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Laws and natural philosophy

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For the period surveyed in this volume, the last century stands out in virtue of a twin innovation. One is the thought that physical objects are subject to laws. Laws govern material bodies too, not just mankind and society. The other is that the science of nature must be built on them; it should have laws at its foundation. This joint development is of enduring interest, because it was a radical departure from what came before, and it remains a distinguishing mark of science as we know it.

This chapter analyzes that twin innovation in its historical context. I begin with two major attempts to explicate the notion of a law of nature then (sec. I). Next, I examine a popular idea at the time, viz. that laws of nature are about causes (sec. II). Then I end with a closer look at the sort of sentences that were called laws in that century (sec. III). As with the other chapters in this volume, the intent is pedagogical: to offer college teachers a helpful survey of an idea central to early modern science.

I. What laws were

Current philosophy of science is home to sustained debates about what it is to *be* a law of nature. These debates rest on a shared intuition and two framing assumptions. The intuition is that there is a real difference between sentences like these:

1. All masses exert gravity on other masses.
2. All the coins in my pocket are dimes.

The assumptions are: a law of nature is a universal generalization ('All *X*s are *Y*s'); and any candidate account of lawhood must vindicate the intuition above —it must entail that (1) counts as a law of nature but (2) does not.

However, this way of framing the issue first arose in 20th century logical empiricism. Early modern thinkers approached the question on different terms. Many then expected that answers be consilient with other domains of philosophy. In particular, with theology (or at least with the idea that the world has a creator) and philosophy of mind. Accordingly, two broad answers emerge after 1600. I call them 'injunctionism' and 'principlism,' respectively. Note: these are interpreter's categories, not agent categories.[1]

Injunctionism is the view that laws of nature are *divine mandates*. They are commands issued to every natural thing. God is the issuing authority, or legislator. And, every object obeys them unconditionally—without exception, save perhaps in the case of miracles:

> God is the author of nature; he created and established it as he pleased. And, he did not prescribe to his own power the laws that he decreed for nature. ... God, who made the laws of nature that he pleased, is not obliged to follow them. (Bernier 1684: ii.106, iii.24)
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> [Deists face] the insuperable difficulty that ... the laws of motion, without which the present state and course of the world could never be maintained, did not necessarily spring from the nature of matter, but depended upon the will of the divine author of things. (Boyle 1738: 245)
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> From [God's perfectly free will], then, have all the laws that are called laws of nature come, in which many traces of the highest wisdom and counsel certainly appear, but no traces of necessity. (Cotes 2008 [1713]: 77)

This answer often went hand in hand with *voluntarism*, the idea that God willed these laws to obtain, or that they are outcomes of an act of willing on God's part. The laws qua propositions state the content of this act of volition: literally, what God willed nature to do.[2]

The other answer, principlism, emerged later. Making sense of it is harder, for two reasons. For one, it is my term: it does not reflect *their* understanding

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[1] That is, they were not created then, nor used then to denote their understanding of lawhood. I created these categories, for the sake of *our* clear understanding and tracking of conceptual relations. A brief account (of the distinction between agent's and historian's categories) is Anstey 2015.

[2] Voluntarism was really a thesis with two variants. Strong voluntarism was the idea that God wills laws (for nature to obey), and his willing is a brute fact: there is no further, rational explanation for it. Weak voluntarism granted that God did will the laws, but claimed that his will [*voluntas*] was constrained—or at least guided—by certain factors, e.g. the Principle of Sufficient Reason, the demands of wisdom, and the like. Leibniz was a case in point.

of 'law,' because the figures in this group did not *have* an overt, explicit understanding of it. For another, I use 'principlism' as a mere identifying label, not a semantic source of insight. I do so to reflect their linguistic habit: they used 'law,' 'principle,' and 'rule' as interchangeable terms. John Wallis and Robert Boyle in England were cases in point, as was Edmé Mariotte in 1670s France. They referred to certain propositions as laws, principles, and rules—with no indication that they saw any difference.[3] In plain English, then, some thought a law is a rule or principle, but they left these terms unanalyzed. So, we must analyze it on their behalf. Then let us try that here.

Principlism is the view that a law is a sentence privileged on pragmatic grounds: it *does* certain things—of value for inquiry—that other propositions cannot do, though they too are part of science. In particular, a law could be valuable on four different grounds. **Epistemic**: some laws were very strongly confirmed, thus able to channel warrant to other parts of science downstream from them. For some, that strong evidence was empirical: "in mechanics, it is a very certain axiom that, on account of the motion that comes from bodies being heavy, their common center of gravity cannot rise."[4] For others, it was a priori, or non-empirical:

> The general principles of the rules of motion are called the laws of motion. ... Nowadays only those ignorant of Mathematics do not know that, in the rules of motion, there are general principles *from which* these rules can be derived. These principles once established, the rules of motion, i.e. of impact, were proved from them. Mathematicians assume these laws without proof; but it behooves the Metaphysician to *demonstrate* them. (Wolff 1731: §§ 302-3; my italics)

Explanatory: laws counted as the explanans of last resort:

> There are certain general laws that run through the whole chain of natural effects. These ... are by men applied as well ... to the explaining the various phenomena: which explication consists only in showing the conformity any particular phenomenon has to the general laws of nature. (Berkeley 2008: 93)
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> ...the [method of] synthesis consists in assuming the causes discovered, and established as principles, and by them explaining the phenomena proceeding from them, and proving the explanations. (Newton 2008: 187)

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[3] For textual evidence, see Steinle 2008: 222, 225.

[4] See Huygens 1673: 382. In modern terms, Huygens means that, in a weak gravity field, a system of masses does not gain potential energy.

Predictive: laws counted as the key premises in deductive arguments where the conclusion asserts a state of affairs not yet observed, but observable. This is paradigmatically the case with Newton's four laws in *Principia:* the three laws of motion, and the law of universal gravitation. From the former, in Book I he derived a number of theorems about forces, accelerations, and orbits. These theorems plus the law of gravity enabled Newton in Book III to make novel predictions:

> All of the moon's motions, and also their inequalities [viz. changes in speed], follow from the principles I have expounded above. ... Also, there are certain inequalities that astronomers so far *have not yet observed.* Due to them, the moon's motions are so perturbed that, *until now*, we have been unable to reduce them to a certain rule *by means of some law.*
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> Comets move in conic-section orbits, with foci at the center of the sun. Their radii (drawn to the sun) sweep areas proportional to the times in which they are swept. (Newton 1687: 427-8, 480; my italics)

Constructive: laws are fruitful sentences. In the course of theory building, it turns out that we need to reach for these sentences over and over—just as some theorems in mathematics count as lemmas because they are often cited in the course of many, disparate proofs.[5] Alternatively, some items counted as laws or principles because they helped organize vast bodies of knowledge. Such were the 'rules of collision' in post-Cartesian science, and various propositions counted as principles in rational mechanics then:

> We can reduce all the principles of mechanics to three, viz. the law of force of inertia, of composite motion, and of equilibrium. I hope to show in this treatise that the *whole* science of mechanics can be *deduced* from these three principles. (d'Alembert 1743: 3; emphasis mine)

The epitome of an organizing law was a statement now known as 'Lagrange's Principle.' It resulted from taking a very general law of statics (the principle of virtual work), a novel way of thinking about masses in motion (d'Alembert's Principle, so called), and then inferring from them a law that applies to any

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[5] One such nomic lemma was the Parallelogram of Forces. Another was the Law of Inertia, in its contrapositive form, i.e. the statement that, if a body does *not* move uniformly in a straight line, then *there is a net force* acting on it.

mechanical system, be it at rest or in motion. Though Lagrange made full use of it in 1788, he had his insight above much earlier:[6]

> Geometers have long accepted the principle [of virtual work] as the fundamental principle of equilibrium. ... This principle of statics, if we combine it with the principle of dynamics given by Mr. d'Alembert, results in a general formula that contains the *solution to all the problems* on the motion of bodies. (Lagrange 1873 [1764], 10, 12; my italics)

These pictures (injunctionism and principlism) were the two main contenders by the mid-18th century. Now I take a brief critical look at them.

Brief assessment

Injunctionism seems to have gone extinct after Malebranche and Berkeley.[7] As a position held sincerely, however, it faces a dilemma. Either 'injunction' functions here as a metaphor, and then the thesis (that laws are injunctions) fails to genuinely explain, because the exact *literal* content of that metaphor is obscure. Or, 'injunction' is meant literally, but then to say that laws are injunctions to *unminded* things is a category mistake.

Historical figures then were sensitive to this danger. Ralph Cudworth and Robert Boyle worried that the concept of a mandate, or injunction, is only intelligible if it is aimed at—it has as its subjects—minded agents. Namely, entities that count as capable of understanding, in some sense: understanding the *content* of that mandate, and its *imperative* force, or that they must obey it. However, material bodies, the things to which laws of nature are supposedly mandated, are prima facie mindless. That makes them ostensibly the wrong kind of thing to govern, or issue injunctions to. Then saying that a law of nature is an injunction issued to unminded subjects seems a category mistake:[8]

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[6] For Lagrange's work in mechanics, see the chapter by Stan in this volume. There were two senses to the term 'principle' in rational mechanics at the time, viz. heuristic and evidential; for extensive discussion, see Brading & Stan 2023, who call them 'E-principles' and 'H-principles,' respectively. Often, 'law' was used as a synonym for 'principle' in the evidential sense.

[7] Though see Ott 2019, who argues for the continued viability of Berkeley's original view.

[8] For further examples, see Steinle 2008: 227; for Boyle's own picture of laws of nature, see Anstey (2000: 158-85).

> The works of nature [are] dispensed by a *divine law and command*, yet this is not to be understood in a vulgar sense, ... because inanimate things are *not* commandable nor governable by such a law. ... and therefore besides the divine will and pleasure, there must needs be some other immediate *agent* and executioner provided, for the producing of every effect. (Cudworth 1678: 147; my italics)

> I look upon a law as a moral, not a physical cause; as being, indeed, but a notional thing, according to which, an *intelligent and free agent* is bound to regulate its actions. But inanimate bodies are utterly *incapable* of understanding what a law is, or what it enjoins, or when they act conformably or unconformably to it. (Boyle 1738 [1690]: 245; my italics)

In sum, if the claim 'laws are injunctions to bodies' is meant literally, it is either unintelligible—an *explanatio per obscurius*—or a category mistake. This problem is not hard to see, and yet it is striking how little the early moderns stopped to ponder and grapple with it. I know of just two explicit attempts to face up to the threat of incoherence behind injunctionism.

One attempt, by Robert Boyle, bites the bullet and admits that talking about laws of nature is improper speech. It simply denies that such laws are *literal* injunctions. Rather, it claims, we call them laws *by analogy* with literal laws, or injunctions issued to rational agents. The analogy is structural: it amounts to similarity of order. Laws of ethics or politics state an order, or way of ordering human subjects (and enjoin that ordering to them). And, laws of nature describe an order among things: a way of ordering bodies and events in terms of constant succession, fixed ratios, or conserved quantities:

> There is often some *resemblance* between the *orderly and regular* motions of inanimate bodies, and the actions of agents, that proceed conformably to Laws. And I, sometimes, scruple not to speak of the laws of motion and rest, that God has established among things corporeal, and, now and then, to call them the laws of nature. But, in strictness, to say that the nature of this or that body, is but the law of God prescribed to it, is an *improper*, and *figurative* expression. (Boyle 1738 [1686]: 111; my italics)

In sum, laws of nature are *als ob* mandates: as-it-were injunctions, not literal commands. Now this view comes at a cost: it is not explanatory. It lacks insight into what laws of nature *really* are, without metaphor or pretense. So, it frustrates the desire for genuine understanding, which requires literal language in the explanans, not metaphors.

The other attempt denied that their subjects—the entities that laws of nature bind, or obligate—are really unminded. This solution came in three variants. The first was that laws are divine commands to a class of incorporeal agents called 'plastic natures.' The second construed them as commands to a single agent, called the 'Spirit of Nature.' The third saw them as commands that God chooses for himself: they guide his *own* actions. All these variants regarded the targets of laws-qua-injunctions as true subjects: entities capable of understanding and action based on it. The third variant above was Berkeley's solution. He construed laws of nature as divine rules for certain divine actions:

> The ideas of sense ... have likewise a steadiness, order, and coherence, and are not excited at random, ... but in a regular train or series, the admirable connexion whereof sufficiently testifies the wisdom and benevolence of its Author. Now the set rules or established methods wherein the *mind we depend on excites in us the ideas of sense*, are called the laws of nature. (Berkeley 1871 [1734]: 170f., §30; my italics)

The mind that *we* depend on is God's mind: "Berkeleyan laws are the most general rules God follows in producing sensations" in minds like ours (Ott 2019: 1). Another variant of this view came from Samuel Clarke. He regarded laws as God's self-imposed for his acting on *bodies* (not on human minds) by effecting kinematic changes in them:[9]

> [The world] depends every moment on some superior being for the preservation of its frame, and that *all the great motions in it are caused by some immaterial power* ... perpetually and actually *exerting itself* every moment in every part of the world. ...
>
> So that all those things which we commonly say are the *effects* of the natural powers of matter, and *laws of motion;* of gravitation, attraction, and the like; are indeed (if we will speak strictly and properly) the effects of *God's acting* continually and every moment, either immediately by himself, or mediately by some created *intelligent* beings. (Clarke 1738: 601, 697; my italics)

In both cases, then, the laws of nature are injunctions that God issues to *himself:* genuine injunctions, fit for minded subjects.

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[9] For additional discussion, see also Harrison 2019 and Steinle 2008.

The other two variants came out of a group we call the Cambridge Platonists. In a nutshell, their attempted solution went as follows. 1. Laws are divine mandates issued to 'spirits.' 2. Bodies *have* spirits associated with them. 3. Ergo, laws of nature are mandates—literal commands—that govern a certain class of spirits.

Some clarification might help here. Behind premise (1) is the Christian idea that God issues laws that bind not only human agents, but also beings that count as unembodied spirits, such as angels. In support of premise (2) some devised a whole theory about certain entities they called 'plastic natures.' They were incorporeal—so, they counted as *spirits*, not bodies—yet able to act on bodies. There were many such plastic natures; one per kind of body, at least. Henry More, another Cambridge Platonist, had just one, which he called the 'Spirit of Nature,' and also the 'hylarchic principle.'[10]

> Wherefore since neither all things are produced fortuitously, or by the unguided mechanism of matter, nor God himself may reasonably be thought to do all things immediately and miraculously; it may be concluded, that there is a *Plastick Nature* under him, which, as an inferior and subordinate instrument, doth drudgingly execute that part of his providence, which consists in the regular and orderly motion of matter. (Cudworth 1678: 150)
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> The *Spirit of Nature* therefore, ... is a substance incorporeal, but without sense and animadversion, pervading the whole matter of the universe, and exercising a plastical power therein according to the sundry predispositions and occasions in the parts it works upon, raising such phenomena in the world, by directing the parts of matter and their motion, as cannot be resolved into meer mechanical powers. (More 1659: 450)

In effect, then, laws of nature govern bodies indirectly: by mandating to *spirits* to act *on* bodies in accordance with the content of the laws. That enabled Cambridge Platonists to assert that laws of nature are injunctions in the literal sense: commands that God has issued to agents, be they many plastic natures or just one Spirit of Nature. For Clarke, some laws might be injunctions that God issued to some minded agency below himself:

> All things that are done in the world, are done either immediately by God himself, or by *created intelligent beings:* matter being evidently not at all capable of

[10] Etymologically, 'hylarchic' denotes something that has governing authority (*arkh*ē) over matter (*hyl*ē).

> any laws or powers whatsoever, any more than it is capable of intelligence. (Clarke 1738: 697; my italics)

Principlism, the idea that laws are rules or principles, has a problem peculiar to it: *equivocation*. It construes the terms 'rule' and 'principle' in several but distinct senses. For some, a rule denoted a fixed proportion between two quantities; for instance, the 'rule' that, when a light ray passes through two media, its respective angles of refraction are in a fixed proportion. For others, it denoted a regularity, or repeatable pattern.[11] Yet others let 'rule' denote an if-then proposition, or conditional statement. For instance, Kepler's third rule: if a planet moves around the sun in an ellipse, its periodic time squared is proportional to its average distance cubed.

It is hard to discern what the genus concept is—the general notion of rule of which these three senses would count as species. That makes it hard to identify the precise content of the idea that laws of nature were rules. *Was* there a single idea?

II. Laws and causes

Some thought the new science (that laws of nature meant to ground) aimed at causal knowledge—it aimed to discover "true physical causes" (Boyle 1772: 165). Thus it is worth asking, how did early moderns think that laws relate to causes; and how good were those answers? Two distinct answers emerged at the time. One had it that *laws* were causes. The other was that laws were *about* causes. I present them in turn.

The first answer requires some preliminaries about a tacit assumption. Nowadays we take it for granted that, at least as far as scientific knowledge goes, the only causes are efficient causes. Some early moderns, however, subscribed to a richer picture, inherited from Aristotle. On that picture, a thing or event—for instance, a stone falling to the ground—had four causes: material,

[11] See the examples from Copernicus, Regiomontanus, and Kepler in Ruby 1986: 354-6.

formal, efficient, and final (aim-directed). This richer picture allowed some to claim that laws of nature are *formal causes* of things:[12]

> We should study matter, and its structure, and structural change, and pure act, and the law of act or motion; for forms are figments of the human mind, unless one chooses to give the *name of forms to these laws* of act. ...
>
> The task and purpose of human Science is to find for a given nature its Form, or true difference, or causative nature.
>
> ... nothing exists in nature except individual bodies which exhibit pure individual acts in accordance with law.... It is *this law* and its clauses which we understand by the term Forms. (Bacon 2000 [1620]: 45, 102, 103; my italics)

This leaves it open that the efficient cause (of the changes described by the law) could be other things; or even God, the primary cause.

The second answer was that laws assert facts about causes, viz. efficient causes in nature. Subscribers to it included Newton, it seems:

> By this way of analysis we may proceed from compounds to ingredients, and from motions to the forces producing them; and in general, from effects to their causes, and from particular causes to more general ones, till the argument end in the most general. (Newton 2008 [1731]: 187)

Plainly put, they thought that laws are statements about cause and effect within broad classes of objects in nature. I call this view 'causalism.' It seems to have remained popular into the 1780s, when Kant, for instance, asserted it with confidence. However, as science progressed—especially mechanics, which many then took to be *the* foundation for the rest of science—causalism about laws looked less and less plausible.[13]

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[12] Schliesser 2021 (chapter 5) explores this idea and its possible influence on Newton. More broadly, the Aristotelian notion of form had a complex fate then. The early moderns variously rejected it, defended it, or reappropriated it for their novel purposes; see the helpful survey by Anstey 2015. In regard to Bacon, however, some scholars think his construal of laws as forms was an aphoristic thought, not considered doctrine: "no one has ever succeeded in subsuming everything that Bacon said about laws and forms into a single coherent account" (Milton 1998: 686).

[13] To be sure, most figures at the time did not acknowledge this tension (between the philosophical tenets of causalism and the practice of exact science. D'Alembert and Lagrange were the only exceptions.

In particular, the evolution of exact science after 1680 raises a novel question: what aspect of a law *justifies the distinction* between cause and effect? This question is surprisingly difficult; consider.

Cause and form. Suppose we say it was the form of the laws that justified the distinction. Here, 'form' might denote mathematical structure or logical syntax. In either version, however, this answer leads to a dead end. Take mathematical form first. After Leibniz's version of the calculus comes to dominate Continental Europe, the laws of mechanics, be they general or specific, come to be stated as equalities between two magnitudes. For instance:[14]

$$\sum m_i v_i^2 = 0 \; ; \qquad\qquad \int \mathbf{F} dt \; = \; \Delta(m\mathbf{v})$$

It is anyone's guess which side of such an equality might count as the cause, and why. Any equality can be flipped—we can move the left-side terms on the right, and vice versa—and the equality remains true. In fact, consider that all the expressions below are equivalent; they have the same empirical content, and follow from one another:

$$\mathbf{f} = m\mathbf{a}; \qquad m\mathbf{a} = \mathbf{f}; \qquad \mathbf{f} - m\mathbf{a} = 0; \qquad m\mathbf{a} - \mathbf{f} = 0.$$

That makes it hard to see how form alone could single out cause and effect. Prima facie, then, nothing about the mathematical structure of such statements underwrites claims that expressions like them are causal laws.

Now consider logical form. In Newton's *Principia*, many laws (including the results nowadays known as Kepler's laws) are stated in the form of if-then sentences.[15] Specifically, he assumes the if-part, and proves that the then-part follows from it (plus premises already available) by deduction and diagrammatic reasoning. For instance, consider Theorem 7 of Book I, or Newton's version of 'Kepler's third law':

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[14] The first expression states Leibniz's Conservation of Vis Viva; the second states Newton's second law of motion as it was used then.

[15] Newton proved Kepler's laws (so called) as theorems, or 'propositions.' E.g., Kepler's second law is Proposition I of the *Principia.*

(α) If bodies move in elliptic orbits under an inverse-square force, then the squares of their periodic times are proportional to the cubes of their major axes. (Newton 1687: 56)

We might be tempted to claim that the if-part (the antecedent) singles out the cause, because the consequent is conditional on it obtaining, just as effects depend upon their causes.[16] However, Newton also proves that sometimes—in certain mechanical contexts—the logical implication also holds in reverse. For instance, consider Corollary 1 to Prop. 45 of Book I:[17]

(β) If a body moves in a precessing orbit, then it is acted on by a central force proportional to $R^{[(n/m)\hat{}2\,]-3}$. (Newton 1687: 141-2)

This subverts the idea of using logical form as a clue to causation in laws. Specifically, if forces count as causes of motion because of the logical syntax of proposition (α) above, then (β) entails that forces are effects of orbital motion, which thus count as a cause of force. An awkward outcome.

Strikingly, one thinker then might have seen that problem. Berkeley in *De Motu* denied that, in a conditional sentence (embedded in physical theory), the antecedent states the cause and the consequent the effect:[18]

> It is not ... in fact the business of physics or mechanics to establish efficient causes, but only the rules of impulsions or attractions, and, in a word, the laws of motion, and *from the established laws to assign the solution*, not the efficient cause, of particular phenomena. (Berkeley 1951: 40, § 35; my italics)

In sum, logical form alone does not quite support causalism, or the view that laws of nature describe causes and effects.

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[16] In essence, this was Kant's picture in the 1780s. In the First Critique, he argued that we have two pairs of a priori (non-empirical) concepts, viz. ground/consequence and cause/effect. The first pair denotes any two propositions in an if-then syntactic relation. Kant argued that the second pair (cause and effect) results from the first by 'schematization'—roughly, by injecting the first, purely logical pair with semantic content that has temporal aspects (namely, the earlier-than relation), due to his intuition that causes precede their effects.

[17] In the exponent $[(n^2/m^2) - 3]$, the ratio m/n is the rate of precession. The relation (β) is known as the the 'apsidal precession theorem,' because it relates quantities of motion in a precessing orbit.

[18] For extensive discussion of the implications of Berkeley's view here, see Ott 2019.

Cause and definition. Another possibility is to point to definitions. Specifically, some early modern theories of physics rested on a dual foundation: laws of motion and definitions.[19] On this construal, forces get *defined* as causes; all laws are laws of force; and so all laws are really causal expressions. This idea, however, faces its own difficulties; three, in particular.

First, some versions of mechanics then did not have 'force' as a term in their foundation. They were *forceless* theories, in effect. The chief example is Lagrange's first mechanics; as it happens, it was the most powerful theory available by 1760. In that theory, the fundamental concept is 'action,' defined as the path integral $\int ds$ of the momentum $m\mathbf{v}$ (for each particle in a system of interacting masses). Lagrange did not need a concept of force, and so his mechanics does without a definition of forces as causes.[20]

Second, some theories then did have laws as their basis, but they were explicitly non-causal laws. An example is d'Alembert's mechanics, a theory stronger than Newton's, in terms of descriptive scope. D'Alembert asserted trenchantly that there *are* causes (of change in motion), but they are *unknown* to us.[21] He *defined* some forces as non-causal properties; and other types of force as quantities (differentiable functions) but *denied* that such forces are causes of change:

> In general, we call a power or a moving cause anything that obliges a body to move. ... We have *no* precise and distinct idea of the word 'force,' unless we restrict it to designate some *effect* ... If we wish to reason from clear ideas alone, then by 'force' we must understand *just the effect* produced in overcoming or resisting an obstacle. (d'Alembert 1743: xxi, xx, 4; emphasis mine)

More importantly, his mechanics is built from laws of acceleration and momentum, not of force.

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[19] The epitome is Newton's *Principia*, with its seven definitions and three laws (1687: 1-5, 12-20). Historically, the distant source of this approach to foundations is Euclid's *Elements*, which rests on 23 definitions, five postulates, or 'axioms,' and five 'common notions.'

[20] See also the chapter on mechanics by Stan in this volume.

[21] Except for one cause that he counted as transparently knowable, namely, impulse—change of velocity in collision—caused by bodies being *impenetrable*. Not by there being a *force* of collision. And, the one force he admitted in his mechanics does not count as a cause: "Following Mr Newton, I call force of inertia the *property* that bodies have of remaining in their state" (d'Alembert 1743: 3; my italics).

> To demonstrate the [fundamental] principles of my mechanics, my approach has been to derive all three principles merely from the concept of motion, considered in the simplest and clearest way. All we grasp distinctly about motion is that a body crosses a certain space over a certain time. Then we ought to derive the principles of mechanics *solely from this fact*, if we wish their demonstration to be clear and precise. Unsurprisingly, then, my derivation does without 'motive causes,' and considers merely the motion they produce. And, it banishes entirely the notion of forces inherent in moving bodies—entities obscure and metaphysical, which do nothing but cover in darkness a science that by itself is clear. (d'Alembert 1743: xvi; my italics)

Thus d'Alembert and Lagrange separately articulated powerful versions of mechanics that rest on explicitly non-causal laws.

Third, it is not enough to define force as a type of cause. One must show as well that the definition *refers*: that 'is a cause' picks out a genuine property of forces (if forces exist at all). We can put this point in historical terms, to illustrate it in context. The early moderns distinguished between 'nominal' and 'real' definitions. The former merely spelled out the semantic content of a term [*nomen*]. It bracketed completely the question of whether the term refers, hence also the question whether anything actual had the properties listed by a nominal definition. A 'real' definition would capture the true essence of a real thing [*res*]. Early modern figures cautioned against confusing the two; for instance, the *Port-Royal Logic:*

> We sought to spell out this distinction at some length, because philosophers habitually commit two errors that involve it. The first error is mistaking the definition of the word for the definition of the thing, thereby *attributing to the latter what merely belongs to the former*....
>
> In Part I we discussed nominal definitions at length, and showed that we must not confuse them with the definitions of things. For nominal definitions are arbitrary, whereas definitions of things do not depend on us; they depend on what is contained in the true idea of a thing. We must not take such definitions to be principles. Rather, we must regard them as propositions that must be *confirmed with reasons*, and which *can be contested.* ([Arnauld & Nicole] 1668: 116, 198; emphasis mine)

In sum: if someone claims that laws are causal because they are laws of force and forces are defined as causes—then she must show that definition to be

real, not nominal.[22] But, if anyone before 1750 had tried to show that at all, it remains to be seen.

III. Which laws?

Asking what they thought a law *was* is not the only source of insight into that notion at the time. We can learn much by looking at the sort of propositions that the early moderns did call laws. This approach reveals two patterns of verbal behavior among them—two distinct habits of talking about laws. I call them *austere* and *exuberant*, respectively. They worked as follows.

Austere discourse. One way of talking resulted from the commitment, often tacit, to reserving the term 'law' for only a very small number of items regarded as privileged, or special. For some, that privileged status was *epistemic:* a proposition counted as a law only if it had the highest degree of certainty—ideally, demonstrative certainty, resting on evidence secure against any chance of future disproof. For others, laws were special on *pragmatic*, or architectonic grounds: they were the few propositions that supported, be it evidentially or explanatorily, entire theories or disciplines built upon them.

For that reason—the requirement of privilege, epistemic or pragmatic—in the austere picture only a few items deserve to be called laws. They earn that title in two ways. A proposition counts as a law if it is fundamental on two counts: it is maximally general (it applies to all bodies, not just one natural kind), and it counts as a last *explanans:* the process of explaining change in nature eventually ends with us citing such laws. Alternatively, it counts as a law on epistemic grounds: the evidence for it is very strong. Strong enough to make that proposition 'morally' certain: more certain than inductive generalizations, though not as certain as a priori truth.

Descartes and his followers preferred the austere discourse about laws. In his epoch-making *Principles of Philosophy*, only three propositions earn that title. From them, he deduced various results, including seven propositions that *others* called laws, but not him. He referred to them as 'rules': the rules of collision. After Descartes, his disciples—Regius, Cordemoy, Rohault, and Regis—were likewise sparing in their use of 'law.' And so were John Wallis and

[22] As illustration, consider the contrast with the status of definitions in Euclidean geometry. Euclid defines a certain object, or type of figure, and then *proves* that at least one such figure *exists.* For instance, in Book I of the *Elements*, Definition 20 defines an equilateral triangle, and Proposition 1 shows that equilateral triangles exist. It does so by constructing a triangle with three equal sides.

Christopher Wren, in 1660s England. They chose to call law just one or two propositions, namely, the key premises in their respective derivations of the rules of impact, or collision.[23]

The poster child for linguistic austerity about laws was Huygens. Though his contributions to theory building were enormous—he was second only to Newton, in that century—Huygens almost never referred to his fundamental premises as laws. Rather, he would call them 'hypotheses,' 'propositions' or 'theorems.' Even very important items that *we* call laws without hesitation, such as the law of inertia or the Second Law:[24]

> Hypotheses.
>
> I. If there were no gravity nor any air resistance, a body once in motion will continue at the same speed, in a straight line.
>
> II. As it happens, by the action of gravity, whatever its origin, bodies move by a motion composed of the uniform translation they had (in some direction) and a downward motion due to gravity.
>
> III. We may study either motion separately; and they do not interfere with each other. (Huygens 1673: 21)

In his view, just one item deserved the title of law, for it was both general and very certain:

> I have noticed an admirable law of nature. I can *demonstrate* it for the case of spherical bodies, and it seems to be *general*, whether the bodies be soft or hard, and no matter if their collision is head-on or oblique. It is this: the common gravity center of two or more bodies always moves in the same direction at the same speed, before and after their impact. (Huygens 1669: 24; my italics)

In Newton's *Principia*, Corollary IV of *his* laws entails Huygens' law above as a special instance (for the case of collision, or impact).

Exuberant discourse. The other type of speech was the linguistic pattern of using 'law' for many sentences that differed greatly. Many sentences: quite a few more than the three or four propositions that Cartesians and other austeres

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[23] For textual evidence and discussion of Descartes and his principles, see Roux 2001. For Wallis and Wren, see the discussion in Steinle 2002: 199-200.

[24] Huygens' Hypothesis I is a version of the Law of Inertia; his Hypotheses II and II are jointly equivalent to Newton's Second Law restricted to collisions and terrestrial gravity.

were prepared to call laws. Greatly different, because they belonged in very different disciplines, and differed greatly in scope, content, logical structure, and epistemic credentials.

The figure who gave his posterity license to speak exuberantly about laws was Bacon, who distinguished between 'universal' laws (binding for all of nature) and 'municipal' laws, ordained for this or that limited domain of bodies. Boyle appears to have acted on that license. He acknowledged that there are "catholic [viz. universal] laws of motion," of nature, and even "laws of the universe" that govern "things corporeal" in general.[25] And yet, Boyle thought there are also hydrostatic "laws of the equilibrium of liquors," of gravity, of "naval architecture," of optics, of "mechanics" (the science of machines) and of solid statics.[26] More broadly, he conceded that God's power and wisdom has

> produced *numberless* contrivances, *laws*, and other things, which exceedingly surpass both the *number and variety* that the dim and limited intellect of man could reach to by framing and compounding ideas, without the assistance of the patterns afforded by the works and declarations of God. (Boyle 1738: 262; my italics)

Another exuberant group were Gassendi's two disciples, François Bernier in France and Walter Charleton in England. The former acknowledged the "ordinary laws of nature," but he thought there were also "laws of optics," laws of "rarity and density," and of "fluidity and firmness." As an atomist, Bernier granted that there were "laws of the motions of atoms." He believed there were broad-scope propositions that he called the "law of rest" and the "law of nature" according to which "every body occupies the place that is apportioned to it." But, he claimed as well that there are laws for single objects, e.g. an alleged law that, "among the planets, the highest follows the motion of the fixed stars." And, he thought there were also laws far beyond physics. For instance, an alleged "law of contraries."[27]

As did Charleton. Like Bernier, the English physician admitted that there were "universal laws of motion," or the "few fundamental laws of motion in general." But, Charleton granted nomic status as well to specific, regional

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[25] For Bacon, see the instances collected in Steinle 2008: 331-3. For Boyle, see, respectively, Boyle 1686: 164, 222, 220.

[26] See, respectively, Boyle 1738: 139, 137, 167, 240, 347, 35.

[27] See, respectively, Bernier 1684: III, 47; IV, 373 and VI, 147; III, 11 and 140; V, 532; III, 162; II, 102; IV, 114 and III, 56.

items. Namely, to things like the "several laws of magnetic energy," the "settled and unalterable laws of magnetic attraction," and the "laws of position" for magnetized needles. Also to "laws of projected [bodies'] motion," direct and indirect; to "laws of reflection"; and to the "laws of rarity and density." Likewise, he counted as laws propositions well beyond physics: a supposed "law of mathematical commensuration," one of "contrariety," and a "law of consequence," plus alleged laws of method, of reasoning, and laws "for the production of all common and familiar effects." He also counted as laws idiosyncratic tenets, such as the "law of nature [that] every body in the universe is consigned to its peculiar place," and an alleged "general law of motion, that all bodies moved by an external cause move the slower, the farther they are from their principle." And, he even thought there were "laws of the blood's motion," or "laws of circulation."[28]

This linguistic extravagance about laws has philosophical implications. Because of it, we run the risk that early-modern uses of the term 'law' do not have enough shared content, semantic or pragmatic, to sustain a philosophical account of laws that is clear, univocal, and robustly explanatory. That would reduce the scholar to a mere cataloger of patterns of verbal behavior: data useful to sociologists of knowledge, not to analytic philosophers of science.

I end with a note of caution. Newton might seem to have engaged in exuberant talk of laws, but that is misleading. Specifically, in the *Principia* he uses the term 'law' for items other than his three, canonical laws of motion. Still, that is not enough reason to group him with the exuberants above. Newton's usage there is consistent and methodical. He always uses 'law' for sentences with two features: they follow deductively from his canonical laws (even though they may be well downstream from those, within his rational mechanics); and they always denote a ratio of quantities, or measures: "to find the law of the centripetal force."[29] And also:

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[28] See, respectively, Charleton 1654: 437 and 271; 388, 395 and 400; 463, 214 and 258; 11, 183 and 162; 311 and 263; and also Charleton 1659: 213, 343. For further examples, see also Steinle 2002: 203.

[29] See Newton 1687: 45-51, (Book I, Props. 7-13). In modern terms, in these contexts Newton by 'law' means a functional relation—of equality or proportionality—between quantities such as acceleration (of a particle in orbit), strength of the potential (at some location form the source), arc-length (of an orbital path traveled) or some element of the orbit, e.g. the major semiaxis.

> In these propositions, I suppose the centripetal force, as we recede from the center, varies according to any law we may imagine—but that, at equal distances from the center, it is everywhere the same. (Newton 1687: 131)

That is a far cry from the profligate talk of law that we saw Kepler, Boyle, Gassendi and Bernier indulge in above.

Conclusions

From Descartes to the mid-18th century, a new kind of knowledge arose and quickly moved center stage: early modern science. Among its distinguishing marks was the presence of certain propositions seen as privileged, and often called laws. A few of them were so valuable that they survived into modern science: Newton's laws of motion, Kepler's laws, d'Alembert's Principle, and the Principle of Least Action.

At the same time, however, the notion of law quickly became contested. There was little consensus about what a law of nature was, and which knowledge items deserve the name of law:

> To speak of *the* concept of law (in the late 17th century) has no more sense than to speak of *the* notion of physics: in both cases, we see an amalgam of views that are irreducible—or even built in opposition to one another. (Roux 2001: 570f.)

In effect, their use of the *term* 'law,' while sometimes broad and generous, is not evidence of there being a common, single *concept* of law then.[30]

That makes early modern laws of nature historically important but philosophically challenging. In particular, the lack of semantic uniformity in that period frustrates the attempt to make easy sense of them. And, it is a cautionary tale for contemporary attempts to analyze lawhood or nomic force. Absent any broad, stable consensus about which propositions are laws, what are the chances of consensus about the correct explication of that concept?

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[30] For similar verdicts, see also Steinle 1995 and Milton 1998.

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