Do not revise Ockham's razor without necessity

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Abstract

Ockham's razor asks that we not multiply entities beyond necessity. The razor is a powerful methodological tool, enabling us to articulate reasons for preferring one theory to another. There are those, however, who would modify the razor. Schaffer (2010: 313—our italics), for one, tells us that, 'I think the proper rendering of Ockham's razor should be 'Do not multiply *fundamental* entities without necessity''. Our aim, here, is to challenge such re-workings of Ockham's razor.

1. Introduction

Ockham's razor asks that we not multiply entities beyond necessity. The razor is a powerful methodological tool, enabling us to articulate reasons for preferring one theory to another. There are those, however, who would modify the razor. There are several such 'razor-revisers'. For instance, Schaffer (2010: 313—our italics), tells us that, 'I think the proper rendering of Ockham's razor should be 'Do not multiply *fundamental* entities without necessity''. Cameron (2010: 262—our italics) states that the 'principle of ontological parsimony must tell us to judge theories by what entities they admit to their *fundamental* ontology', whilst Sider (2013: 240) claims, in a discussion of a preference for simplicity in theory choice, that '[t]he epistemic principle should be restricted to theories about the fundamental nature of the world'. This modified razor being proposed is important. In each case the razor-revisers put it to substantial work in selecting between competing metaphysical theories; work that could not obviously be done otherwise.

Our aim is to challenge the razor-revisers and their planned revision. In Section 2 we outline the revised razor as it's described by Schaffer (2015), who gives it the most significant defence to date. In Sections 3 and 4 we outline two arguments against the proposed revision: it gets the wrong results in scientific cases and it cannot be justified using two strategies commonly used to defend other versions of the razor. We argue that this motivates a rejection of the revised razor. In the final section of the paper—Section 5—we consider and reject some responses to our argument.

2. Razor / Laser

From the outset, we should differentiate constructive and comparative principles of theory choice. The distinction can be understood, roughly as follows:

> Constructive Principles of Theory Choice
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> P is a constructive principle of theory choice only if P provides guidance with respect to the correct procedure for *developing* a theory.
>
> Comparative Principles of Theory Choice
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> P is a comparative principle of theory choice only if P provides guidance with respect to the correct procedure for *comparing theories* with one another in terms of one or more theoretical virtues.

Our focus is exclusively on Ockham's razor as a comparative principle of theory choice; we say nothing more about the razor as a constructive principle. As a comparative principle of theory choice, Ockham's razor allows us to judge a theory T as preferable to a theory T* *only in a certain respect*. The razor is not an

all things considered judgement of theory preferability. To make the 'all things considered' judgment that T is preferable to T*, a full cost/benefit analysis would be required; one that scores both theories with respect to each and every theoretical virtue. Note too that in the context in which razor revisers write they are concerned with *metaphysical* fundamentality and *metaphysical* derivatives. We are prepared to allow (here) that such a notion is coherent and may be included as a part of the description of the actual world (though see Hofweber (2009), Tallant (2013a) and Wilson (2014), *inter alia*, for concerns).[1]

So, to the razor itself; the standard statement of Ockham's razor is the simple one given at the outset:

> The Razor   Do not multiply entities beyond necessity[2]

In place of the Razor, Schaffer (forthcoming) recommends the Laser:

> The Laser   Do not multiply fundamental entities beyond necessity.

This statement of the Laser is somewhat unfortunate since, as stated, the Razor implies the Laser.

To distinguish the two principles from one another, it is important to understand that the Laser enforces an injunction against multiplying *only* fundamental entities beyond necessity. It enforces no such injunction when it comes to derivative entities. The Laser is thus to be understood as the combination of an injunction against multiplying fundamental entities beyond necessity plus the further claim that multiplying derivative entities is no theoretical cost. Call this further thesis, the thesis of Free Derivatives:

Free Derivatives   For any two theories T and T*, the preferability of T over T* (or vice versa) on parsimony grounds is unaffected by any differences in the number of derivative entities posited by the two theories.

So understood, both the Laser and the Razor come in two different forms.

First, one might apply the Laser and Razor to entity *types*. In which case, the Laser and the Razor are to be understood as principles of qualitative parsimony.[3] Second, one might apply the Laser and the Razor to entity *tokens*, in which case the two principles are to be understood as principles of quantitative parsimony.[4,5]

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[1] Metaphysical and physical fundamentality can come apart. For instance: Schaffer champions priority monism—the view that there is a single fundamental entity, 'the world', upon which all other objects depend. But this is not to be confused with the claim that the world is physically fundamental. So far as we can tell the question of what (if anything) is physically fundamental is a matter to be determined by (and only by) physicists. Which particles or entities are treated as 'elementary' or taken to feature in our best and final physics is not something upon which metaphysicians can, or should, adjudicate.

[2] What does 'beyond necessity' mean? According to Swoyer (2008) (also Baker (2003)) it means 'beyond what is needed to explain the phenomena'. Interpreting 'beyond necessity' in this spirit would collapse parsimony *qua* principle of theory choice into a principle based on explanatory power. Everything we say here can be reformulated in terms of an explanation-based version of Ockham's razor. The upshot is the same.

[3] To illustrate the qualitative Laser, suppose that we have two competing metaphysical theories, T and T*. T posits only one fundamental substance kind: material substance. In contrast, T* posits two fundamental substance kinds: material substance and mental substance. Suppose, further, that T* posits far fewer derivative entities than T. If we are guided by the qualitative Laser, then we should prefer T to T* despite the imbalance in derivatives moving in the opposite direction.

[4] To illustrate the quantitative Laser, suppose that we have two competing metaphysical theories, M and M*. According to M, Priority Monism is true, and there exists a single fundamental entity upon which all other entities depend for their existence. In contrast, according to M*, Priority Dualism is true, and there exist two fundamental entities (of the same type), upon which all other entities depend for their existence. If we are guided by the quantitative Laser, then we should prefer M to M*.

[5] Suppose that the priority dualist posits two fundamental entities. There is no reason to think that these entities must differ from one another with respect to *type*. We see no objection to there being two fundamental entities that are of the same type and Schaffer himself provides no reason to think otherwise. In that case, only a version of

3.   Against Razor Revision

Our first argument against the revision of the Razor to the Laser demonstrates that the Laser is at odds with scientific practice. Assuming a very weak brand of methodological naturalism, according to which we should not adopt principles of theory choice that explicitly conflict with successful episodes of theory choice from science, we argue that there is a naturalistic push against the proposed razor revision. Because parsimony comes in both quantitative and qualitative forms, our argument is based on two case studies from science. The first is a case of theory selection via qualitative parsimony (3.2), the second is a case of theory choice via quantitative parsimony (3.3). Before we turn to that task, however, it is worth briefly considering Schaffer's (forthcoming) arguments in favour of the Laser over the Razor (3.1).

3.1   In favour of the Laser

Schaffer offers three arguments in favour of the Laser: a thought experiment (3.1.1); an argument from analogy based upon a thought experiment (3.1.2) and an argument from an underpinning principle (3.1.3). We take each in turn.

3.1.1 The thought experiment

Schaffer's (2015: 648) first argument for the Laser is based on consideration of the following hypothetical example:

> Esther posits a fundamental theory with 100 types of fundamental particle. Her theory is predictively excellent and is adopted by the scientific community. Then Feng comes along and—in a moment of genius—builds on Esther's work to discover a deeper fundamental theory with 10 types of fundamental string, which in varying combinations make up Esther's 100 types of particle. This is intended to be a paradigm case of scientific progress in which a deeper, more unified, and more elegant theory ought to replace a shallower, less unified, and less elegant theory. Feng's theory is evidently better in every relevant methodological respect.

If Feng's theory posits more entities than Esther's, then the Razor would have us prefer Esther's theory to Feng's. Since it is obvious, Schaffer thinks, that we should in fact prefer Feng's theory to Esther's, so the Razor delivers the wrong result. If the Razor gets the wrong result, then it should be replaced. The Laser, by contrast, tells us to minimise fundamental posits. The Laser would have us prefer Feng's theory to Esther's—as we should. Thus, Schaffer claims, the Laser is demonstrably preferable to the Razor. As Schaffer (2015: 648) puts the point:

> Yet if one counts by total entities, as per *The Razor*, one will get the case of Esther and Feng *backwards* … So by the lights of *The Razor*, Feng's theory is an affront to ontological economy for positing these additional strings. It is to be strongly dispreferred, all else equal. This is obviously backwards, as far as sound methodological counsel is concerned.

Schaffer seems to be thinking of the Esther and Feng case as a *tie-breaking* case; a case in which two theories are matched with respect to the other theoretical virtues and then parsimony is used as the final decider. Feng's theory is 'to be strongly dispreferred, all else equal'. But all else is not equal. Feng's theory is 'a deeper, more unified, and more elegant theory'. Explanatory depth, unification and elegance, however, all play a part in theory selection. Certainly, we think, *our* preference for Feng's theory seems to be explicable in terms of its being a deeper, more unified and elegant theory, a preference that is not obviously founded on parsimony considerations.

If we take into account the razor *along with* the desire to adopt a deep and unified, elegant theory, does it follow that we will get the wrong result? We don't see that it should. In a non-tie-breaking case (which is how the Esther and Feng case is now being treated) the costs associated with the overall number of

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Ockham's razor that concerned itself with the *number* of fundamental entities would give Schaffer (2010) his desired argument in favour of Priority Monism.

entities can be outweighed. So if we have a package of theoretical virtues that includes the Razor and a package of theoretical virtues that includes the Laser and we apply each to the Esther and Feng case, both packages are capable of yielding the result that Feng's theory is superior. To be sure, one package – namely, the one including the Razor – will imply that Feng's theory has certain costs that the other package doesn't; but so long as the costs are outweighed – and why shouldn't they be? – Feng's theory will still be deemed superior by the Razor package as much as the Laser package. Thus, contra Schaffer, there is no reason based on the Esther and Feng case to think that we have a reason to prefer the Laser to the Razor. Rather, we have a reason to prefer one hypothesis to another on the grounds of independent theoretical virtues.

A second, related concern with the Esther and Feng case is that there are parallel cases that seem to pull in the opposite direction. Consider the following:

> Charlie posits a fundamental theory with 10 types of fundamental string that, in varying combinations, make up 100 types of particles. Her theory is predictively excellent and is adopted by the scientific community. Then Zibeon comes along and builds on Charlie's work to discover a theory with 10 types of fundamental string, which in varying combinations make up 20 types of particle that can do the same work for which Charlie's theory needs 100 types of particle.

We think that Zibeon's theory is better than Charlie's: it can do the same explanatory work positing fewer entities. If we count by total number of entities then we get the right result: Zibeon's theory has fewer entities in it than Charlie's does. If we count only by fundamental entities, however, then we don't get the right result. There is no difference in the number of fundamentals entities between the two theories. Suppose we conclude from this that therefore the Razor is to be preferred to the Laser.

Now, Schaffer could rightly object: the Laser gets the wrong result here only if we completely *ignore* the fact that Zibeon's theory has a much higher degree of explanatory unity than does Charlie's. Once we take that factor into account, there's no reason at all to suppose that the Laser will get the wrong result. But what's good for the goose is good for the gander: if our case involving Zibeon and Charlie provides no argument against the Laser, then Schaffer's case involving Esther and Feng provides no argument against the Razor. In both cases, once all theoretical virtues are properly factored into the picture, the two principles of parsimony are both capable of yielding the correct results.

3.1.2 Argument by analogy

Similar considerations apply to Schaffer's second argument for the Laser; an argument by analogy. First, Schaffer (2015: 649) focuses on what he calls the conceptual razor:

> The Conceptual Razor: do not invoke concepts without necessity!

He then outlines what he calls *The Conceptual Laser*, which is the combination of the recommendation not to invoke *primitive* concepts without necessity, and the idea that the number of defined concepts does not factor into theory choice. Schaffer (2015: 649) goes on to provide the following example that is supposed to motivate *The Conceptual Laser*:

> It should be readily apparent that The Conceptual Laser is preferable to The Conceptual Razor. Consider the following case (a partial conceptual analogue of the case of Esther and Feng). Georg has developed a decent regimentation of set theory. He invokes 10 primitive concepts, and from those 10 primitives he can define 40 other useful set-theoretic concepts. Hamsa though—in a moment of genius—builds on Georg's work to discover a beautiful axiomatization with just a single primitive notion. With her single primitive, Hamsa can define ninety-nine other useful set-theoretic concepts, including all forty of Georg's set-theoretic concepts. Evidently, Hamsa's theory is methodologically preferable to Georg's on every relevant measure. Hamsa has provided an ideologically elegant approach par excellence, finding a single primitive notion through which she can define every concept Georg employs, and others besides. This is as good as it gets.

Schaffer then uses the analogy between the Conceptual Laser and the Laser as a basis for preferring the

Laser to the Razor.

Once again, all else is not equal. This time, the equality between the two theories is broken in two ways. First, Hamsa's theory has greater *conceptual unity* than does Georg's. Hamsa's theory invokes a few fundamental concepts to define all of the concepts that Georg believes in. Accordingly, as in the Esther and Feng case, we should be able to recover the same result as Schaffer by appealing to the Conceptual Razor in conjunction with the advice to carefully apply the Conceptual Razor in conjunction with considering other theoretical virtues (virtues like conceptual unity).

Second, the equality is broken in another way: Hamsa's theory can simply derive more *useful* concepts than can Georg's. So there is something that Hamsa's theory can do that Georg's cannot, other than define Georg's 40 concepts using just 1 concept. Schaffer does not tell us what Hamsa's extra concepts are good for, and it doesn't really matter. All that matters is that the concepts make Hamsa's theory a better theory and that they therefore add to the theoretical prowess of that theory in some respect. But if such concepts are useful, then they are (in some sense) *necessary* to some part of our deliberations. If such concepts are necessary, however, then the Conceptual Razor will not deliver the result that Hamsa's extra concepts are an added cost, and so should compel us to prefer Hamsa's theory just as much as the Laser does.

As with the Esther and Feng case, we think it's possible to construct a case that pulls in the other direction. Consider the following:

> Gail has developed an axiomatisation of set theory that invokes 1 primitive concept, from which she can defined 99 other useful set-theoretic concepts. Milena builds on Gail's work to discover an axiomatization of set theory that invokes 1 primitive concept as well, but from which she can define 299 other set-theoretic concepts, only 50 of these are useful.

The conceptual Laser gets this case wrong. The conceptual laser would have us care only about the primitive concepts we invoke and what is at issue here, clearly, are the *defined* concepts. Because both theories posit the same number of primitive concepts, the Laser suggests that the two theories are on a par. After all, it requires that we not posit *primitive* concepts without necessity, but the number of defined concepts does not factor into theory choice. The Conceptual Laser is thus doubly blind to the fact that Milena can define *fewer* concepts than Gail *tout court*, as well as the fact that many of the concepts that she can define are of no theoretical use.

The Razor, by contrast, gets the case right. We have no need of 249 of Milena's concepts. We should not multiply concepts by necessity. Thus, we have reason to dislike Milena's axiomatization.

Now, as before, Schaffer may object: it's perfectly clear that once we include considerations of conceptual power/conceptual unity, and so on, we should think very little of Milena's theory. Once again, though, what's good for the goose is good for the gander; once we factor considerations of conceptual conceptual unity into the Georg and Hamsa case, the argument against the Razor from that case no longer seems plausible either.

3.1.1 The more fundamental principle

Schaffer has one more trick up his sleeve. He argues that the Laser is recommended by a more fundamental principle concerning the relationship between parsimony and fruitfulness. As before, Schaffer (2015: 652) starts from the conceptual case and then argues by analogy into the ontological case. The conceptual principle is this:

> *Conceptual Bang for the Buck*: Optimally balance minimization of primitive concepts with maximization of defined concepts (especially useful ones).

Schaffer contends that Conceptual Bang for the Buck is plausible and thus, by analogy, so is:

> *Ontological Bang for the Buck*: Optimally balance minimization of fundamental entities with maximization of derivative entities (especially useful ones).

Schaffer then argues that Ontological Bang for the Buck recommends the Laser over the Razor because it tells us to minimize the fundamental entities; the kind of simplicity that is being trade-off against fruitfulness with respect to the derivatives is always simplicity with respect to the fundamentals. Simplicity with respect to the derivatives plays no role in the relevant trade-off.

We propose two counterexamples to the claim that Ontological Bang for the Buck unambiguously recommends the Laser over the Razor. First, consider the following two theories: T1 and T2. According to T1, there exists 4 derivative entities and 1 fundamental entity, where the one fundamental entity grounds all 4 of the derivative entities. According to T2, there exists 3 derivative entities and 3 fundamental entities, where each fundamental entity grounds one derivative entity each. Ontological Bang for the Buck tells us to select T1 over T2. That choice jibes with the Laser, which also recommends T1 over T2. The choice, however, is also aligned with the Razor which also recommends T1 over T2. Ontological Bang for the Buck then is agnostic between which kind of simplicity is being traded off against fruitfulness in this case: whether we trade simplicity with respect to total number of entities off against the number of derivative entities produced, or whether we trade simplicity with respect to the fundamentals off against the number of derivative entities produced, the result is the same.

Second, consider the following two theories, T1 and T2. According to T1 there exist 9 entities in total. 8 entities are derivative, and 1 entity is fundamental. The grounding structure of the situation is as follows: the 1 fundamental grounds 4 derivative entities which, in turn, each ground 1 further derivative entity. According to T2, by contrast, there exist 11 entities in total. 10 entities are derivative, and 1 entity is fundamental. The grounding structure of the situation is as follows: the 1 fundamental grounds 2 derivative entities which, in turn, ground 4 derivative entities each.

Bang for the Buck counsels us to accept T2 over T1. The selection, however, is not based on any trade-off between the number of fundamentals and the number of derivative entities. Both theories are matched for the number of fundamentals. Rather, the difference seems to be contained entirely at the level of derivatives. T2 gets more Bang for the Buck in virtue of the fact that it uses *fewer* derivative entities to do *more* work. The trade-off in simplicity, then, that seems to underlie the recommendation offered by Bang for the Buck appears to be based on maximizing the number of 'top level' entities whilst minimizing the number of 'interlevel' entities. In this case, then, Bang for the Buck would seem to recommend the Razor and not the Laser, since only the former can handle parsimony considerations directed at interlevel objects.

3.2   Qualitative Parsimony

Thus far we have considered Schaffer's three arguments in favour of the Laser and have found each wanting. This undermines the motivation for adopting the Laser. We will now argue directly against the Laser. Baker (2007) outlines a case of theory selection in science based on qualitative parsimony. We think it constitutes a counterexample to the Laser. The case is drawn from a classic problem in biogeography. The problem was how to explain two things.

First, Buffon's Law:

        (BL) Areas separated by natural barriers have distinct species.

Second: notable exceptions to Buffon's law. For instance, the island of Madeira has 40% of its native species in common with mainland North Africa, despite there being a 400 mile stretch of ocean separating the two regions.

In the 1950s, there were two distinct theories on offer that explained these two phenomena: the Darwin-Wallace dispersal theory and Croizat's tectonic theory. According to the Darwin-Wallace dispersal theory, Buffon's law and the exceptions to that law can be explained by the combination of *dispersal* with evolution by natural selection. The explanation for Buffon's law via dispersal goes as follows. Over time, species gradually migrate into new areas. This is dispersal. Dispersal determines which species are located where and thus determines the distribution of species over natural regions. Over time, natural selection then shapes and forms species in different areas, thereby giving rise to new species. In other words, as

species migrate into different areas they are subject to distinct evolutionary processes that then force different kinds of speciation. Exceptions to Buffon's law are then explained by 'improbable dispersal'. Improbable dispersal involves some fortuitous means of transport in the recent past that moves a species from one place to another. Accordingly, the Darwin-Wallace theory predicts that there was an improbable transport event in the recent past that accounts for the 40% overlap in species between Madeira and mainland North Africa.

Croizat's tectonic theory accepts that dispersal and evolution occur, but postulates an additional mechanism in the explanation for Buffon's law: tectonic shift. According to Croizat, forces such as continental drift, the submerging of landmasses and the creation of mountains are used to explain why it is that areas separated by natural barriers have different species. Very roughly, the explanation is that these phenomena create natural barriers between species that are then subject to diverging evolutionary pressures, and that therefore evolve in different ways. Following the 1950s a great deal of evidence was gathered regarding continental drift (and so forth) that established Croizat's tectonic theory over the Darwin-Wallace dispersal theory.

As Baker discusses, however, prior to the discovery of this evidence, the choice between the Darwin-Wallace theory and Croizat's tectonic theory appeared to be a choice that was made in terms of parsimony. Croizat's theory posits an extra *kind* of causal mechanism and a new kind of entity, namely: tectonic plates that shift; a mechanism and an entity that no evidence had been provided for at the time. The Darwin-Wallace theory is therefore the more qualitatively parsimonious theory. As Baker (2007, p. 210—our italics) puts the point:

> The Tectonic theory is committed to the existence of tectonic plates *and* to the causal mechanism of continental drift. According to the Tectonic Theory, continental drift provides the best explanation of the observed distribution of species, and the postulation of tectonic plates provides the best explanation for continental drift. Hence we ought to believe in the existence of tectonic plates. Tectonic plates are … novel kinds of entity, moreover they are entities to which the Dispersal theory is manifestly not committed.

As Baker goes on to demonstrate, the scientific consensus in the 1950s prior to the discovery of independent evidence for continental drift was not on the side of the Tectonic Theory. Rather, it would seem that Croizat's Tectonic Theory was roundly criticised for its invocation of new kinds of entities.

According to Baker, the case study of Dispersal versus Tectonic Theory provides evidence that scientists tend to select theories that are more *qualitatively* parsimonious. As noted, Croizat's Tectonic Theory was criticised precisely because it invoked a new kind of entity and, thus, was less qualitatively parsimonious than some of its competitors. So far, so good.

But the case study can also be used to make a further point, one that is directly relevant to the proposed revision of the Razor into the Laser. On no sensible metaphysical theory are Tectonic plates fundamental entities. Tectonic plates are paradigmatic derivative entities. Accordingly, the Laser gets this case wrong. The Laser would have it that there is no basis upon which to select the Dispersal Theory over the Tectonic Theory. After all, there is no difference in the fundamental entities posited by Dispersal Theory and Tectonic Theory.

The Razor, by contrast, gets the case right. Tectonic Theory was criticized by scientists because it was not parsimonious. Tectonic theory posited more (metaphysically derivative) entities than Dispersal Theory. The Razor, of course, allows for parsimony considerations to be directed toward derivative entities and thus toward a preference for Tectonic Theory.

3.3   Quantitative Parsimony

This brings us to the quantitative parsimony case. We consider Avogadro's explanation of the behaviour of gases in chemical reactions. As Nolan (1997: 335-336) notes, to understand the case, it is important to outline three claims that Avogadro accepted at the time.

First, gases are made up of particles and it is the combining or splitting of these particles that underwrites chemical reactions. Second, volumes of gases at equivalent temperatures and pressures combine in fixed ratios where the ratios are in low, whole numbers. Third, a volume of gas at a given temperature and pressure would always contain the same number of particles.

These three assumptions yielded the following natural thought. Given that two volumes of hydrogen combine with one volume of oxygen to produce water, it is reasonable to expect that the amount of water produced would be the same as the amount of oxygen, and half that of the amount of hydrogen. Experimental work did not bear out this prediction: when two volumes of hydrogen are combined with one volume of oxygen, two volumes of steam are produced. Thus, the amount of water is in fact twice that of the amount of oxygen and thus equivalent to the amount of hydrogen.

To explain the experimental findings in a manner that was consistent with the three claims assumed above, Avogadro proposed that each particle in an elemental gas is a molecule composed of two atoms. Thus, a molecule of elemental oxygen gas is composed of two oxygen atoms and a molecule of elemental hydrogen is composed of two hydrogen atoms. Accordingly, when two volumes of hydrogen are combined with one volume of oxygen the result is two volumes of water because each hydrogen molecule now has an available oxygen atom to bind with to produce H_2O.

Avogadro's central insight is that explaining the volume of steam produced in a chemical reaction between oxygen and hydrogen is a matter of adjusting the ratio of oxygen atoms to hydrogen atoms, so that there are enough oxygen atoms to 'go round'. The important point for our purposes is that Avogadro also assumed that each elemental gas molecule is composed of the minimum number of atoms. Given, however, that it is the ratio of oxygen to hydrogen atoms at issue, and not the number of oxygen and hydrogen atoms per se, there are many other hypotheses about the number of atoms that compose hydrogen and oxygen molecules compatible with the experimental evidence. Here is a small list of possible hypotheses about the number of atoms in a gas molecule available to Avogadro:

Hyp_1	The number of atoms per elemental gas molecule is 2 (1 atomic weight)
Hyp_2	The number of atoms per elemental gas molecule is 4 (1/2 atomic weight)
Hyp_3	The number of atoms per elemental gas molecule is 8 (1/4 atomic weight)
Hyp_{10}	The number of atoms per elemental gas molecule is 1024 (1/512 atomic weight)

Avogadro chose Hyp_1. This is, we think, exactly the right choice to make. In Nolan's (1997: 337) words:

> If instead of assuming the minimum number of atoms per molecule needed Avogadro had chosen some other arbitrary number … his theory would have explained the same reactions, would not have any additional kinds of entities, and would differ from his actual theory only in being more quantitatively extravagant. I find it intuitive that in selecting the minimum number of atoms per molecule needed Avogadro was proposing a theory simpler than any of the 'multiple rivals' are, and that if he had, in fact, said that elemental gases all contained eight thousand atoms of the element, or sixteen million, he would have been producing an arbitrary and bad theory.

We want to draw a lesson concerning the importance of quantitative parsimony with respect to derivative entities. But, before that, we owe a quick discussion of the case.

First, we agree that there are other issues in play besides parsimony in the case. That is, we think Nolan is right to flag that each of the 'multiple rivals' would also be *arbitrary*. But, in any case, we do not think that this would be the sole reason that the 'multiple rivals' hypotheses are bad. They are also bad because they are less parsimonious. Second, we agree that Avogadro probably didn't consider the 'multiple rivals' hypotheses. But, again, we don't think this problematic. We are not claiming to sketch Avogadro's thought-processes. What we are interested in is whether or not considerations of parsimony justify Avogrado's preference for Hyp_1. We think that they do. (For discussion of other cases involving quantitative parsimony, see Nolan (1997) and Jansson and Tallant (forthcoming)).

We also think that the case demonstrates the importance of quantitative parsimony with respect to derivative entities. Atoms are not treated as metaphysically fundamental in *any* metaphysical theory of which we're aware (nor do we think that they should be treated as such; just as with tectonic plates, it would be very odd to treat atoms as the foundations upon which all other entities depend).[6] In the cases in question (Hyp$_1$—Hyp$_{10}$), we are therefore not considering metaphysically fundamental entities. Nonetheless, this appears to be a case from the history of science where a preference for the more quantitatively parsimonious hypothesis is justified, *despite* the fact that it in fact posits the same number of fundamental entities as its rivals.

Let us now draw the strands of our discussion together. In the case described, we have seen that there are at least some occasions on which a scientist's preference for a theory T over a theory T* is best justified in terms of the fact that T posits fewer (metaphysical) derivatives than T. If the razor-reviser has their way, then this move is illegitimate; these (metaphysically) derivative entities come at no cost to parsimony. As such, their numbers are immaterial. And yet, in the cases described, their numbers do not seem to be immaterial. This yields the promised tension. The Laser tells us that the number of atoms posited is irrelevant to our theory choice. But the number of atoms posited *does not* seem irrelevant to scientific theory choice. Given the successes of science, we take this to be significant. The putative metaphysical thesis of the razor-reviser pulls us one way; the scientific case-study pulls us in another. Thus there seems to be an obvious and non-trivial preference for keeping numbers of entities (of whatever kind) low; the Razor is in play.

3.4 Responses to the cases

In response to the case studies outline in this section, the razor-reviser might offer two responses. First, she might maintain that it is far from obvious that the Laser gets the wrong result in these cases. In order to adequately determine whether or not the Laser gets the wrong results, we must consider what implications the tectonic theory, say, has for the fundamentals over its rival; or we must consider what implications each of Hyp$_2$ - Hyp$_{10}$ have for the fundamentals as compared to Hyp$_1$. After all, it may well turn out that differences in the number of derivative entities posited by the various competing theories under consideration are being tracked by differences in the number of fundamentals. Indeed, one might hold that differences in the derivatives must correspond to differences in the fundamentals, since the fundamentals fully determine the derivatives. We will discuss a version of this idea further in Section 4. For now, we will respond by clarifying the central claim being made through this section somewhat.

Our claim is not that the Laser can never yield the right results in these scientific cases. Our point is that the decisions about which theory is correct that have been made within science and that have yielded the right results have been made based on the Razor and not based on the Laser. Darwin did not defend his view on the grounds that tectonic theory requires believing in extra fundamental entities. His view was that tectonic plates are an extravagance that we can do without. Similarly, Avogadro's theory is not better because it posits fewer fundamentals. No mention is made of what the fundamentals are in the context of theory choice between Hyp$_1$ - Hyp$_{10}$ at all. Rather, Avogadro's theory seems better because it posits fewer atoms per elemental gas molecule. Accordingly, even if the Laser could select the right theory it would be selecting it for the wrong reasons, where the 'wrong reasons' are, broadly, the reasons that matter to the scientists who were choosing these theories. The fundamentals are not what matters to scientists in these cases; it is the derivative entities that matter. In other words, scientific practice does not involve a restriction of parsimony considerations to the fundamentals, as the Laser would have it. Rather, scientific practice allows parsimony considerations to enter into theory choice without regard for whether the entities at issue are fundamental or derivative. The Laser, then, appears to be at odds with scientific practice.

This brings us to the second response to the scientific case studies considered in this section available to the razor-reviser. The razor-reviser may shift ground to a more restricted version of the razor. She may

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[6] For one thing, they would seem to fail to satisfy Schaffer's (2010a: 38) tiling constraint on fundamentalia: that the basic actual concrete objects collectively cover the cosmos without overlapping.

argue that the Laser is to be applied only to hypotheses from metaphysics. Outside the domain of metaphysical inquiry, the Razor (or other principles) are applicable; the Laser is not. This would solve the problem. We would still have good Ockhamistic reasons to go along with Avogadro / Darwin-Wallace for these hypotheses are not hypotheses of metaphysics—or so goes the thought.

But this is a bad move to make. There are no sharp demarcation criteria as to when a hypothesis is to be regarded as physical, and when it is to be regarded as metaphysical. There is, therefore, no way in which to draw the required distinction between domains where the Laser applies, and domains where it does not. Nor is this an idle concern. Consider the following hypothesis: the world consists of a single, fundamental, quantum entangled state. This hypothesis looks to be the product of physics. Equally, it is a statement of Schaffer's (2010) Priority Monism.[7] Should the Laser apply to this case? We know of no way to legitimately answer this question if we are attempting to demarcate metaphysics from physics.

Even if one can demarcate scientific and metaphysical hypotheses, however, there is a more serious problem with the proposed restriction of the Laser to metaphysics; one that also deepens the worry about going against scientific practice considered above. Why believe that parsimony is a truth-conducive virtue in metaphysics at all? This is a difficult question, but it is plausible to suppose that the stand-out answer is based on an inductive argument from science (cf. Huemer 2007, pp. 228-229). The argument, in brief is this:

> [1] Parsimony is a truth-conducive theoretical virtue in science
>
> [2] Science and metaphysics are analogous
>
> [3] So, we have good reason to suppose that parsimony is a truth-conducive theoretical virtue in metaphysics.

As Huemer notes, whether or not this inductive argument is any good depends on the degree of similarity between science and metaphysics. Of course, mere degree of similarity is not enough: science and metaphysics must be similar in the right ways to support the inductive step. Whether or not science and metaphysics are similar in this manner is not a question we aim to settle here. The point we wish to make is just this: the inductive argument outlined above has some chance of vindicating the Razor, but no chance that we can see of vindicating the Laser. The argument posed as an argument for the Razor would be this:

> [1*] The Razor is truth-conducive in science
>
> [2*] Science and metaphysics are analogous
>
> [3*] So, we have good reason to suppose that the Razor is truth-conducive in metaphysics.

The analogous argument for the Laser would be this:

> [1`] The Laser is truth-conducive in science
>
> [2`] Science and metaphysics are analogous
>
> [3`] So, we have good reason to suppose that the Laser is truth-conducive in metaphysics.

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[7] It is worth noting that if priority monism is true, then there is no further work for the Laser to do in either science or metaphysics. That's simply because any further entities posited that are distinct from the entire cosmic whole will be derivative entities, since there is only one fundamental entity. Accordingly, if the Laser is endorsed and priority monism is true, then the role that ontological parsimony can play in theory choice is severely limited.

If we give up the idea that the Laser is applicable to science, then the second argument is indefensible. There won't be a viable induction from the truth-conducive use of the Laser in science to the truth-conducive use of the Laser in metaphysics via the analogy between the two disciplines. Now, of course, this is not to say that there is no further way to argue that the Laser is truth-conducive in metaphysics. The point is just that no argument from science will be available, and so the best current argument we have for the truth-conduciveness of parsimony in metaphysics can't be used to show that the Laser is truth-conducive in science. Some further argument must be provided. We have no idea what such an argument might be, but we hope to have shown, at the very least, that such an argument is owed if the applicability of the Laser is to be restricted along disciplinary lines.

4.   Justifying the Razor

In the previous section we outlined our first argument against the revision of the Razor to the Laser. The Laser cannot do the same work as the Razor in scientific theory choice, and so we should prefer the Razor. The second argument against the Laser centres around the justificatory basis for Ockham's razor generally. Exactly how to justify Ockham's razor is a contentious issue, one that we have no intention of trying to settle here. Rather, we wish to make only the following modest point: two particularly salient classes of justifications for Ockham's razor do not seem to also vindicate the Laser. We have in mind: probabilistic justifications and explanatory justifications. Schematically, then

(1) We have probabilistic and explanatory justification for the Razor and no such justification for the Laser
(2) Where we have probabilistic justification for or explanatory justification for T, and no such justification for T*, we have some reason to prefer T to T*

Thus,

(3) We have some reason to prefer the Razor to the Laser

A number of probabilistic justifications for the Razor have been offered. We will focus on just two of the more promising options and show that neither carries over to the Laser. Then we will turn our attention to explanatory justifications.

4.1.1   Huemer's likelihood account

The first such justification that we will consider is that suggested by Huemer (2009: 221): the 'Likelihood account'.[8] The idea, briefly, is that simpler theories are better because they are better supported by the data:

> The essential point is that typically a simple theory can accommodate fewer possible sets of observations than a complex theory can: the simple theory makes more specific predictions. The realization of its predictions is consequently more impressive than the realization of the relatively weak predictions of the complex theory.

Given Bayes' Theorem, we can calculate the probability of a simple theory, S, and a complex theory, C, given data, E, as follows:

$P(S \mid E) = [P(S) \times (P(E \mid S)] / P(E)$ $P(C \mid E) = [P(C) \times P(E \mid C)] / P(E)$

Allowing that the prior probability of both simple and complex theories is equal (and not equal to zero or one), it follows that the simple model is more likely.[9] As Huemer (2009: 223) points out:

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[8] Probabilistic justifications of the razor are not original to Huemer. See the citations in fn. 11 p. 221 of Huemer (2009) for a list of philosophers and scientists who have employed probabilistic justifications for the razor at some point.

[9] This assumption about the priors being equal is, obviously, a simplification, but it is a natural one to make. For when we are at the point of choosing between theories using theoretical virtues, we are typically in a tie-breaking

If S is compatible with and neutral between possible items of evidence E_1 and E_2, while C is compatible with and neutral among E_1, E_2, E_3 and E_4 (where E_i are mutually exclusive), then $P(E_1 \mid S) = 1/2$, whereas $P(E_1 \mid C) = 1/4$.

Less formally:

Complex models typically have lower likelihoods relative to a given set of data, because complex models have more parameters which can be adjusted to accommodate the data (Huemer (2009: 231)).

Huemer's likelihood account is a straightforward corollary of standard probability theory. Suppose you roll a die and that you must bet on the kind of die rolled based on the observation you make. You only ever see the number rolled and observe nothing else about the die. There are two bets you can place: (i) the die is 6-sided; (ii) the die is 4-sided. Your priors are equal between it being a 6-sided die and it being a 4-sided die. You roll a 3. How should you bet? Well, there are 4 possible numbers you can roll with a 4-sided die: 1, 2, 3 and 4 and there are 6 possible numbers you can roll with a 6-sided die: 1, 2, 3, 4, 5 and 6. Accordingly, the probability of rolling a 3 *given* that the die is 6-sided is 1/6 and the probability of rolling a 3 given that the die is 4-sided is 1/4. So because the probability of rolling a 3 given that the die is 4-sided is higher than the probability of rolling a 3 given that the die is 6 sided, you should bet on the die being 4-sided.

In the case of *theories* an observation is analogous to a die roll and the *possible observations compatible with a theory* are analogous to the possible numbers that may be rolled for each die. Just as you should bet on the 4-sided die over a 6-sided one, so too should you bet on a simple theory over a complex one in light of a piece of evidence that is compatible with both.

In so far as it goes, Huemer's likelihood account justifies the Razor: the addition of any entity – no matter whether it is derivative or fundamental – amounts to the addition of an extra adjustable parameter to a theory. Accordingly, a theory with more entities or entity types will always be less probable than a theory with less in relation to a given piece of evidence, regardless of what those entities or entity types are.

The Likelihood account does not justify the Laser. The Laser tells us to select theories on the basis of the number of fundamentals that they posit. But now consider the following simple case: theory T1 posits 1 fundamental: A, and 3 derivatives: C, D and E; theory T2 posits 2 fundamentals: A and B and 1 derivative: C. T1 has more adjustable parameters in it than T2. T1 has 4 adjustable parameters, whereas T2 has 3. Suppose that we perform an experiment that randomly tells us about the existence of exactly one of the derivatives, and the result of this experiment is "the experiment shows us that C exists". Which theory should we think is more probable? Well, assuming that the two theories have the same prior probability, the likelihood account tells us to select T2. That's because the probability of performing the experiment and it showing us that C exists *given* T1 is 1/3 and the probability of performing the experiment and it showing us that C exists *given* T2 is 1. The Laser, however, tells us to select T1, because

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situation: we already know that the theories at issue do not come apart in any of the normal ways, and so something extra is needed to select between them. If our priors were not equal between the theories, then the theories would probably come apart in a standard way, and so considerations of parsimony would be less likely to weigh in.

it has fewer fundamentals.[10] So the Likelihood account and the Laser come apart on this case. The former won't justify the latter.[11]

4.1.2 Free parameters and derivatives

With respect to this toy example, one might wonder from what fundamentals C, D and E in T1 are derived. Suppose that they are not derived from A. Then T1 tacitly employs extra fundamentals, and so may not be favoured by the Laser after all, in which case the Laser and the likelihood account may align. Suppose, however, that C, D and E *are* derived from A in T1. Then A in T1 is, presumably, different in nature or configuration as compared to A in T2. This difference, however, may well be a difference that is relevant to theory choice.

It is possible to reformulate the example slightly so as to avoid this kind of concern. Consider the following two theories: theory T1 posits 1 fundamental: A, and 3 derivatives: C, D and E; theory T2 posits 2 fundamentals: B and F and 1 derivative G. Suppose that A, B, C, D, E, F and G are all distinct. Suppose, however, that the two theories are matched with respect to the theoretical virtues - they explain the evidence equally well, they are equally unified and so on - and thus that the only difference between the two theories is that they posit differing numbers of entities. As above, let us assume that we perform an experiment that randomly tells us about the existence of exactly one of the derivatives, and the result of this experiment is "the experiment shows us that C exists". We have no other evidence that favours or confirms T1 over T2 (or vice versa). In short, let the example be a tie-breaking case, in which the tie is to be broken only via parsimony. The likelihood account will tell us to break the tie by selecting T2; the Laser will tell us to break the tie by selecting T1. The recommendation from the likelihood account in the tie-breaking case does not line up with the recommendation from the Laser. So the likelihood account won't justify the results of the Laser in this case. If the likelihood account is to serve as a justification of the Laser, however, then it should justify the results that the Laser yields in every case, including tie-breaking cases.

A worry: the Bayesian argument does not turn on the parameter in question merely being "adjustable", but crucially on its being adjustable *independent of the other parameters*. Since the fundamental and derivative are not *independent*, so we face a problem. A reply: not so. The fundamental and derivative *are* independent—in the relevant sense. Witness: it is at least plausible that the Eiffel Tower is derivative and that what are fundamental are the elementary particles that make it up. Nonetheless, the Eiffel tower is modally independent of the particles that (currently) make it up in the sense that they could exist in the absence of the Eiffel Tower, and the Eiffel Tower could exist without being composed by those particles. This kind of modal independence is all we need to apply the Bayesian reasoning outlined above.

4.1.3 Adjustability and modal recombination

Our opponent might argue that while the above account of parameter adjustability does not presuppose free modal recombination, such a notion, if correct, is still a problem for our argument. That's because, possibly, the derivative entities are different only if the fundamental entities are different. This would not pose a problem yet, however. It only poses a problem when coupled with something stronger such as: *increasing the number of derivative entities means increasing the number of fundamental entities*. If this were true, then applying the likelihood reasoning to the number of derivatives just is to apply it to the number of fundamentals. In such a situation Huemer's likelihood justification would gain traction enough to work for the Laser.

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[10] We assume, here, that the existence of the derivative entities isn't a logical entailment of the existence of the fundamental entities, so it won't be the case that the existence of D and E will be a logical entailment of the existence of A either according to T1 or T2. Theories of fundamental and derivative entities are usually taken to postulate (at most) metaphysically necessary connections between fundamental and deriviative. That is, the relation between fundamental and derivative is weaker than logical entailment. Many thanks to an editor and referee for discussion and advice on this point.

[11] An opponent might worry that our point is somewhat redundant since Huemer argues that the likelihood account won't justify any metaphysical principle. That seems to us too fast, since Tallant (2013) looks to deploy the likelihood account in defence of presentism in the philosophy of time.

But how plausible is it that: possibly, the number of derivatives could have been increased only if the number of fundamentals were increased? We doubt that many would be willing to accept such a claim. For consider: suppose that whichever view about the number of fundamentals is true and necessarily so. Suppose too that priority monism is a necessary truth. Then, necessarily there is one fundamental entity. Further, suppose that actually there exists n derivative entities in total. If the number of derivatives cannot increase without an increase in the number of fundamentals, then one would be committed to the view that, necessarily, there are n derivative entities.[12] So the plausible claim that there might have been one extra derivative entity in the universe, such as an apple, turns out to be false. The thought that we could have just one more apple in the world is not so very far-fetched. It is something that should be accommodated by our best theories. Here, though, it cannot be so accommodated. And so, in short, if the number of derivatives is not permitted to vary independently of the number of fundamentals, modal space will be too tightly constrained by one's theory of what is fundamental.

Besides even if there could be no difference to the number of derivatives, without a proportional difference in the number of fundamentals, it would then seem that the question of whether we should prefer the Laser to the Razor would be completely moot. If an increase in derivatives always corresponds to an increase in fundamentals; and if a decrease in derivatives always corresponds to a decrease in fundamentals, then selecting a theory by total number of entities will always yield the same result as selecting a theory by total number of fundamental entities. In such a situation there would be no motivation for using the Laser instead of the Razor or vice versa; the choice between them becomes irrelevant from the perspective of theory choice. That is an outcome we could live with, but we doubt it will sit comfortably with proponents of the Laser.

One may still be worried: derivative entities are just not adjustable parameters because their nature and number is determined completely by the fundamentals. Accordingly, the only viable application of the likelihood account is to the fundamentals, for only they are truly 'adjustable' and so if the likelihood account justifies any principle of parsimony, it justifies the Laser.

Ultimately, however, it does not matter whether it is the derivatives or the fundamentals that are the adjustable parameters. What matters is that two theories can differ probabilistically with respect to the available evidence and in virtue of disagreeing about the number of derivative entities that are posited. To see this, let's use a case study and return to the case of Avogadro. Let us once again compare Hyp_1 and Hyp_{10}.

Hyp_1	The number of atoms per elemental gas molecule is 2 (1 atomic weight)
Hyp_{10}	The number of atoms per elemental gas molecule is 1024 (1/512 atomic weight)

Suppose, that, alongside hypotheses, let us agree that Priority Monism is true. The difference between Hyp_1 and Hyp_{10} is generated by adjusting the nature of that fundamental base. So far so good.

But notice: by virtue of making those adjustments to the fundamental base, Hyp_{10} differs from Hyp_1 in two important and connected ways. First, Hyp_{10} posits more existing, derivative entities than does Hyp_1. Second, by positing more derivative entities than Hyp_1, Hyp_{10} is compatible with a greater range of potential evidence than Hyp_1. That being so, and for now familiar reasons, Hyp_1 is better confirmed than H_{10} by the actual evidence that we have. Notice, though, that it is the number of derivative entities posited that generates this result. That being so, it doesn't matter whether what is *really* 'adjustable' is

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[12] The appeal to priority monism is for illustrative purposes only. As a referee has usefully pointed out to us, this point can be made without assuming that priority monism is a necessary truth. It is plausible to suppose that a certain number of atoms arranged in a coherent way may ground more derivative entities than the same number of atoms that are not so arranged but, rather, are scattered.

fundamental. What matters is how many derivatives are posited, since it is the number of derivatives that generates the compatibility with a greater number of potential items of evidence.[13]

4.1.4   Jansson and Tallant's 'QP'

The second probabilistic justification for the Razor we will consider is that provided in a recent paper by Jansson and Tallant (forthcoming). Their 'guiding principle' is as follows:

> QP: First, assume a framework of theoretical and background knowledge. Second, locate directly competing hypotheses, compatible with that framework, that allow for the explanation of some explanandum. Third, prefer, ceteris paribus, the hypothesis that minimizes the number of entities that the hypothesis involves in the explanation.

The overarching strategy adopted is, again, Bayesian. Jansson and Tallant show that there are Bayesian justifications available for the preference for the more parsimonious theories in cases involving pair-wise theory choice (ceterus paribus), not that the reasoning in fact deployed by scientists at the point of theory comparison is Bayesian.

The cases Jansson and Tallant discuss have a common core. In each case they consider, they identify two competing hypotheses, H1 and H2. Both hypotheses are framed against a shared framework of theoretical and background knowledge. The more quantitatively parsimonious hypotheses, H1, entails the evidence. The less parsimonious hypothesis, H2, does not. In order to entail the evidence, H2 requires supplementation by a non-trivial hypothesis, H3. H2 and H3 entail the evidence. Given that both H1, H2 and H3 operate against a common theoretical background, this gives us some reason to expect H1 and H2 to be equiprobable (or at least close to it). However, since the conjunction of H2 and H3 is less probable than H2 independently, and H2 and H1 are equiprobable, this gives us reason to prefer H1 over the conjunction of H2 and H3.

As with Huemer's account, the Jansson and Tallant account fails to vindicate the Laser. Consider the same example as the one used above, in Section 4.1.2: theory T1 posits 1 fundamental: A, and 3 derivatives: C, D and E; theory T2 posits 2 fundamentals: A and B and 1 derivative: C. Suppose that the two theories are framed against a shared framework of theoretical and background knowledge. Theory T2 is a conjunction of n-many existence claims. Theory T1 is a conjunction of the same n-many existence claims, plus one further existence claim. Accordingly, theory T1 will be the less probable theory since it makes more existence claims. The Laser, however, tells us to select it anyway. The Razor, by contrast, does not. So only the verdict of the Razor lines up with the probabilistic justification under consideration.

4.1.5   Generalising

Now, of course, the options considered so far are not the only options for probabilistically justifying some version of Ockham's razor. A little reflection, however, reveals that probabilistic justifications of Ockham's razor are not going to extend to the Laser. When considering probabilistic differences between theories, those probabilistic differences are standardly insensitive to the distinction between derivative and fundamental entities. This is especially so in science: the probability of a theory is partly a function of the total number of entities the theory posits; it is not a function merely of the fundamental entities. Indeed, for some theories in areas such as psychology, fundamental entities play no role in the theories at all. And so any probabilistic justification of the razor as applied to those theories can *only* be based on some probabilistic function of the derivatives, where that function establishes an appropriate connection between theory and evidence.

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[13] If talk of 'adjustable' parameters can be dispensed with, what value is the discussion in 4.1.2? We think it remains important. One way of seeing the concerns in that section is as concerns about whether or not the fundamentals and derivatives really come apart from one another and, if not, how that impacts our assessment of a theory. The question of whether or not they do come apart and how this impacts our theory is independent of whether we choose to call derivatives 'adjustable parameters'.

Of course, one could argue that the manner in which we probabilistically select between theories should *not* be insensitive to the differences between theories in this respect; the probabilistic difference between any two theories ought only to be a function of the number of fundamental entities that the theory posits. No doubt that's what the proponent of the Laser will think, should she seek to defend the Laser probabilistically. But then we need some account of how determinations of probability are being made with respect to theories, and some account of how it is that derivative entities can be prevented from making a probabilistic difference to a theory given that, as we have just seen, they tend to do exactly that. While we cannot rule out the provision of such an account, it is notable that no proponent of the Laser has done so to date.[14]

4.2   Explanatory Justifications

Having dealt with probabilistic justifications of the razor, we turn now to explanatory justifications. The idea behind an explanatory justification for the razor is this: the reason *why* we should prefer simpler theories is because simpler theories tend to be more explanatorily powerful. Our question is then whether or not, in cases involving episodes of theory choice in science, a preference for the simpler theory can be defended on explanatory grounds and, if so, whether those grounds can be extended to the Laser.

4.2.1.   Explanatory Power

Consider the following case given by Nolan (1997), intended to show that quantitative parsimony (generally) is taken to be a virtue of physical theories, in *at least some* cases.

> In the 1920s and 1930s, physicists were puzzled by an aspect of Beta decay—the emission or electrons (these electrons being known as Beta particles) from the nuclei of some radioactive atoms. The problem was that the drop in energy of the nuclei during Beta decay was more than the combined mass-energy and kinetic energy of the emitted electron. Mass energy seemed to have been annihilated... Pauli … suggested that a new, neutrally charged, never before detected particle was emitted along with the electron in Beta decay, and that the sum of its mass-energy and kinetic energy went to make up the missing energy… Yet another advantage of the postulation of the neutrino was that it could be used to account for the missing ½ spin in Beta decay which violated conservation of spin laws. (1997: 332)[15]

While Nolan's discussion focuses on the missing mass-energy in beta decay, following Baker (2003) we focus upon the missing spin. As Baker (2003: 246–247) notes, there are a number of competing hypotheses that would serve to explain the "missing" spin.

H_1	1 particle with a spin of 1/2 is emitted in each case of Beta decay
H_2	2 particles, each with spin 1/4 is emitted in each case of Beta decay
H_3	3 particles, each with spin 1/6 is emitted in each case of Beta decay
H_{10}	10 particles, each with spin 1/20 is emitted in each case of Beta decay

However, no hypothesis *other* than H_1 was seriously considered by physicists. In Nolan's (1997: 333) words:

> Pauli and Fermi did not consider in their papers outlining the new theory the possibility that there may be more than one tiny neutral particle produced in each case of Beta decay….

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[14] Similarly, a proponent of the Laser may look to undermine the probabilistic justifications provided for OR in section 4. Again, that's a very reasonable line to pursue, but no reviser has yet taken up the challenge.
[15] It's important to note, of course, that we now know that spin comes in values of 1/3, not 1/2. But since spin was little understood at the time, it is apt to talk here of spin coming in values of 1/2, and being emitted in denominations of this value. This, after all, is what physicists were trying to explain. We'll proceed, below, as if spin really is emitted in values of 1/2. We do so, simply to ease presentation. Even if one changes the detail, such that spin is emitted in values of 1/3, rather than 1/2, the general shape of the argument holds.

I take the fact that they saw fit only to postulate one additional particle in each Beta-decay, and either did not consider postulating more or at least did not give it serious consideration, as evidence that there was some reason for their quantitatively sparse postulation.

Nolan goes on to conclude that quantitative parsimony is at least *among* the possible theoretical virtues of a scientific theory. In choosing between H_1 and H_{10} it (at least seems as if) physicists were abiding by the injunction to not posit more entities than were required to complete the explanatory project. What was required was an explanation of Beta-decay. A single object could be posited, to explain the phenomena. Thus, a single object *was* posited.

According to Baker (2003), this preference for the simpler theory, H1, can (in part) be justified on explanatory grounds. A salient difference between H2 and H1 is that H2 would seem to allow that there *could* be cases of beta-decay in which a single particle of ¼ spin is released, and so there could be cases of Beta decay where ¼ spin is missing, as opposed to ½ spin. However, no such case has ever been observed. H2 must therefore explain *why* it is that we don't observe cases of missing ¼ spin, whereas H1 does not face the same explanatory burden. Of course, a proponent of H2 can provide such an explanation, but to do so one must posit some additional law that constrains the way in which these particles are emitted (namely, together), but that leaves the resulting and now revised H2 with a commitment to a law—a law for which we have no independent justification. As such, H1 seems the more natural, tighter explanation of the data. Accordingly, H1 is the better theory. In short, it is the fact that H1 has 'less to explain' that justifies a preference for that theory. It thus *seems* (though such seemings may be misleading) that this could be a case where we can give an explanatory justification for preferring the more parsimonious theory.

On the assumption that neutrinos are not metaphysically fundamental, the explanatory considerations just discussed justify the Razor and not the Laser. The Razor tells us to select H1 over H2, because it deploys fewer derivative entities. The Laser tells us that H1 and H2 are on a par, because neither theory boasts an economy of fundamentals over the other. The recommendation given by the Razor, then, can be justified in terms of H1 being the more explanatorily powerful theory. The recommendation given by the Laser, by contrast, cannot be justified on the same grounds, since the recommendation given by the Laser is only justified if H1 and H2 are explanatorily on a par, which they are not.

In response, one might take issue with the assumption that neutrinos are not metaphysically fundamental. On some physical theories, such as the standard model of particle physics, it may turn out that neutrinos are fundamental. If so, then the Laser would tell us to select H1 over H2; a preference that can be duly justified on explanatory grounds. The neutrino case, however, is merely an illustration of a more general phenomenon. The same general reasoning used in the neutrino case will generalise to all 'additive' cases in science. As Baker (2003, p. 248) explains, additive cases:

> …involve the postulation of a collection of individual objects, qualitatively identical in the relevant respects, which collectively explain some particular observed phenomenon. The explanation is 'additive' in the sense that the overall phenomenon is explained by totaling the individual positive contributions of each object.

The Avogadro case considered above is an additive case in the relevant sense. In the Avogadro case, we total the number of elemental gas molecules in order to explain a particular phenomenon, namely the emission of steam in the chemical reaction between oxygen and hydrogen. Accordingly, consider again the space of hypotheses:

Hyp_1	The number of atoms per elemental gas molecule is 2 (1 atomic weight)
Hyp_2	The number of atoms per elemental gas molecule is 4 (1/2 atomic weight)
Hyp_3	The number of atoms per elemental gas molecule is 8 (1/4 atomic weight)
Hyp_{10}	The number of atoms per elemental gas molecule is 1024 (1/512 atomic weight)

The Razor recommends that we select Hyp_1. We can justify this choice using the same explanatory reasoning that Baker deploys for the neutrino case. Given Hyp_1, a chemical reaction between hydrogen

and oxygen can produce two volumes of water. Given Hyp$_2$, a chemical reaction between hydrogen and oxygen can produce two volumes of water or it could produce four volumes of another chemical entirely. That's because Hyp$_2$ posits extra elemental gas molecules that Hyp$_1$ does not posit, and so there are even more oxygen and hydrogen atoms available for recombination during the chemical reaction, and so the space of possible chemicals that can be produced is correspondingly widened. As in the neutrino case, then, we require some explanation for why it is that we do not observe the further chemical reactions compatible with Hyp$_2$. Some law will be required that forces hydrogen and oxygen atoms to combine only in certain numbers, a law that is not required under Hyp$_1$. Accordingly, the preference for Hyp$_1$ over Hyp$_2$ delivered by the Razor can be justified on explanatory grounds. The Laser, by contrast, treats both hypotheses as on a par, because they do not differ with respect to the number of fundamentals; a verdict that cannot be justified in the same fashion.

It is easy to see that there will be many more cases like the Avogadro case in science. Indeed, in any additive case where we are attempting to explain some phenomenon by positing an unobservable of some kind, where the unobservable is a derivative entity, we can expect the Razor and the Laser to make competing demands. It is, however, only the demands of the Razor that line up with the explanatory structure of the situation.

5. Other Razors

Thus far we have argued that neither probabilistic justifications nor explanatory justifications vindicate the Laser. We imagine that the proponent of the Laser could reply in a number of ways. In this closing section of the paper we consider a few of these, and show them to be lacking.

Razor-revisers could say that parsimony matters at both the fundamental and non-fundamental level, but that parsimony matters more at the fundamental level than it does at the level of derivatives. To give an example: suppose that we have two plausible theories. T1 commits us to one fundamental object and ten derivative objects. T2 commits us to two fundamental objects and four derivative objects. The proposal we're currently exploring would allow that T1 is less parsimonious over all, but, because of the weight given to the number of fundamental entities a theory posits, the proposal might allow that T1 is nonetheless preferable to T2. So, although it's not the case that only the fundamentals matter, it is the case that the fundamentals matter more than the derivatives.

This, we think, might be an interesting route to pursue. We don't believe that this view is the one that razor-revisers are looking for; they are explicit that we should only count the fundamentals. We nonetheless recommend this line to those who wish to pursue the idea that there is an important sense in which the fundamentals outweigh the derivatives.

There are, however, tricky issues in the offing. For instance, is there some number of derivatives, n, such that holding fixed the fundamentals posited by T1 (one fundamental object) and T2 (two fundamental objects), we should prefer T2 to T1? A hundred derivative objects? A thousand? A million? We aren't sure. But we think the question relevant. There is some nagging doubt in our minds that the following case is easy to decide: T1* posits one fundamental object and one million derivative objects. T2* posits two fundamental objects and four derivative objects. In this case, we think we should prefer T2* to T1* on parsimony grounds.

At any rate, we're reluctant to take the route of saying that razor-reviser should respond by differentially weighing parsimony at the derivative and fundamental levels. More details are required if we're to understand how to properly understand the claim that parsimony matters more at the fundamental level than it does at the level of derivatives.

Included in the required details of such a theory are answers to the following questions: what is the final weighting? Will the revised-razor with revised weightings yield the correct result in the Avogadro and Buffon's Law cases? Do levels of fundamentality matter? (That is: if the xs are more fundamental than the ys, and the ys are more fundamental than the zs, then, when engaged in weighing competing theories, is a theory that posits a number, n, of xs superior to a theory that posits 2n of ys, but n xs? Is a theory

positing n xs, superior to a theory that posits 8n zs, but n xs?) We cannot see any straightforward way in which to answer these questions, but we think that a razor-reviser should answer them, if they wish to revise the razor. We would welcome attempts to provide the requisite weightings and explanations of how these yield sensible answers to the questions just asked.

An alternative option, one that does not obviously involve weighing fundamental and derivative entities differently, is to concede that the number of derivative entities makes a difference to parsimony, but only as a tie-breaker. The thought here is that for any two theories T and T*, if T* has fewer fundamentals than T, then no degree of economy with respect to derivative entities in T could outweigh its profligacy with respect to the fundamentals. If, however, T and T* have the same number of fundamentals, then T's relative saving in derivative entities does constitute a reason to prefer T to T*.

This is an initially promising line of thought. One difficulty, however, is that it may still require weighing the fundamentals more heavily. For suppose we extend the probabilistic argument outlined in the previous section as follows: treat every fundamental entity as an adjustable parameter, and treat some derivative entities as adjustable parameters. Now, suppose that the difference to the likelihood of a theory being true is a function of the number of adjustable parameters in that theory, where that function is blind to the difference between fundamental and derivative entities, in this sense: each additional fundamental entity decreases the likelihood of a theory's being true by the same amount as each additional derivative entity. Now, suppose we have two theories: T and T*. T has 2 fundamentals and 10 derivatives; T* has 5 fundamentals and 2 derivatives. In this situation, T* will be more probable than T. So the first part of the tie-breaking strategy – that the number of derivatives makes no difference to parsimony considerations, only the fundamentals count – seems to flout this natural extension of the Bayesian picture. The only way to address the problem, it would seem, is to claim that increasing the number of fundamentals makes a theory much less likely to be true as compared to increasing the number of derivative entities. So the fundamentals are weighed more heavily with respect to likelihood. But what grounds do we have for this way of weighing entities? We can see no justification for this move, especially in light of the fact that the significant shift in entities available threatens to leave us with different background, theoretical commitments. Razor-revisers would do well to look elsewhere for a response.

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