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Occam's Razor in science: a case study from biogeography

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Introduction

There is a widespread philosophical presumption – deep-rooted and often unarticulated – that a theory whose ontology exceeds that of its competitors is at a *prima facie* disadvantage. This presumption that ontologically more parsimonious theories are preferable appears in many guises. Often it remains implicit. Sometimes it is invoked as a primitive, self-evident proposition that cannot be further justified or elaborated upon (for example at the beginning of Goodman and Quine's 1947 paper,[1] and in Quine's remarks about his taste for "clear skies" and "desert landscapes"). Other times it is elevated to the status of a "Principle" and labeled as such (for example, the "Principle of Parsimony"). However, perhaps it is best known by the name "Occam's (or Ockham's) Razor."

The question I wish to address in this paper is whether Occam's Razor is a methodological principle of science. In addition to being a significant issue in its own right, I am also interested in potential connections between attitudes towards parsimony in science and in philosophy. Metaphysicians might once have aimed to justify the use of Occam's Razor in science by appeal to *a priori* philosophical principles. The rise of scientific naturalism in the second half of the 20th Century has undercut this style of approach. If anything, the direction of potential justification is reversed. Philosophy of science is conceived of as continuous with science, and not as having some independently privileged status. The perspective of the naturalistic philosopher may be broader, but her concerns and methods are not fundamentally different from those of the scientist. Thus scientific methodology neither needs, nor can legitimately be given, external philosophical justification. It is against this broadly naturalistic background that I am raising the above question: is Occam's Razor a principle of science?

My main case study, presented in Part 2 of the paper, is taken from biogeography. This is a field which has been studied in detail by historians of

[1] They state that their refusal to admit abstract objects into their ontology is "based on a philosophical intuition that cannot be justified by appeal to anything more ultimate." (Goodman and Quine [1947, p. 174]).

science, including Fichman and Nelson.[2] Biologists and biogeographers themselves have also weighed in with reflections on the methodology of the discipline.[3] It has received only intermittent attention from philosophers, though the sparse philosophical literature includes a useful pair of papers by Kleiner.[4] There has also been some more recent work addressing issues of model selection in biogeography.[5] I will have more to say about how my own analysis connects with this literature in later sections of the paper. As far as I am aware, however, there has hitherto been no attempt to analyze competing theories in biogeography specifically through the lens of ontological parsimony.

Part 1 is devoted to sharpening and clarifying Occam's Razor as a principle of parsimony, and to contrasting it with other related simplicity principles. A distinction is also made between two kinds of evidence which bear on the issue of whether Occam's Razor is a principle of science. The first part concludes with a look at some putative case studies from physics and points out some problems with trying to derive conclusions about the status of Occam's Razor from such studies.

Part 1

Formulating Occam's Razor

A distinction is often made between two fundamentally distinct senses of simplicity: syntactic simplicity (roughly, the number and complexity of hypotheses), and ontological simplicity (roughly, the number and complexity of things postulated).[6] These two facets of simplicity are often referred to as *elegance* and *parsimony*, respectively. For the purposes of the present overview we shall follow this usage and reserve "parsimony" specifically for simplicity in the ontological sense. It should be noted, however, that the terms "parsimony" and "simplicity" are used virtually interchangeably in much of the philosophical literature.

In analyzing simplicity, it can be difficult to keep its two facets – elegance and parsimony – apart. Occam's Razor is frequently stated in a way which is ambiguous between the two notions, for example, "Don't multiply postulations beyond necessity." Here it is unclear whether 'postulation' refers to the entities being postulated, or the hypotheses which are doing the postulating, or both. The first reading corresponds to parsimony, the second to elegance. While these two facets of simplicity are frequently conflated, it is important to

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[2] Fichman (1977), Nelson (1978).

[3] See e.g. Ball (1976), Andersson (1996).

[4] Kleiner (1981, 1985).

[5] See e.g. Shrader-Frechette (1990), Sismondi (2000), Mikkelson (2001).

[6] N.B. some philosophers use the term "semantic simplicity" for this second category. e.g. Sober (2001, p. 14).

treat them as distinct. For considerations of parsimony and of elegance often pull in different directions. Postulating extra entities may allow a theory to be formulated more simply, while reducing the ontology of a theory may only be possible at the price of making it syntactically more complex. For example the postulation of Neptune allowed observed perturbations in the orbit of Uranus to be explained without complicating the statements of the laws of celestial mechanics.

On the ontological side of the divide we have characterized parsimony as a measure of the number and complexity of things postulated. But what counts as a "thing" for present purposes? In keeping with the broader approach of this paper, we can approach this question both from the direction of philosophy and from the direction of science. As we shall see shortly, Quine links parsimony to his notion of ontological commitment and thus anything quantified over by our best theories will count. The criterion for thinghood becomes partly a matter of the choice of logical language and metaphysical framework. Objects, properties, events, even mathematical parameters may end up contributing to parsimony. On the scientific side, ontological simplicity seems more closely tied to causation. Roughly speaking, in assessing the ontology of a scientific theory, scientists focus on the causally efficacious kinds of objects, properties, and forces which it invokes. Ironically, although the philosophical notion is potentially more inclusive, much of the debate over ontological parsimony in the philosophical literature has operated with a narrowly object-orientated point of view. Burgess has criticized this narrowness, arguing that science does not have a "fenced ontology" of this sort.[7] To do justice to the various issues involved here would take a whole separate paper. Fortunately for present purposes, and in the context of the case study from biogeography, no definitive answer is needed to the question of precisely what should be counted as a "thing" when tallying the parsimony of a given scientific theory.

One line of objection to the purported distinction between elegance and parsimony is to claim that less elegant theories normally also imply that the world is less parsimonious, especially if parsimony is broadly construed. Take the Neptune example. The alternative to postulating Neptune was to accept greater complexity in the statement of the laws of celestial mechanics. But if the extra syntactic complexity of these laws involves postulating, for example, new forces acting on the planets then the new theory is also less parsimonious than the old one. In this case the trade-off in the Neptune example might more accurately be characterized as between two less parsimonious theories, one postulating a new planet and the other postulating new forces, rather than between a relatively less parsimonious theory and a relatively less elegant theory. It should be noted, however, that extra complexity cannot always be linked to extra entities. Consider an alternative theory according to which celestial bodies move in convoluted curves rather than in ellipses. These curves are mathematically – and thus syntactically – more complex to describe. But

[7] Burgess (1998, pp. 212–3).

the theory need not postulate any extra objects or forces: the movement along convoluted curves may just be a brute fact about the universe.

Before setting aside the definitional question for ontological parsimony, it is worth mentioning one further distinction, between *qualitative* parsimony (roughly, the number of kinds of thing postulated) and *quantitative* parsimony (roughly, the number of individual things postulated). The default reading of Occam's Razor in the bulk of the philosophical literature is as a principle of qualitative parsimony, and the qualitative notion will be my focus in this paper also. The case mentioned above concerning the postulation of Neptune turns out to be an example of quantitative parsimony: Neptune is one more individual member of the known class of planets.

It should be noted that interpreting Occam's Razor in terms of *kinds* of entity brings with it some extra philosophical baggage of its own. In particular, judgments of parsimony become dependent on how the world is sliced up into kinds. Nor is guidance from extra-philosophical usage – and in particular from science – always clearcut. For example, is a previously undiscovered subatomic particle made up of a novel rearrangement of already discovered sub-particles a new 'kind'? What about a biological species, which presumably does not contain any novel basic constituents? Also, ought more weight to be given to broad and seemingly fundamental divisions of kind – for example between the mental and physical – than between more parochial divisions? Intuitively, the postulation of a new kind of matter would seem to require much more extensive and solid justification than the postulation of a new sub-species of spider. I will return to this issue when we come to discuss the specifics of the biogeographical case study.

For the purposes of this paper, I shall be setting aside more general questions concerning the nature and role of simplicity considerations. In particular, I shall not be addressing the issue of whether there is a single, 'correct' definition of simplicity, nor whether there is a theoretically best way to balance the competing demands of elegance and parsimony when formulating theories.[8] My focus will be solely on Occam's Razor as a principle of ontological parsimony. Perhaps the most common formulation of the ontological form of Occam's Razor is the following;[9]

(OR) Entities are not to be multiplied beyond necessity.

Considered as a principle of theory choice, OR implies that – other things being equal – it is rational to prefer theories with fewer ontological commitments. This suggests the following paraphrase of OR;

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[8] For a useful discussion of an influential attempt to answer this latter question, based on work of the statistician Akaike, see Forster and Sober (1994). For a more general overview of recent work on simplicity and theory selection see Forster (2001).

[9] Modern formulations of Occam's Razor are connected only very tenuously to the 14th-century figure William Ockham. I should stress that I am not here interested in the exegetical question of how Ockham intended his 'Razor' to function, nor in the uses to which it was put in the context of medieval metaphysics.

(OR_1) Ontological parsimony is a significant theoretical virtue.

What does it mean to say that one theory is more ontologically parsimonious that another? The basic notion of ontological parsimony is quite straightforward: if two theories, T_1 and T_2, have the same ontological commitments except that T_2 is ontologically committed to F's and T_1 is not, then T_1 is more parsimonious than T_2.[10] More generally, a sufficient condition for T_1 being more parsimonious than T_2 is for the ontological commitments of T_1 to be a *proper subset* of those of T_2.

OR_1 is intended to operate against the background of a broadly Quinean picture of theory choice in natural science. According to this picture, scientists choose between competing theories by comparing their various theoretical virtues. Different theoretical virtues are given different implicit 'weights' according to their relative importance. Other things being equal, scientists will tend to prefer the theory with the best overall balance of theoretical virtues.[11] One of the central tasks for a naturalistic philosophy of science is to identify and elucidate these various theoretical virtues. Popular candidates include features such as explanatory power, deductive strength, consistency, elegance, and fruitfulness. Viewed against the background of this (admittedly idealized) picture, OR_1 proposes *ontological parsimony* as one of these theoretical virtues.

There are two basic approaches to the task of collecting evidence for the claim that Occam's Razor is a methodological principle of science. One approach is to look at the pronouncements of scientists about the features of theories which they value and about the considerations that affect their theory choices. Such pronouncements would constitute *explicit* evidence concerning Occam's Razor. A second approach is to look at the patterns of acceptance and rejection of competing theories by working scientists, and to see if these patterns reflect systematic preferences for ontologically more parsimonious theories over their rivals. Such patterns would constitute *implicit* evidence for Occam's Razor. For ease of exposition, my examination of the evidence for Occam's Razor will be organized under these two basic headings.

Explicit evidence for Occam's Razor: principles of parsimony

The first kind of evidence for Occam's Razor as a principle of scientific theory choice is explicit evidence gleaned from scientists' pronouncements concerning

[10] A theory is *ontologically committed* to F's if and only if F's must be included within the range of the theory's variables in order for the theory to come out true. [Quine]

[11] This process of assessment and weighting is mostly implicit; the picture does not imply that scientists are in fact able to identify and articulate the values which they attach to different features of theories.

their own methodological practices. One might expect explicit evidence of this sort to provide a clear-cut verdict concerning the scientific credentials of Occam's Razor. However, there are several factors which make assessment of this evidence less straightforward.

One point is that when scientists use the term "Occam's Razor" they often have in mind a version which is not specifically ontological; rather it is a vaguer and more general principle along the lines of "prefer simpler theories." This may get cashed out in syntactic terms, emphasizing a preference for formulations of laws and principles that are compact and elegant. Or it may be phrased in terms of a prohibition against multiplying hypotheses or principles, rather than entities *per se*.[12] It would be wrong, therefore, to assume that support expressed for "Occam's Razor" is necessarily support for an ontological version of this principle. A second point is that scientists may not actually *act* in accordance with the explicit principles which they proclaim. If scientists claim that ontological parsimony is an important theoretical virtue, then we expect this to be manifested in the choices between theories which they make. However the link is not guaranteed, and it is always possible for agents to be mistaken (either individually or collectively) about the principles which underly their own actions.[13] We should bear in mind, then, that it is possible for the explicit and implicit evidence for Occam's Razor to conflict.

Thinkers are fond of formulating principles and dictums that encapsulate their own preferred methods of scholarship and inquiry. In this respect scientists are no exception. Occam's Razor is but one example of a whole family of "principles of parsimony" which have been proposed in various forms by theologians, philosophers, and scientists in the 600 years since Ockham first formulated his razor. Both Galileo and Newton accepted versions of Occam's Razor. Indeed Newton includes a principle of parsimony as one of his three 'Rules of Reasoning in Philosophy' at the beginning of Book III of *Principia Mathematica*.

> Rule I: We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances.

Newton goes on to remark that "Nature is pleased with simplicity, and affects not the pomp of superfluous causes."[14] Galileo, in the course of making a detailed comparison of the Ptolemaic and Copernican models of the solar system, maintains that "Nature does not multiply things unnecessarily; that she makes use of the easiest and simplest means for producing her effects; that she

[12] That these versions are the ones most commonly referred to by scientists is born out by more own informal survey. For one of (many) such references in the scientific literature see Balasubramanian (1997).

[13] This is a point which is central to philosophical analyses of rule-following. Much of current work by historians of science is devoted to uncovering the inaccuracies in scientists' conception of the 'objectivity' of the scientific enterprise.

[14] Newton [1964 (ed.), p. 398]. Note the explicit restriction here to *causal* entities.

does nothing in vain, and the like."[15] Nor are advocates of parsimony principles restricted to the ranks of physicists and astronomers. Here is the chemist Lavoisier writing in the late 18th Century;

> If all of chemistry can be explained in a satisfactory manner without the help of phlogiston, that is enough to render it infinitely likely that the principle does not exist, that it is a hypothetical substance, a gratuitous supposition. It is, after all, a principle of logic not to multiply entities unnecessarily. Perhaps I should provide falsifying arguments and be satisfied with having proved that one account for these phenomena better without phlogiston than with it.[16]

The label 'Occam's Razor' was not coined until the early 19th Century, when Sir William Hamilton introduced the term to refer to one facet of a more general "Law of Parcimony" [sic], according to which "nature never works by more complex instruments than are necessary." These various principles of ontological parsimony have run in a fairly continuous thread through the recent history of science. Their presence provides circumstantial support – and explicit evidence – for the claim that Occam's Razor is indeed a methodological principle of science.

Complicating this initial assessment is the presence of a second family of principles which do appear directly to conflict with Occam's Razor. These are so-called 'principles of plenitude.' Perhaps the best-known version is associated with Leibniz, according to whom God created the best of all possible worlds with the greatest number of possible entities. More generally, a principle of plenitude claims that if it is *possible* for an object to exist then that object *actually* exists. In other words, we ought to postulate the existence of anything that is not ruled out by our best theories. Principles of plenitude conflict with Occam's Razor over the existence of physically possible but explanatorily idle objects. Our best current theories presumably do not rule out the existence of unicorns, but nor do they provide any support for their existence. According to Occam's Razor we ought *not* to postulate the existence of unicorns. According to a principle of plenitude we *ought* to postulate their existence.

The fact that principles of plenitude conflict with Occam's Razor is not normally regarded as a serious problem because plenitude seems historically to have been of marginal importance. In particular, plenitude principles have been more of a preoccupation of philosophers than of scientists. However, this assessment may be premature; the rise of particle physics and quantum mechanics in the 20th Century has seen various principles of plenitude being appealed to by scientists as an integral part of their theoretical framework. This phenomenon has not, I think, been widely noticed, thus it is worth looking at some examples in more detail.

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[15] Galileo [1962 (ed.), p. 397].

[16] Lavoisier (1862, pp. 623–624).

A particularly clear-cut example of an appeal to a principle of plenitude in modern physics is provided by the case of magnetic monopoles. The theory of electromagnetism, developed in the 19th Century, postulated numerous analogies between electric charge and magnetic charge. One theoretical difference is that magnetic charges must always come in oppositely charged pairs, called "dipoles" (as in the North and South poles of a bar magnet), whereas single electric charges, or "monopoles," can exist in isolation. However, no actual monopole had ever been observed. Physicists began to wonder whether there was some theoretical reason why magnetic monopoles could not exist. In the early decades of the 20th Century it was thought that the newly developed theory of quantum mechanics ruled out the possibility of monopoles, and this is why none had ever been detected. However, in 1931 the physicist Paul Dirac showed that the existence of monopoles is consistent with quantum mechanics, although it is not required by it. Despite the inconclusive nature of this theoretical result, Dirac went on to assert the existence of monopoles, arguing that their existence is not ruled out by theory and that "under these circumstances one would be surprised if Nature had made no use of it."[17] This appeal to plenitude was widely – though not universally – accepted by other physicists.

> One of the elementary rules of nature is that, in the absence of laws prohibiting an event or phenomenon it is bound to occur with some degree of probability. To put it simply and crudely: anything that *can* happen *does* happen. Hence physicists must assume that the magnetic monopole exists unless they can find a law barring its existence.[18]

Others have been less impressed by appeals to plenitude;

> Dirac's ... line of reasoning, when conjecturing the existence of magnetic monopoles, does not differ from 18th-century arguments in favor of mermaids. ... [A]s the notion of mermaids was neither intrinsically contradictory nor colliding with current biological laws, these creatures were assumed to exist.[19]

A more recent example of an appeal to a principle of plenitude involves the postulation of tachyons, 'superluminal' particles which travel faster than light. Much as the existence of magnetic monopoles was originally thought to be ruled out by quantum mechanics, the existence of tachyons was thought to be ruled out by special relativity. Then, in 1969, Bilaniuk and Sudarshan showed that tachyons could be consistently described within the framework of special relativity. Having proved this result, the authors then argued as follows;

[17] Dirac (1930, p. 71, note 5).

[18] Ford (1963, p. 122).

[19] Kragh (1981, p. 149). This criticism is slightly unfair to Dirac since the 18th-century biologists were making a very restricted existence claim, that mermaids exist now somewhere on earth, whereas Dirac's claim is spatiotemporally unrestricted.

> If [tachyons'] existence would not lead to any contradictions [with laws of physics] one should be looking for them. There is an unwritten precept in modern physics, often facetiously referred to as Gell-Mann's totalitarian principle which states that in physics anything which is not prohibited is compulsory.[20]

It is difficult to know how to interpret these principles of plenitude, and physicists are often unclear about just how strong the claim is supposed to be. One of the many respects in which quantum mechanics diverges from classical physics is in its replacement of a deterministic model of the universe with a model based on objective probabilities. According to this probabilistic model, there are numerous ways the universe could have evolved from its initial state, each with a certain probability of occurring that is fixed by the laws of nature. Consider some kind of object, say unicorns, whose existence is not ruled out by the initial conditions plus the laws of nature. Then one can distinguish between a weak and a strong version of the principle of plenitude. According to the weak principle, if there is a small finite probability of unicorns existing then given enough time and space unicorns will exist. According to the strong principle, it follows from the theory of quantum mechanics that if it is possible for unicorns to exist then they do exist. One way in which this latter principle may be cashed out is in the 'many-worlds' interpretation of quantum mechanics, according to which reality has a branching structure in which every possible outcome is realized.[21]

I do not want to delve too deeply into the issues surrounding these principles of plenitude in modern physics, since they are tangential to the main thrust of our discussion. However the presence – and at least partial acceptance by working scientists – of these principles, together with the fact that they seem to go directly against the dictates of ontological versions of Occam's Razor, further muddies the waters concerning the explicit evidence for Occam's Razor.

Setting aside these principles of plenitude, the explicit evidence for Occam's Razor is anyway less decisive than it might at first appear. It is true that many influential thinkers since William Ockham have promoted versions of Occam's Razor, and that there is something widely appealing about the pursuit of ontological economy in our theorizing about the world. However, the extent to which these principles are best viewed as principles of *science* is unclear. The post-medieval period coincided with the gradual transition from theology to science as the predominant means of revealing the workings of nature. In many cases, espoused principles of parsimony and plenitude continued to wear their theological origins on their sleeves, as with Leibniz's thesis that God has

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[20] Bilaniuk and Sudarshan (1969, p. 44).

[21] Legitimate doubts may begin to creep in here, however, concerning whether "exists" is here being used in its normal, everyday sense.

created the best and most complete of all possible worlds.[22] Insofar as principles of parsimony are advanced as theological or metaphysical principles, their relevance to the issue of the scientific status of Occam's Razor is marginal at best. Given the broadly naturalistic outlook which underlies this debate, care needs to be taken to ensure that the principles being asserted are genuinely part of science. Otherwise the debate loses its moorings and threatens to drift towards the anti-Quinean dystopia of 'first philosophy' overriding actual scientific practice.

To summarize, I have pointed to four factors which complicate the assessment of explicit evidence for Occam's Razor as a principle of science. First, often when scientists talk about "Occam's Razor" they do not have a specifically ontological version in mind. Second, explicit pronouncements about the value of parsimony may not always go hand in hand with practice that conforms to these pronouncements. Third, principles of plenitude which seem to directly contradict Occam's Razor have also been appealed to by scientists. Fourth, historical cases of parsimony principles in science may have been put forward based on reasons that were theological or metaphysical rather than genuinely scientific.

Implicit evidence for Occam's Razor: the elimination of the ether

Given these difficulties, it is tempting to look instead at *implicit* evidence for Occam's Razor as a principle of science. This is evidence based on the patterns of acceptance and rejection of competing theories by working scientists. It is not difficult to find episodes from the history of science in which the more ontologically parsimonious of two rival theories has been preferred by scientists. However, episodes of this sort constitute implicit evidence for Occam's Razor only if the ontologically more parsimonious theory is preferred *despite being inferior in other respects*. It is this condition which most of the case studies discussed in the literature fail to meet.

Einstein's development of Special Relativity – and its impact on the hypothesis of the existence of the electromagnetic ether – is one of the episodes most often cited (by both philosophers and scientists) as an example of Occam's Razor in action.[23,24] In many respects this is a nice example of parsimony considerations in action, hence it will be worth examining in some detail. I shall argue, however, that this episode has little bearing on Occam's Razor as a putative methodological principle because

[22] cf. Smart (1984, p. 121) who writes: "There is a tendency ... for us to take simplicity ... as a guide to metaphysical truth. Perhaps this tendency derives from earlier theological notions: we expect God to have created a beautiful universe."

[23] see e.g. Sober (1981, p. 153).

[24] Another favorite is the triumph of the Copernican model of the solar system over the Ptolemaic model; however this has more to do with syntactic simplicity than with ontological parsimony, so I will not discuss it here.

Special Relativity has several other theoretical advantages in addition to being more parsimonious.

In the second half of the 19th Century James Clerk Maxwell, building on the earlier work of Ampère and Faraday, developed a comprehensive and detailed theory of electromagnetism. This theory was based around four key equations – the so-called 'Maxwell equations' – together with the Lorentz force law, and it provided an impressively accurate description of the dynamical behavior of charges and electromagnetic fields. An indication of the predictive and explanatory power of Maxwell's theory is that its theoretical core – the field equations and the force law – has been retained more-or-less intact as the basis of our current theory of electrodynamics.

There is, however, another component of Maxwell's theory which has not fared so well. The theory originally included a mechanical model in which electromagnetic waves were transmitted through a medium which Maxwell called the *ether*. The postulation of the ether was central to Maxwell's own thinking, and it was a recurring theme in early models of electromagnetic phenomena. As far back as 1822, Ampère was suggesting that light was a wave motion in a "luminiferous ether" made up of two types of electric fluid. The assumption of the existence of the ether was no idle metaphysical hypothesis, for it contributed to the explanatory power of Maxwell's theory. The assumption also had testable consequences, since it implies that Maxwell's equations must be altered depending on the motion of the frame of reference relative to the ether. In particular it implies that the velocity of light is dependent on the speed and direction of the earth's motion through the ether. This set the stage, in 1887, for Michelson and Morley's celebrated experiment to detect if the earth was indeed in motion relative to the ether, which involved firing beams of light in different directions and measuring the difference in their velocities.

The Michelson–Morley experiment detected no difference in the velocity of light beams projected in different directions. The only way in which this result could be made to fit with Maxwell's theory was if either

(a) The earth is in the rest frame of the ether.

or

(b) The earth is dragging the ether along with it in its orbit around the sun.

Both these possibilities were quickly ruled out as wildly implausible, and this meant that Maxwell's theory needed to be modified if it was to 'save the phenomena' observed in the Michelson–Morley experiment.[25]

[25] I am ignoring here some recent historical studies (e.g. Collins and Pinch [1993]) which indicate that the results from the Michelson–Morley experiments were far from clear-cut, and that in several cases the quantities measured were less than the experimental error of the apparatus.

In response to this experimental evidence, Lorentz proposed the following modification to Maxwell's theory: add to the theory's basic postulates the assumption that a rigid body *contracts*, by a factor of $(1 - v^2/c^2)^{1/2}$, along the direction of its motion through the ether.[26] It can be shown mathematically that this 'Lorentz contraction' exactly cancels out the effect of the slower moving light waves in the Michelson–Morley experiment because the distance which they travel is correspondingly shorter. To forestall objections that this extra assumption is merely an *ad hoc* device to rescue a falsified theory, Lorentz argued that the electromagnetic forces between the particles making up a rigid body are affected by the motion of the body through the ether, and this accounts for the resulting contraction of the body. After the failure of several other experiments to detect the presence of the ether, Poincaré extended Lorentz's idea and put it into the form of a principle. According to Poincare's principle, motion through the ether is theoretically undetectable: any effect that might be detectable is always exactly canceled by an equal and opposite compensating effect.[27]

Einstein's insight was to see that the problems raised by the Michelson–Morley experiment arose neither from Maxwell's equations nor from the principle of relativity but rather from the uncritical acceptance of intuitive ideas about the nature of space and time. The ether is by hypothesis a fixed medium and reference frame for the propagation of light (and other electromagnetic waves). The Special Theory of Relativity includes the radical postulate that the speed of a light ray through a vacuum is constant relative to an observer no matter what the state of motion of the observer. Given this assumption, the notion of a universal reference frame is incoherent.[28] Hence Special Relativity implies that the ether does not exist.

At one level this episode can be viewed as the replacement of an empirically adequate theory (the Lorentz-Poincaré theory) by a more ontologically parsimonious alternative (the Special Theory of Relativity). This is why it is often taken to be an example of Occam's Razor in action. The problem with using this example as evidence for Occam's Razor is that Special Relativity (SR) has several other theoretical advantages over the Lorentz-Poincaré (LP) theory in addition to being more ontologically parsimonious. Firstly, SR is a syntactically simpler and more unified theory than LP, since in order to "save the phenomena" a number of *ad hoc* and physically unmotivated patches had been

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[26] Here v is the velocity of the body relative to the ether, and c is the velocity of light.

[27] The mathematical physicist N. M. J. Woodhouse sums up the situation with characteristic irony: "According to Poincaré's point of view, the ether exists but cannot be detected. This is not a good starting point for a physical theory." (Woodhouse [1988, p. 29]).

[28] Since if an observer is moving at velocity v with respect to the universal reference frame, U, in the same direction as a ray of light that is moving with velocity c (with respect to U) then this implies that the velocity of the light ray relative to the observer is $(c-v)$, and this contradicts the assumption that the speed of light is invariant relative to all observers.

added to LP.[29] In other words, in this particular case of theory comparison, parsimony (ontological simplicity) and elegance (syntactic simplicity) pull in the *same* direction. Secondly, LP raises doubts about the physical meaning of distance measurements. According to LP, a rod moving with velocity, v, contracts by a factor of $(1-v^2/c^2)^{1/2}$. Thus only distance measurements that are made in a frame at rest relative to the ether are valid without modification by a correction factor. However, LP also implies that motion relative to the ether is in principle undetectable. So how is distance to be measured? In other words, the issue here is complicated by the fact that – according to LP – the ether is not just an extra piece of ontology but an *undetectable* extra piece. A third advantage of SR over LP is that – in the case of SR – various observational symmetries are mirrored by deeper theoretical symmetries.[30]

Given these various advantages of SR over LP, it seems clear that the ether example is not a case of ontological parsimony making up for an otherwise inferior theory. Ontological parsimony was merely one of several theoretical advantages that Special Relativity had over the Lorentz-Poincaré theory. I conclude, therefore, that the ether example fails to provide implicit evidence for the thesis that Occam's Razor is a principle of scientific theory choice.

Part 2

We have found the extant evidence – both explicit and implicit – that bears on the issue of the methodological role of Occam's Razor in science to be inadequate. The cited explicit evidence consists mainly of vague, general, and often mutually conflicting pronouncements with little direct connection to actual practice. The cited implicit evidence comes from case studies – such as the ether example – where ontological parsimony does not play a pivotal role in theory choice. Furthermore, the explicit and implicit evidence come from different contexts, making it impossible to analyze how the two interact.

A genuine test-case for Occam's Razor must involve two or more competing theories, one of which is more ontologically parsimonious than its rivals whilst not being clearly superior in other respects. As my main case-study I shall examine a historical episode from the interdisciplinary field of biogeography which meets these basic requirements. My goal is to examine both what scientists said and how they acted with respect to the issues of ontological parsimony which arose in this context.

[29] There is a danger of begging the question here in calling devices such as the Lorentz contraction factor "physically unmotivated." After all, if LP was the best available theory then this in itself would provide 'physical motivation' for the theoretical apparatus it employs. My point is rather that these devices do not flow as consequences from any general physical model of the phenomena in question.

[30] cf. Sober (1981, p. 153).

Biogeography and 'Buffon's Law'

The scientific subdiscipline of biogeography originated towards the end of the 18th Century. Its central purpose was to catalog, systematize, and explain the geographical distribution of plant and animal species.[31] Trained naturalists traveled on many of the voyages of discovery made during this period, and they brought back with them vast quantities of new zoological, botanical, and ecological data. These data formed part of the raw material that was to lead, eventually, to Darwin's theory of evolution by natural selection. The principal aim of Darwin's theory was to explain the variation of different species and the relationships between them. However, natural selection does not in itself explain how different species come to be geographically distributed in the way that they are. In other words, evolution by natural selection provides an answer to the *how* question of species variation, but it leaves the *where* question unanswered.

The 18th-century naturalists noticed two especially striking and pervasive phenomena which they hoped that the emerging field of biogeography would help to explain. Firstly, if two arbitrary areas in two widely separated regions of the globe are examined, a completely distinct set of species is likely to be found in each area. This is true even if the local climatic and environmental features are very similar in both places. For example, the desert regions of Australia are home to marsupials such as kangaroos and dingoes, but no mammals. By contrast the desert regions of North Africa are home to mammals such as rodents and camels, but no marsupials. This phenomenon was first noted by the French naturalist Buffon in 1761, who pointed to the almost total non-overlap of species of large mammal between the New World and the Old World, despite broad similarities of climate. Between 1761 and 1820 the scope of 'Buffon's Law' was gradually generalized to cover all species and all sharply separated regions. The Law can be paraphrased as follows;

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

Biogeographers knew that there were exceptions to Buffon's Law and that it could at best be a *ceteris paribus* law. However, they were impressed enough with its general accuracy that they took its explanation to be a central task of their newly created discipline.

The second class of phenomena for which biogeographers sought an explanation comprised precisely the exceptions (or apparent exceptions) to Buffon's Law. Among the most striking cases are remote islands which share species with continental regions a large distance away. For example the island of Madeira has 40% of its native species in common with the North African mainland, despite being separated from it by an ocean barrier of over 400 miles. The presence of these so-called 'cosmopolitan' species – species

[31] My principal sources for the historical details of the following discussion are Nelson (1978) and Fichman (1977).

which are found in two or more mutually inaccessible regions – was both a thorn in the side of Buffon's Law and a phenomenon which required explanation in its own right.

Two rival theories were developed to explain Buffon's Law and its occasional exceptions. The first theory originated with Darwin and Wallace in the 1850's and 1860's. The second theory can be traced back to earlier ideas of Candolle and Lyell in the 1820's, but was only developed into its fully-fledged form by Croizat in the 1950's. It turns out that these two theories differ in their ontological parsimony, and this is what makes this biogeographical case study relevant to the debate over Occam's Razor. Let us first examine the two competing theories in more detail.

Darwin and Wallace's Dispersal Theory

According to the Darwin–Wallace theory, both Buffon's Law and the existence of cosmopolitan species can be explained by the combined effects of two causal mechanisms – the first is dispersal and the second is evolution by natural selection. The proposed explanation for Buffon's Law is as follows. The initial stage involves the gradual migration of species into several new areas, a process which Darwin calls "dispersal." The timing and nature of these migrations determines the initial stock of species in a given area. Subsequently, over the course of time, the initial stock of species is shaped and altered by the forces of natural selection. Some species become extinct, while others adapt into new forms.[32] There will always be some differences in the initial distribution of species in different areas, hence it is likely that natural selection will eventually produce completely distinct sets of species, even in two areas with very similar local conditions.[33]

What about the exceptions to Buffon's Law, namely cosmopolitan species which are found in two or more mutually inaccessible regions? According to Darwin and Wallace, the existence of cosmopolitan species can also be explained by dispersal. In this case, however, the primary mechanism is *improbable dispersal*. This is Darwin's term for dispersal across seemingly impenetrable barriers by "occasional means of transport" such as ocean currents, winds, and floating ice. As the name suggests, dispersal by such means is highly unlikely (especially in cases where the distances to be covered are large). Hence when it does occur – as for example when a new species is washed up on a remote island – its effect is to immediately isolate that species from its parent stock. Cosmopolitan species are to be explained, then, as the

[32] It is assumed that the areas are remote enough from each other that little or no interbreeding of the respective populations occurs.

[33] Darwin writes; "The dissimilarity of the inhabitants of different regions may be attributed to modification through natural selection. ... The degree of dissimilarity will depend on the migration of the more dominant forms of life from one region to another having been effected with more or less ease, at periods more or less remote." (Darwin [1859, p. 350]).

result of improbable dispersal in the relatively recent past. In this way a single species might end up in two mutually inaccessible locations without there being enough time subsequently for the evolutionary paths of the two populations to significantly diverge to the extent where interbreeding is no longer possible and separate species are formed.

Note that Darwin and Wallace sought to explain Buffon's Law and its exceptions by reference to dispersal over a basically stable geography. It was presumed that the major geographical features had remained more-or-less unchanged over the course of evolutionary history, and that the positions of land masses, oceans, mountain ranges, and so on had not differed significantly from how they are today.

Croizat's Tectonic Theory

In the early 1950's, Croizat proposed an alternative to the Darwin–Wallace theory which rejected their presupposition of geographical stability. Croizat argued that tectonic change, not dispersal, is the principal causal mechanism which underlies Buffon's Law. Forces such as continental drift, the submerging of ocean floors, and the formation of mountain ranges have acted within the time frame of evolutionary history to create natural barriers between species where at previous times there were none. Croizat was in effect postulating the existence of ancient geographical features, different from those we observe today, in order to explain both Buffon's Law and its exceptions.[34]

Croizat's theory was in fact the sophisticated culmination of a theoretical tradition which stretched back to Buffon's original arguments in the late 17th Century. Followers of this so-called "extensionist" tradition postulated the existence of ancient land bridges to account for anomalies in the geographical distribution of plants and animals.[35] Thus Buffon argued for the existence of an ancient land bridge between South America and Africa to account for the various cosmopolitan species which the two continents have in common, while Forbes (in 1846) postulated five past land bridges to account for various exceptions to Buffon's Law. Extensionists such as Croizat did not deny that both dispersal and evolution by natural selection are causal factors in the explanation of the geographical distribution of species. However, Croizat argued that improbable dispersal alone was an insufficiently powerful mechanism to explain the many cases of cosmopolitan species in widely separated and mutually inaccessible regions. According to Croizat, cases such as the island of Madeira – where 40% of its species are shared with the continental land-mass

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[34] Thus Croizat writes: "[The distribution of plants and animals] was cast on maps other than the ones of the current world, and it is these maps, not the one of this hour, which dominate in the equations of life. The map of this day keeps therecords; the map of the past rationally accounts for them." (Croizat [1962, p. 85]).

[35] Such theories were called "extensionist" because they postulated the past existence of "continental extensions" such as land bridges.

over 400 miles away – can only be explained by dispersal if the odds in the past were considerably better than they are today. Croizat's postulation of tectonic change and land bridges can be seen as an attempt to supplement the Darwin–Wallace explanation by showing how its mechanism of improbable dispersal did not need to be as improbable as had hitherto been supposed.

Ontological commitments compared

For this biogeographical case study to be relevant to the assessment of Occam's Razor, the competing theories must both be minimally acceptable. Geological evidence collected over the last 50 years has established the basic claims of Croizat's Tectonic Theory beyond any reasonable doubt, and to this extent has refuted the assumptions of the Dispersal Theory concerning the permanence of major geographical features. Thus, as far as our current epistemic situation is concerned, the Dispersal Theory is not minimally acceptable.[36] Until the mid-1950's, however, no strong geological evidence had been found to favor Extensionist theories over the Dispersal Theory; up to this point both theories were very much in the running. By focusing solely on the debate prior to 1955, we are left with a situation in which there are two main alternative theories that are both minimally adequate given the available evidence, and this makes it viable as a test-case for Occam's Razor.

What makes the dispute between these competing theories of species distribution particularly pertinent to our discussion of Occam's Razor is that Extensionist theories are less ontologically parsimonious than the Darwin–Wallace Dispersal Theory, or so I shall argue. Both categories of theory share a commitment to species dispersal and evolution by natural selection as two of the causal mechanisms which have contributed to the distribution of species that we now observe, but Extensionist theories are also committed to the existence at some point in the past of various geographical and geological features which are no longer present today.

This claim of relative parsimony is crucial to the force of the biogeographical case study, so it is worth considering a couple of potential objections to it. One objection is that the geological features postulated by Extensionist theories are not genuinely new kinds of entity. Consider for example the (now submerged) land bridges postulated to connect various islands to nearby mainland. The hypothesis is that what are now islands were once peninsulas. But the Dispersal theorist has no problem conceding the *current* existence of peninsulas. So in what sense are the historic land bridges novel kinds of entities? Defending the claim of novelty in the case of land bridges will turn on nebulous issues concerning criteria for natural and scientific kinds. (It might, for example, be

[36] One way to rescue the "minimal acceptibility" of the Dispersal Theory would be to replace its claim of the permanence of major geographical features with an agnosticism concerning whether such features have changed over time or not.

argued that geologically unstable land bridges are a different kind of entity than stable land bridges.) Fortunately, this particular debate can be bypassed, since a much more clear-cut example of novelty can be found in the context of the Tectonic Theory. Recall that the Tectonic Theory falls within the category of Extensionist theories. 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.[37] Tectonic plates are more obviously novel kinds of entity, moreover they are entities to which the Dispersal Theory is manifestly not committed.

Our new, more focused claim is thus that the Tectonic Theory in particular is less parsimonious than the Dispersal Theory. A second objection (to this revised claim) is that the Dispersal Theory has distinctive ontological commitments of its own. If this were the case then the ontology of the Dispersal Theory would not be a subset of the ontology of the Tectonic Theory, and thus a claim of relative parsimony would be more difficult to establish. Pursuing this objection, it might be argued that the Dispersal Theory has a commitment to the mechanism of improbable dispersal which the Tectonic Theory lacks. However it is questionable whether this difference should be construed as one of ontology, especially given that both theories are anyway committed to the basic mechanism of dispersal. Improbable dispersal by winds, ocean currents, floating debris, and so on invokes neither new kinds of entities nor novel causal mechanisms. I conclude that our initial judgment that the Dispersal Theory is more qualitatively parsimonious is correct.

The dispersal and extensionist theories compared

The key question which remains to be answered whether the putative theoretical value of ontological parsimony – as embodied in Occam's Razor – has played any role in scientists' preference of one of these theories over the other. The rhetoric used by scientists on each side of the biogeography debate to defend their own position and attack that of their opponents is of direct relevance to the issue of whether Occam's Razor is a genuine principle of theory choice in science. I should stress once again that I am interested only in the period up to the mid-1950's, before the accumulation of geological evidence swung the balance decisively in favor of Extensionist theories.

[37] It is worth mentioning also that tectonic plates, unlike earlier Extensionist postulations such as land bridges, have more claim to be considered "unobservables" in the sense relevant to the traditional realism-instrumentalism debate in the philosophy of science. Mikkelson (2001, p. 534) makes a useful distinction between this debate and a related debate between reductionism and holism which he argues has application in biogeography and in ecology more generally.

Darwin (as might be expected) was an early critic of Extensionist theories, and he wrote in 1876 of his "protest against sinking imaginary continents in a quite reckless manner."[38] At other points, Darwin expresses his opposition in even more colorful language; addressing a potential supporter of Extensionist Theories, he writes

> [I]f there be a lower region for the punishment of geologists, I believe ... you will go there. Why, your disciples in a slow and creeping manner beat all the old Catastrophists who ever lived.[39]

Darwin's basic problem with Extensionist theories was that they went beyond the "legitimate deductions of science." This was a view shared by many other scientists, as well as more recent commentators on this debate. Martin Fichman, writing about the Dispersal Theory, argues that it "freed zoogeography from its dependence on ad hoc hypotheses, such as land bridges and continental extensions of vast extent, to meet each new distributional anomaly."[40] Others have agreed with Darwin that the evidence was not strong enough to warrant the postulation of continental features strikingly different from those present today;

> There may well have been quite different connections between continents in the past, but their existence must be verified in terms of independent evidence, and not invoked merely to explain away difficulties.[41]

This criticism of lack of direct evidence for Extensionist theories applied as much to the later Tectonic Theory as it did to the Land-Bridge Theory. That this was indeed perceived as the principal drawback of such theories is evident from the fact that opponents of land bridges were less resistant to postulating them in specific cases where the evidence was more clear-cut. One such case involves the islands of the Malay Archipelago. It turns out that there is a striking correlation between the similarity of species on neighboring islands and the shallowness of the sea between the islands. Pairs of islands separated by deep sea tend to have fewer species in common than pairs of islands separated by shallow sea. Even opponents of the land-bridge theory tended to concede that in this case shallowness of the sea-bed is good evidence for the past existence of a land bridge.

The debate over the more parsimonious Dispersal Theory centered on whether the mechanism of dispersal is sufficient on its own to explain the known facts about species distribution, without postulating any extra geographical or tectonic entities. Critics of the theory argued that it is not;

[38] This quote is taken from a letter written by Darwin to Alfred Wallace in 1876.
[39] Darwin (1901, p. 431).
[40] Fichman (1977, p. 62).
[41] Ghiselin (1969, p. 40).

> [A] much exaggerated effect, in producing the present distribution of animals, has been imputed to the accidental transmission of individuals across intervening seas.[42]

In response, more recent defenders of the Dispersal Theory have occasionally appealed to probabilistic considerations to try to establish the explanatory power of improbable dispersal;

> If the probability that some member of a population will cross a barrier is 0.000001 in any one year, in a large population this means that the probability for any one designated individual is almost infinitesimally small .... Yet during the course of a million years the event would be probable, $p = 0.63$.[43]

As with Extensionist Theories, debate over specific cases often ran parallel with the more general discussion, and the same kind of specific evidence that was used to defend Extensionist theories in particular cases was also used to attack the Dispersal Theory. For example the island of Celebes shares 20% of its species with its larger neighbor Borneo, while the island of Madeira shares 40% of its species with continental Africa despite its corresponding separation being four times as great. This sort of example was used by critics to cast doubt on the hypothesis that ocean dispersal is the principal mechanism of species distribution for remote islands.[44]

The criticisms leveled at the Extensionist and Dispersal theories follow a pattern that is characteristic of situations in which one theory is more ontologically parsimonious than its rivals. In such situations the debate is typically over whether the extra ontology is really necessary in order to explain the observed phenomena. The less parsimonious theories are condemned for profligacy, and lack of direct evidential support. The more parsimonious theories are condemned for their inadequacy to explain the observed facts.[45] Both of these sides of the argument are reflected in the specifics of the debate between scientists over the correct explanation of Buffon's Law. Thus the main criticism of Extensionist theories was that the geographical features they postulate are *ad hoc* and unsupported by the evidence, whereas the main criticism of the Dispersal Theory was that its causal mechanisms are insufficient to explain the observed distribution of species.

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[42] Wallace (1860, p. 183). This was written before Wallace switched to supporting the Dispersal Theory.

[43] Simpson (1952, p. 171).

[44] This evidence is certainly not decisive against the Dispersal Theory. One objection is that this example fails to take into account possible differences in the speed and direction of ocean currents and prevailing winds in the two cases.

[45] cf. Kleiner (1985, p. 375), who writes: "Establishing the occurrence of ... phenomena requires empirical argument, but establishing that the phenomena require explanation of a certain kind and that this is the best available explanation requires conceptual argument."

Conclusion

What conclusions can be drawn from the biogeography case study? Extensionist theories were widely criticized by scientists for being less ontologically parsimonious, because these theories postulated extra entities, namely land bridges, which were not postulated by the rival Dispersal Theory. This constitutes explicit evidence that considerations of ontological parsimony play a role in scientific practice. How strong a version of Occam's Razor does this case study support? The implicit evidence indicates that ontological parsimony was not considered to be an overwhelming consideration in choosing between rival theories. When Extensionist theories were first proposed, the more parsimonious Dispersal Theory was already available. Despite this fact, many scientists accepted the new, less parsimonious theory. If ontological parsimony were such an overwhelming virtue from the point of view of science, one would not expect scientists to systematically switch in this way to a less parsimonious theory. This suggests that considerations of ontological parsimony were not (in general) taken to be a decisive factor in this case.

I conclude on the basis of the biogeography case study that the implicit and explicit evidence for Occam's Razor as a principle of scientific theory choice is favorable, but not conclusive. Ontological parsimony appears to be a significant – but not overwhelming – theoretical virtue for scientists, a virtue which is reflected both implicitly in their patterns of theory choice and explicitly in their descriptions of their own methodological practices. However, ontological parsimony is not as crucial a virtue as consistency, or empirical adequacy. The mere fact that one theory is more ontologically parsimonious than another – even radically more parsimonious – does not mean that it will automatically be preferred by scientists. From the perspective of science, ontological parsimony is more like a tie-breaker than a trump card.

In terms of its relevance to the Occam's Razor issue, this biogeography case study has several advantages over previous examples in the literature. Firstly, the explicit and implicit evidence are integrated. Rather than merely making pronouncements about general 'principles of parsimony', the explicit evidence in the biogeography case consists in scientists giving specific justifications for their decisions to accept or reject a given theory. This helps to neutralize many of the typical drawbacks of explicit evidence; there is less ambiguity about what is meant by 'Occam's Razor', and the link between words and action is more direct, since the rhetoric is aimed directly at justifying – and influencing – patterns of theory choice. A second advantage, with respect to implicit evidence, is that parsimony was a key factor in distinguishing the competing biogeographical theories.

Despite these advantages, this is just one example and hence any conclusions drawn from it can only be tentative at best. It is possible, for example, that the force accorded to Occam's Razor varies from one historical period to another, or from one scientific sub-discipline to another. Doubtless there are other relevant case studies whose examination would help sharpen our preliminary assessment of the status of Occam's Razor in science. The problem in marshaling evidence for Occam's Razor lies in finding episodes in which parsimony considerations are clearly a central factor. Without 'control' cases of this sort, it is difficult to isolate the different factors which enter into scientists' decisions to pick one theory over another.[46] One promising example, also with roots in 19th-Century natural science, concerns early debates over the "central heat theory," which postulated a hot central Earth's core to explain various observed geological and volcanic phenomena. The greater the force Occam's Razor turns out to have, the more cases it will make a difference to and hence the easier such cases will be to find.

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[46] In this connection, consider the following remark by biologist Kent Holsinger: "Since Occam's Razor ought to be invoked only when several hypotheses explain the same set of facts equally well, in practice its domain will be very limited. ... [C]ases where competing hypotheses explain a phenomenon equally well are comparatively rare." (Holsinger [1981, pp. 144–145]) Note that this will only be true if Occam's Razor is a relatively weak principle of theory choice in science.

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