only to fend off the misunderstandings it involves, and to take the opportunity to extend our result through to Schrödinger-style quantum mechanics.

This third reply begins by dismissing Newtonian mechanics as a false theory (as of course it is), and then declares that the situation with a false theory such as Newtonian mechanics sheds no real light on the connection between scientific practice and Link. We imagine this respondent saying, 'Link may fail in Newtonian scenarios, but for all that, it may still hold true in the actual world. You've shown nothing to call that into doubt'. (The same would then be said of Lagrangian and Hamiltonian scenarios.)

This third reply involves two misunderstandings. The first misunderstanding is empirical. Newtonian mechanics is false but quantum mechanics is still a going candidate for a true fundamental theory, and standard (Schrödinger-style) formulations of quantum mechanics involve Schrödinger's equation, whose time-dependent expression is: $ih\frac{\partial}{\partial t}\psi = \hat{H}\psi$ The term '$\hat{H}$' is the Hamiltonian operator taken up from Hamiltonian mechanics. So, in part due to the historical continuities of physics, our point about Hamiltonian mechanics (Section 5.2) remains applicable to quantum mechanics.

The second and perhaps deeper misunderstanding in this third reply is conceptual. For false scientific theories may still shed light on proposed metaphysical principles. The underlying issue is whether Link is tenable, and Newtonian mechanics (false though it may be) provides one with historically real and indeed paradigmatic examples of what scientifically elite laws might look like. We are arguing that this example reveals Link to be in conflict with scientific practice.[25]

Indeed, the rise of quantum mechanics furnishes yet another historical example of pragmatically driven choice as to the scientifically elite equations. For in the early days of quantum mechanics, it emerged that Heisenbergian matrix mechanics and Schrödingerian wave mechanics were mathematically equivalent.[26] Physicists largely adopted Schrödinger's wave mechanics, explicitly on grounds of familiarity. Thus Weinberg ([1994], p. 69) notes:

> The quantum mechanics [. . .] used in their everyday work by chemists and physicists today is not in fact the matrix mechanics of Heisenberg and Pauli and their collaborators, but a mathematically equivalent—though far more convenient—formalism introduced a little later by Erwin Schrödinger.

Weinberg ([1994], pp. 70–1) then clarifies that the convenience involved was largely a matter of mathematical familiarity to the physicists of the day:

> The Schrödinger equation is mathematically the same sort of equation (known as a partial differential equation) that had been used since the nineteenth century to study waves of sound or light. Physicists in the 1920s were already so comfortable with this sort of wave equation that they were able immediately to set about calculating the energies and other properties of all sorts of atoms and molecules.

Again, we are giving an argument from scientific practice (Section 3.1). We are arguing that scientists have routinely invoked properties they deem metaphysically non-elite to state the laws they deem scientifically elite. They have done so through Newtonian, Lagrangian, and Hamiltonian classical mechanics, continuing on through to Schrödingerian quantum mechanics. And

[25] Of course if one were only allowed to judge principles like Link by the lights of the true fundamental laws of our world, then there would be little basis for judgment one way or another, since it is not yet known what the true fundamental laws of our world are. Such a stance would not support Link but only a complete agnosticism.

[26] Matrix and wave mechanics were widely believed to be equivalent virtually from the start (Schrödinger claimed an equivalence proof in 1926). But as Muller ([1997a], [1997b]) details, the first equivalence proofs were invalid, the original versions of matrix mechanics and wave mechanics were actually inequivalent, and it was only with further theoretical developments in the next decade (due to von Neumann) that mathematical equivalence could in fact be proven to attain.

they have done so because doing so improves the practical utility of the equations (such as by rendering them simpler, more transparent, more modular, or even just more familiar to them in form). Thus, given that our understanding of the notion of a fundamental law should fit with scientific practice, it should be an understanding severed from Link. On this matter we agree with van Fraassen ([1989], p. 56):

> [...] actual science begins with theories not known to be true, but in any case, not very simple, not very strong, with regrettable sacrifices of simplicity for strength or vice versa, and formulated with predicates for which we claim no virtue beyond familiarity.

Indeed, we are saying something even stronger: actual science is not merely 'formulated with predicates for which we claim no virtue beyond familiarity', it is even formulated with predicates in which one can already detect the 'vice' of the metaphysically non-elite.

6 Consequences

So far we have focused on defending the first premise of our argument from scientific practice, on the expectation that this would be the controversial premise:

1. Scientific practice allows metaphysically non-elite properties to be invoked in scientifically elite laws.

But our argument does feature a second premise:

2. If scientific practice allows metaphysically non-elite properties to be invoked in scientifically elite laws, then metaphysically non-elite properties can be invoked in scientifically elite laws.

In our concluding section, we aim to explain why (2) is plausible, or at least more plausible than any insistence on following metaphysical preconceptions to the contrary. We also aim to explore the consequences of replacing Link with Loose, with respect to the motivations behind Link (Section 2.2), the question of which properties are metaphysically elite, and the metaphysical nature of lawhood.

We see these two aims as connected, insofar as we imagine that what it would take to overturn (2) (an instance of the generally plausible maxim 'respect scientific practice') would be showing that scientific practice proved confused or otherwise disastrous on this score. But we will argue that Loose allows one to preserve the core insights of, and motivations behind, Link; liberate the metaphysical idea of fundamentality; and motivate a deflationary view of laws as convenient summaries. In this matter, we think that scientific practice proves insightful.

6.1 Consequences for the motivations for Link

Does replacing Link with Loose lead to consequences so unacceptable that scientific practice should be discarded, and our premise (2) rejected? The first matter to consider is that of the motivations behind Link (Section 2.2). Presumably, what need there is to maintain Link should show up in the motivations for Link. But we will argue that the core motivations behind Link can actually be retained.

To see how the core motivations behind Link can be retained, it may be useful to think of Link as deriving from the following background idea:

> Background: Only eligible properties may be invoked in the scientifically elite laws.

Link is Background with 'eligible' interpreted as 'metaphysically elite'. But our point is that other interpretations are possible as well. For instance, one might interpret 'eligible' as merely 'natural enough'.[27] This would yield:

> Weakened Link: Only natural enough properties may be invoked in the scientifically elite laws.

After all, '*F*' and '*a*' in Newtonian mechanics are defined terms but the definitions are simple and straightforward, which we take to be a sign of a non-hideously gruesome property. Alternatively, one might go in for a more holistic and multi-dimensional conception of eligibility, on which families of properties get an eligibility score, which might be a joint function of their overall degrees of naturalness plus the usefulness of the equations they engender:

> Holistic Link: Only properties in the best family may be invoked in the scientifically elite laws.

There are many ways this could go and our point is not to advocate for one of them, but rather that one can accept Background without automatically going in for the conception of eligibility as metaphysical eliteness that yields Link.

Once it is seen that everything we have said—including our principle Loose—is compatible with principles such as Weakened Link and Holistic Link, it can be seen that all of the original rationales for Link can be retained. These were (Section 2.2):

1. Link helps provide a naturalist epistemology for the metaphysically elite properties;

[27] Along similar lines, Cohen and Callender ([2009]) suggest a 'relativized MRL' (Mill–Ramsey–Lewis) combined with a kind of 'modest realism' about kinds, according to which there are many different ways of carving nature at the joints. Their modestly real kinds look to correspond to the natural enough properties. There is also the option—endorsed in (Cohen and Callender [2010])—of going in for a kind of pluralistic, theory-relative view of the natural enough. For present purposes, we stay neutral between a theory-independent and theory-relative view of the natural enough.

2. Link keeps gruesome properties out of the scientifically elite laws; and
3. Link explains why positing new scientific laws can require positing a new metaphysical picture.

First, Loose plus either Weakened Link or Holistic Link would equally fit a naturalist epistemology. A connection between the scientifically elite laws and the metaphysical status of properties is still posited, only not one so tight as Link. Second, Loose plus either Weakened Link or Holistic Link would still keep gruesome properties out of fundamental laws, and thus serve to explain why Lewis's trivializing axiomatization $(\forall x)Fx$ does not automatically state the one and only scientifically elite law. After all, Lewis's F will almost certainly be hideously gruesome and holistically ineligible. Third, Loose plus either Weakened Link or Holistic Link does explain why positing new scientifically elite laws can require positing new and deeper joints of nature. If physicists succeed in explaining the contemporary standard model of particle theory by treating particles as composed of oscillating strings, they would then require oscillations to be natural enough or holistically eligible (respectively), and we would get some (albeit indirect) insight into fundamental metaphysical reality.

Indeed, both Weakened Link and Holistic Link preserve a connection between the metaphysically elite properties and the scientifically elite laws. They merely redraw the connection in a less direct but, we think, more realistic and informed way. So both would still sustain a naturalistic motivation for the Armstrong–Lewis posit of metaphysically elite properties. And so we think that, rather than undermining the Armstrong–Lewis posit, the rejection of Link actually helps liberate this posit from the false image of science to which it has been chained.

6.2 Consequences for metaphysically elite properties

What follows if Link is false is not just a liberation of the Armstrong–Lewis posit of metaphysically elite properties from a false image of science, but also a liberation of hypotheses about which properties are metaphysically elite and which laws are scientifically elite? For instance, Albert ([2000]; see also Loewer [2001]) argues that, in order to explain thermodynamics, the scientifically elite laws should be expanded to include:

- The past hypothesis: The initial conditions are low entropy.
- The statistical postulate: There is a probability distribution uniform on the standard measure over those regions of phase space compatible with our empirical information.

Space precludes a serious engagement with these ideas. Suffice it to say that we think that this is, at minimum, a very serious contender view. This is the sort of serious empirical hypothesis that ought not to be quickly dismissed on metaphysical grounds.

But Link would underwrite an overly quick dismissal of Albert's explanation of thermodynamics. For predicates such as 'low entropy' clearly do not denote metaphysically elite properties.[28] So the past hypothesis cannot be a scientifically elite law (and probably the statistical postulate cannot be a law either). That seems too quick. That seems a poor basis to dismiss Albert's serious empirical hypothesis.

But replacing Link with alternatives like Weakened Link or Holistic Link would allow one to consider Albert's account. The quick argument sketched above would not go through. (One might still try to argue against Albert's account using Weakened Link and/or Holistic Link, but that would take a lot more work, and we doubt any such argument would succeed.) So we think that breaking from Link may also help leave room for serious and potentially enlightening empirical hypotheses.

A second example: It has been argued that the metaphysically elite properties are holistic features of the world (see generally Campbell [1990]; Albert [1996]; Schaffer [2009]). Thus Schaffer ([2009], pp. 59–60) maintains that the metaphysically elite properties are distributional properties of the entire cosmos (for example, having such-and-such a total distribution of mass). Space precludes a serious engagement with these ideas. But suffice it to say that we think that there are interesting empirical and conceptual considerations (including quantum entanglement) that may favour this sort of holistic approach, and regard it as a serious contender.

But Link would equally underwrite an overly quick argument against such holistic approaches to metaphysically elite properties (whatever other virtues such approaches might have), since these properties do not seem to fit the scientifically elite laws. To illustrate, the mass properties invoked in candidate scientifically elite laws such as $F = ma$ are the mass properties of various individual particles (those subject to resultant forces, and thereby liable to accelerations), not the total mass distribution of the entire cosmos. Insofar as mass properties of individual particles and the total mass distribution of the entire cosmos cannot both be metaphysically elite (for the same combinatorial reasons that tell against component and resultant forces both being metaphysically elite; Section 5.1), such a holistic approach—whatever advantages it

[28] Thus Schaffer ([2007], p. 130; see also Cohen and Callender [2009], p. 14) comments: 'The Albert package contains predicates such as "low entropy" that refer to properties that are not perfectly natural—in microphysical vocabulary, that property is infinitely disjunctive. Hence the Albert package is *not even in the running* for the Lewis laws. It is ineligible from the start'.

might otherwise claim—would be out of the running. Again this seems too quick.[29]

So overall we think that breaking from Link may also help open the door for some further empirically serious hypotheses about scientifically elite laws and metaphysically elite properties that might be otherwise plausible, or that at least should not be dismissed out of hand. Again we find the replacement of Link with Loose to be liberating.

6.3 Consequences for lawhood

Suppose we are right that Link should be replaced by Loose. We think that this provides some lessons about the metaphysical nature of the scientifically elite laws. In particular, we think that certain influential and inflationary 'governing' views of the scientifically elite laws are falsified, while a deflationary conception of laws as 'summarizing' gains further support.

To illustrate the sort of view of the scientifically elite laws that we think gets falsified, consider Armstrong's ([1978], Chapter 24; [1983]) conception of such laws as relating sparse universals. Armstrong conceives of such laws as second-order necessitation universals of the form Nec(F, G), where F and G are first-order sparse categorical universals, which for Armstrong are the metaphysically elite properties (Section 2.1). But given that acceleration and resultant force are not metaphysically elite properties, they are not Armstrongian universals. And so $F=ma$ cannot have the form that Armstrong claims laws must have. Scientifically elite laws need not relate such universals. Armstrong's view of laws is thus inextricably bound to Link. Nor is there any straightforward way to restate Armstrong's view given Weakened Link or Holistic Link, since for Armstrong the merely natural enough and the merely eligible properties are not universals, and hence cannot be connected by second-order universals.[30]

Generalizing, we take Armstrong's conception of scientifically elite laws to exemplify a metaphysically inflationary picture of such laws as governing the fundamental:

> Fundamental Governing: Scientifically elite laws operate only on metaphysically elite properties to govern their distribution through space–time.

[29] Indeed, given the natural bias of scientists to equations applicable to lab experiments, there are natural practical reasons for scientists to prefer laws applicable to local systems. Aspects of laws that trace merely to the practical preference of experimenters ought not to play a role in evaluating what is metaphysically most fundamental. These are further examples of the sorts of practical considerations that exert a pull on scientific practice.

[30] Dretske ([1977]) and Tooley ([1977]) equally treat the scientifically elite laws as relations between universals, but do not commit to the thesis of universals as sparse. They thus uphold the idea of such laws as governing, but are not committed to the idea of such laws as governing the fundamental level of reality. Indeed, Tooley is explicitly an abundant Platonist about properties, treating all manner of properties as (necessarily) existing, and so acceleration and resultant force presumably do correspond to Tooleyan universals.

The picture of Fundamental Governing is familiar from a wide range of historical and contemporary authors, and traces back to the Cartesian conception of the scientifically elite laws as divine decrees (Milton [1998], p. 699; see also van Fraassen [1989], pp. 5–7; Beebee [2000], pp. 580–1). As an illustrative example, Maudlin ([2007b], p. 182; see also North [2003], p. 186) describes this picture as one strand of 'our initial picture of the world':

> [. . .] the fundamental asymmetry in the passage of time is inherent in our basic initial conception of the world, and the fundamental status of the laws of physics is, I think, implicit in physical practice. Both of the strands of our initial picture of the world weave together in the notion of a productive explanation, or account, of the physical universe itself. The universe, as well as the smaller parts of it, is *made*: it is an ongoing enterprise, generated from a beginning and guided towards its future by physical law.

This picture views scientifically elite nomic connections as extra threads woven through the fundamental fabric of reality, holding it all together and governing how the fabric rolls out through time, thereby allowing for a distinctive sort of explanatory connection between events that no mere deflationary conception of lawhood can match.[31]

Fundamental Governing requires Link. For if the scientifically elite laws are operating at the fundamental level to govern the distribution of metaphysically elite properties, then of course they can only relate the metaphysically elite properties. That is, given that the fundamental fabric of reality consists in instances of metaphysically elite properties in space–time, metaphysically non-elite properties are not to be found in this fundamental fabric, and hence are not in line for any imagined scientifically elite nomic threads to lace together. And so:

4. If scientifically elite laws operate only on metaphysically elite properties to govern their distribution through space–time, then only metaphysically elite properties can be invoked in scientifically elite laws.

Plugging in the denial of Link, one has (from (3)):

5. It is not the case that only metaphysically elite properties can be invoked in scientifically elite laws.

And so one gets the denial of Fundamental Governing:

6. It is not the case that scientifically elite laws operate only on metaphysically elite properties to govern their distribution through space-time.

[31] Thus Maudlin ([2007b], p. 178) says that a primary advantage of his primitivism about fundamental laws is that it authorizes 'a distinctive sort of explanation of the non-physical state of the universe that the Humean must, of necessity, foreswear'.

We conclude then that the influential but inflationary view of Fundamental Governing must be false. The scientifically elite laws need no longer be so rigidly linked with the metaphysically elite fundamental structure of nature. In a Newtonian regime, $F = ma$ cannot be governing fundamental reality, because acceleration and resultant force are not part of the fundamental fabric of reality in the first place. They are not there for any fundamental lawgiver to govern, nor for any necessitation universal to connect, nor for any fundamental nomic thread to lace. Moreover, there is no natural way to revive this fundamental governance picture given Weakened Link or Holistic Link, since the merely natural enough and the merely holistically eligible properties are still not part of the fundamental fabric of reality.

The proponent of Fundamental Governing might resist the claim (encoded in (4)) that Fundamental Governing requires Link, by distinguishing scientifically elite laws from scientifically elite law-statements, and holding that it is the former that govern fundamental reality but only the latter that can invoke the metaphysically non-elite properties. We can accept her distinction between scientifically elite laws and their statements so long as these notions are at least taken to have a direct correspondence (as they usually are). For instance, for Armstrong a scientifically elite law is a second-order necessitation universal Nec(F, G), which directly corresponds to a scientifically elite law-statement 'F-hood necessitates G-hood'. If scientifically elite laws have a direct correspondence with their statements, everything we say about the scientifically elite law-statement involving a defined predicate should carry over to the scientifically elite law it corresponds to invoking a metaphysically non-elite property, so the proponent of Fundamental Governing will find no solace.

But if the proponent of Fundamental Governing denies that laws and laws-statement (whether scientifically elite or not) have a direct correspondence, then we lose our grip on what she even has in mind by 'laws'. All she will find in the science textbooks are law-statements. And all she will find in scientific practice are law-statements in use. Scientific explanation involves law-statements, not laws. Separated and disconnected from the law-statements that do all the work in science, her 'laws' (scientifically elite or not) would become a mere metaphysical invention unworthy of our credence.[32] To clarify: we are not objecting to a distinction between laws and law-statements, but only to ways of drawing that distinction in which laws do not even correspond to law-statements, and thereby float free from their basis in science.

Given that Link is false, not only is Fundamental Governing false, but a rival deflationary conception of the scientifically elite laws as summarizing

[32] Thus when Weinberg ([1987], p. 64) speaks of 'our quest: to look for a simple set of physical principles [. . .] from which everything we know about physics can be derived', it should be clear that this quest is for law-statements. For these are the only things that can be involved in derivations.

gains support (Lewis [1986], Section 4; Beebee [2000], pp. 578–80; Loewer [2007]; Cohen and Callender [2009]). To illustrate the sort of view that we think gains support, consider Lewis's ([1983], pp. 366–8) conception of the scientifically elite laws as the axioms of that summary of all occurrences, cast in eligible terms, that optimally balances simplicity and strength. Of course we are rejecting Lewis's identification of eligible terms with metaphysically elite terms (Section 6.1). We—in potential agreement with Loewer ([2007])—would happily say instead that simplicity and related factors are playing a role, not just in the contest between rival summaries cast in antecedently eligible terms, but also in the very contest to be an eligible term. For we see that definitionally connected families of notions like position, velocity, and acceleration—and also like gravitational force, electrical force, and resultant force—are all available for summarizing a Newtonian world.[33]

Generalizing, we take Lewis's conception of scientifically elite lawhood to exemplify a metaphysically deflationary picture of laws as summarizing:

> Summarizing: Scientifically elite laws are the axioms of best summaries.[34]

There are three respects in which we take Summarizing to gain some abductive support. First, insofar as 'summary virtues' like simplicity and utility explain the presence of metaphysically non-elite properties in scientifically elite laws (Section 4), such laws are implicitly selected to serve the role of summaries. The most natural answer for why $F=ma$ finds its way into the Newtonian lawbook despite its use of transparently metaphysically non-elite properties is that the Newtonian lawbook with $F=ma$ achieves such a beautiful balance of simplicity and strength, as well as further summary virtues like transparency and modularity.[35]

Second, Summarizing—at least unlike one of its main rivals, Fundamental Governing—is not bound to Link. At most Summarizing seems tied to Background, and is compatible with various different ways of characterizing eligibility, including not just Link but also alternatives such as Weakened Link and Holistic Link. One merely needs to weaken Lewis's requirement that the

[33] An independently converging reason to reject Lewis's identification of eligible terms with metaphysically elite terms: there can be special sciences laws (Cohen and Callender [2009], pp. 10–11, 14–15).

[34] One should separate the Lewisian idea that the laws are summaries, from the additional Humean idea that the properties summarized are categorical. As Demarest ([forthcoming]) shows, one can also treat laws as summaries of possible power distributions. We think that the presence of derivative properties in fundamental laws favours the idea that laws are summaries, but is neutral on the question of whether the properties summarized are categorical or dispositional. So there is room for anti-Humeans to accept Summarizing by treating properties as inherently potent.

[35] See Hicks ([unpublished]) for an account of the scientifically elite laws that respects Summarizing while integrating these further theoretical virtues (going beyond just simplicity and strength), in ways that helps resolve some standing problems for Lewis's account.

summary be cast in perfectly metaphysically elite terms, and the rest of the picture can remain intact.

Third, Summarizing is threatened by intuitions generated by the picture of scientifically elite laws as governing the fundamental (Carroll [1994]). The deflationary conception struggles to capture the intuition that Maudlin nicely describes in terms of the universe being 'guided towards its future by physical law'. Insofar as we have shown that this influential intuition is bound to Link and thus tied into a false metaphysical image, we have thereby defused what might be the main threat to Summarizing.

By way of conclusion, we think that the scientifically elite laws serve two masters: they answer to nature, but they equally answer to humans hoping to fathom nature. Metaphysically non-elite properties can thereby earn their keep in scientifically elite laws since a minor loss in fit to nature may be more than offset by major gains in practical matters useful for us, such as simplicity, transparency, and modularity. In other words, given that nature has this structure, and that humans have these hopes, it may prove overall best to summarize nature in our own words.

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