*Brit. J. Phil. Sci.* **0** (2013), 1–26

# Chance, Possibility, and Explanation

Nina Emery

ABSTRACT

I argue against the common and influential view that non-trivial chances arise only when the fundamental laws are indeterministic. The problem with this view, I claim, is not that it conflicts with some antecedently plausible metaphysics of chance or that it fails to capture our everyday use of 'chance' and related terms, but rather that it is unstable. Any reason for adopting the position that non-trivial chances arise only when the fundamental laws are indeterministic is also a reason for adopting a much stronger, and far less attractive, position. I suggest an alternative account, according to which chances are probabilities that play a certain explanatory role: they are probabilities that explain associated frequencies.



## 1 Introduction

There seems to be an important connection between chance and possibility, along the following lines: if there is some non-trivial chance that Sally will attend the party (that is, if the chance of Sally attending the party is between zero and one), then it is possible for Sally to attend the party and possible for her to not attend the party. Any theory of chance has a prima facie obligation to either capture this apparent connection between chance and possibility or explain it away.

One way of spelling out the connection between chance and possibility is in terms of the incompatibility of chance and deterministic laws. If there is some non-trivial chance that Sally will attend the party, then it is possible that Sally


doi:10.1093/bjps/axt041

will attend and possible that she will not attend, in the following sense: the complete physical state of the world right now plus the laws of nature do not entail that Sally will attend or that she will not attend. Although this view, which I will call 'incompatibilism about chance and deterministic laws', is not often defended in print, it is widely accepted by philosophers.[1] Arguments against it (arguments for 'compatibilism about chance and deterministic laws') are taken to establish a significant and surprising result.

In this article, I will argue that this way of thinking is a mistake: compatibilism about chance and deterministic laws ought to be the default view. For one thing, incompatibilism involves taking on substantial metaphysical commitments—commitments that are not necessitated by our best science and that are, at least on the face of it, rather implausible. For another, there is a straightforward way to capture the connection between chance and possibility outlined above without endorsing incompatibilism.

Crucially, my argument does not apply only to those who fall into one or another of the various partisan camps that have been built up around the metaphysics of chance; it does not require that you be a Humean, in David Lewis's sense, or an advocate of the best systems analysis of laws, or that you not be a member of either of those groups. (In this way, it differs from arguments for compatibilism put forward by Loewer ([2001]) and Hoefer ([2007]).) Nor does my argument rely on the assumption that any adequate theory of chance will capture our everyday use of 'chance' and related terms. Although I take correspondence with ordinary language to be a desirable attribute of any metaphysical theory, I also leave open the possibility that there may be theoretical, scientific, or pragmatic reasons for adopting a philosophical account of chance in which that correspondence is not perfect. (In this way, my argument differs from those found in Handfield and Wilson ([forthcoming]) and Handfield ([2012]).)[2]

Instead, my argument begins from two simple assumptions: first, that a certain case is a paradigm case of chance—that if there is such a thing as non-trivial chance, it arises in that case; second that a certain widely accepted theory about the spacetime structure of our world is correct. As I will demonstrate, careful attention to the consequences of that widely accepted theory shows that any reason for being an incompatibilist about chance and deterministic laws is unstable. Any reason for believing incompatibilism is also a

[1] The classic example of this view is found in (Lewis [1980]). A recent example is (Schaffer [2007]). See (Eagle [2011]) for more on how this debate bears on compatibilism and incompatibilism regarding determinism and free well.

[2] A related assumption, found in (Handfield and Wilson [forthcoming]), as well as in (Glynn [2010]), which I also avoid, requires that any theory of chance capture our scientific use of 'chance' and related terms—in particular, our use of such terms in the non-fundamental sciences.

reason for believing a stronger claim, and according to that stronger claim, there are no non-trivial chances, even in the paradigm case.

This argument presents us with a choice: accept the surprising conclusion that even the paradigm case is not a genuine instance of chance, or reject incompatibilism. That the latter is the more attractive option is due to the fact that there is another, often overlooked feature of the paradigm case that serves as a conceptual constraint on the notion of chance. The details of that case suggest that chances are distinctive among probabilities in their explanatory power. More work remains to be done on this 'explanatory criterion', but even in a minimal and relatively uncontroversial form, it classifies some non-trivial probabilities that arise when the fundamental laws are deterministic as genuine instances of chance.

## 2 A Paradigm Case

Suppose that Sally is a physicist and that she is in the process of running an experiment that involves sending a stream of silver atoms, which have all been prepared in a certain way, through a special set of magnets that will deflect each atom either up or down.[3] The following two facts are true of Sally's experimental set-up: (i) the fundamental laws governing the behaviour of the silver atoms are indeterministic (that is, there is no feature, *F*, such that all and only the silver atoms that have *F* before going through the experimental set-up will be deflected up)[4] and (ii) the results of the experiment exhibit a robust pattern: most (but not all) of the silver atoms are deflected up.

This case is generally treated as a paradigm case of chance. Everyone who thinks that it is possible to identify a distinctively objective sort of probability, one deserving of the name 'chance', thinks that it arises in this sort of case.[5]

[3] The details do not matter for our purposes, but the sort of case I have in mind is one where the silver atoms were prepared by being sent through an initial set of Stern-Gerlach magnets, after which the atoms that were deflected down were discarded, and the experiment consists of sending the remaining atoms through a second set of magnets, which is rotated, but only slightly, with respect to the initial set. This sort of experiment is often used to demonstrate quantum mechanical phenomena and one can find a further description in many introductory texts on the subject.

[4] Whether this is true of the actual world is up for debate. According to the orthodox interpretation of quantum mechanical phenomena (the interpretation presented in physics textbooks) it is, but other interpretations disagree. Among the contenders taken seriously by philosophers of physics, the GRW interpretation posits indeterministic fundamental laws, whereas Bohmian mechanics and most versions of the many worlds interpretation do not.

[5] Notice that the claim is not that chances arise only in this case or only in cases that are relevantly like this in some important way. For instance, this case, like the others I focus on throughout the article, involves probabilities as they arise in a scientific setting. This is not to imply that chance plays no role in our everyday unscientific lives. The scientific cases are merely chosen for clarity—in those cases, it is easy to find agreement about the nature of the underlying laws.

Consider, for instance, Sally's utterance of (1):

(1) It is very likely, but not certain, that the next silver atom will be deflected up.

One straightforward way of interpreting (1) is as a claim about Sally's credence or degree of belief. Because she knows that it has been prepared a certain way, Sally is confident, although not certain, that the next silver atom will be deflected up. But according to virtually every theory of chance (and according to many people's pre-theoretic intuitions about the concept), it is also possible to interpret (1) as making a stronger claim—a claim about the chance, or the objective probability, of the next silver atom being deflected up. This stronger claim, whatever else it amounts to, is supposed to be independent of Sally's particular epistemic position: the chance-interpretation of (1) is true or false in virtue of what the world is like, independent of what anyone happens to believe about that world. If, unbeknownst to Sally, someone has broken into her laboratory and tampered with her experimental set-up, the chance-interpretation of (1) may turn out to be false, even though the credence-interpretation of (1) will still be true.

It will be important to keep in mind in what follows that this familiar distinction between chance and credence is not generally taken to be exhaustive. Consider Sally's utterance of (2):

(2) It is very likely, but not certain, that the last silver atom was deflected up.

Certainly we can interpret (2) as a true claim about Sally's credences. (Suppose, for instance, that Sally has gone to lunch and left the experiment running so that she does not know whether the last silver atom was deflected up.) But the description of the experimental set-up here also seems to warrant a stronger interpretation of (2), an interpretation according to which (2) is not a mere report of a particular person's credence at a particular time, but a more general claim about the credences that anyone in Sally's epistemic position ought to have. On this second, stronger interpretation, (2) is supposed to convey the normative fact that anyone who knows what Sally knows about the experimental set-up and about the results obtained so far, but is ignorant with respect to the question of whether the last silver atom was deflected up, ought to have a high credence in the last silver atom having been deflected up. But whatever this normative interpretation of (2) amounts to, it is not obviously a fact about the chance of the last silver atom having been deflected up. In particular, anyone who thinks that the past is not chancy—anyone who thinks that the chance of any proposition that is wholly about events in the past being true is zero or one—will think that the normative interpretation of (2) cannot simply be a claim about chance.

For this reason, in what follows, I will refer to the distinction we are interested in as the distinction between chance on the one hand and epistemic probability on the other. Claims about epistemic probability include straightforward ascriptions of credences to a particular person at a particular time, but they also potentially include claims like (2), when they are interpreted as claims about what credences a person should have, under certain sorts of conditions, even if they do not qualify as genuine claims about chance.[6]

## 3 The Incompatibilist's Criterion

Consider Sally's counterpart Sally-C, who lives in a classical world where the laws of nature include the laws of classical statistical mechanics.[7] For our purposes, this means two important things. First, the dynamical laws that govern the fundamental particles in Sally-C's world are deterministic: the micro-state of an isolated system at a time, combined with the fundamental laws, is sufficient to determine the micro-state of that system at all other times.[8] Second, in addition to characterizing any system in terms of its complete micro-state, it is also possible to characterize it in terms of macro-physical variables like pressure, volume, and temperature, and there are robust patterns in the macro-physical behaviour of the system. In particular, there are certain sorts of macro-physical behaviour that people in Sally-C's world never observe, even though those sorts of behaviour are entirely possible, according to the fundamental dynamical laws.

Suppose, for instance, that Sally-C runs an experiment that involves putting an ice cube in a glass of lukewarm water and watching for an hour to see whether the ice cube melts.[9] She knows, just by having examined the

[6] Singular propositions like (1) are not the only sorts of probabilistic claims that arise in the paradigm case. In the last section of the article, I will be particularly interested in more general claims that are also presumably candidates for claims about chance, especially claims like: 'Any silver atom that was prepared in the way described above and that is about to go through experimental set-up described above, is very likely, though not certain, to be deflected up'.

[7] The way in which probabilities arise in classical statistical mechanics has received a great deal of recent attention in the debate on deterministic chance (see Loewer [2001]; Albert [2000]; Maudlin [2007b]; and Schaffer [2007]). The case is interesting in large part because, although we know that the laws of classical statistical mechanics are not true in our world, the way that probabilities arise in classical statistical mechanics is remarkably similar to the way that probabilities arise in Bohmian mechanics, and it is very much an open question whether Bohmian mechanics is true in our world.

[8] Another way to say the same thing: trajectories through phase space that are compatible with the fundamental laws will never cross. (Phase space is the $6N$-dimensional space in which each point corresponds to a specification of the position and momentum of each particle in the N-particle system.) Although there can be violations of determinism when the fundamental laws are Newtonian, as they are in classical statistical mechanics (see Earman [1986]), these violations occur in very specific and unusual situations. No harm comes from ignoring these situations here.

[9] I assume here and throughout the article that the system comprised the ice cube, the water, and the glass is an isolated system that can be easily characterized in the standard macro-physical

fundamental laws, that there are micro-states that are compatible with the current macro-state of the ice cube and the glass that lead deterministically to a surprising result: the ice will not melt but rather will become significantly larger as the water in the glass around the ice cube begins to boil. However, Sally-C has run many, many trials of this particular experiment, and every time she has run the experiment, the ice has melted. Based on these observations, plus her background information about the fundamental laws, Sally-C utters (3):

(3) It is very likely, but not certain, that the next ice cube will melt.[10]

Certainly, there are true epistemic interpretations of (3); given the observations she has made and what she knows about the fundamental laws, Sally presumably has (and should have) a high degree of belief in the next ice cube melting. What about when (3) is interpreted as a claim about the chance of the next ice cube melting?

Here is an initial reason for thinking that the chance-interpretation of (3) must be false: if it were true, it would conflict with the chances generated by the fundamental laws in Sally-C's world. In particular, it seems that the fundamental laws described above entail that the chance of any particular ice cube melting is either zero or one.[11] The chance-interpretation of (3) implies that the chance of the next ice cube melting is non-trivial. How can the chance of the next ice cube melting both be either zero or one and be non-trivial?

This sort of conflict appears worrisome, but it is the sort of thing that arises with respect to claims about chance all the time. As Lewis ([1980]) demonstrates, claims about chance are already widely acknowledged to be context-dependent in at least two ways: their truth values vary depending on the world and the time at which they are evaluated. Compare the world in which Sally's experimental set-up is as originally described (call it '$\omega$'), to a possible world (call it '$\omega_1$') in which someone has broken into Sally's laboratory and tampered with the set-up by rotating the magnets by 180°.[12] Then there need not be anything inconsistent in saying both that the chance of the next silver atom being deflected up is very high, and that the chance of the next silver atom

variables of thermodynamics. This is not true, but no harm comes from our assuming that it is for the purpose of the example.

[10] Assume that the experimental set-up is such that there is an obvious referent for 'the next ice cube'.

[11] Notice that my response to this reason for thinking that the chance-interpretation of (3) must be false (which is presented in the next two paragraphs) applies regardless of how the incompatibilist argues for this claim.

[12] To avoid unnecessary complications, assume that this was all the tampering that was done, and thus that the tampering left a unique obvious candidate for the referent of 'the next silver atom' in $\omega_1$ and that that candidate, on standard accounts of trans-world identity, is the same silver atom as the referent of 'the next silver atom' in $\omega$.

being deflected up is very low—it is very high in ω and very low in $\omega_1$. Similarly, suppose that the tampering occurred at 10:00 pm. Then there need not be anything inconsistent in saying both that the chance of the next silver atom being deflected up is very high in $\omega_1$, and that the chance of the next silver atom being deflected up is very low in $\omega_1$—it is very high in $\omega_1$ before 10 p.m. and very low in $\omega_1$ after 10 p.m.

With respect to the worry voiced above—that there is an apparent conflict between the chances generated by the fundamental laws and the chance-interpretation of (3)—the compatibilist can make a similar move. There need not be anything inconsistent in her saying both that the chance of the next ice cube melting is either 0 or 1 and that it is non-trivial, as long as we understand her to be saying that the chance of the next ice cube melting is either zero or one relative to the micro-physical facts about the system and the chance of the next ice cube melting is non-trivial relative to the macro-physical facts about the system. Or, to coin some new terminology: the compatibilist need only claim that the 'macro-chance' of a particular ice cube melting within the hour can be very high, even if the micro-chance of it melting is very low.[13]

Given that claims about chance are already acknowledged to be context-dependent in the two ways described by Lewis, it is up to the incompatibilist to give some reason for thinking that they cannot be context-dependent in the further way described above. It is up to the incompatibilist, in other words, to provide some criterion for distinguishing between chance and mere epistemic probability, one that classifies micro-chance in the former category, while relegating macro-chance to the latter.

As it is usually presented in the recent literature on chance, this criterion is a precisification of the vague but compelling thought that was introduced at the beginning of this article. According to that initial thought, possibility is a necessary condition for non-trivial chance: if there is a chance of something happening, it is possible for that thing to happen and possible for that thing not to happen.[14] Saying only that much does not get us very far, however,

[13] One advantage of this terminology is that just talking about 'the chance' suggests that one is using a definite description, which implies uniqueness. We often use similar constructions in context-dependent claims. For example, 'the weather was awful' was true when said of this morning, but false when said of this afternoon. A disadvantage of this terminology is that it implies that there are two distinct types of chance. Notice that for all we've said here, macro--chance is a distinctive type of chance only in the same way that chance at $t_1$ is a distinctive type of chance.

[14] Notice that the view is not that possibility is sufficient for chance. The standard probability calculus entails that whenever there are continuously many possible outcomes the chance of any particular outcome is zero. So, for instance, if you are throwing a point-sized dart at a continuous dart board the chance of the dart hitting the bull's-eye (or any other point) will be zero, even though it is possible for the dart to hit the bull's-eye. Eagle ([2011]) argues that whether some $X$ can $\varphi$ provides both a necessary and a sufficient condition on the chance of $X$ $\varphi$-ing being non-trivial. He does so by arguing that '$X$ can $\varphi$' is not synonymous with 'it is possible that $X$ $\varphi$'s'. Handfield and Wilson ([forthcoming]) present a related but distinct connection between

because whether something is possible depends on what sense of possibility we are interested in—what facts we are holding fixed across the space of possibilities that we are considering. Is it possible for Sally to attend the party? Holding fixed all of the laws of nature, the fact that the party is on the other side of town, and the fact that Sally is still in her office 1 second before the party ends, the answer is 'no'. But if we are willing to entertain possibilities in which Sally isn't in her office one second before the party ends, or in which she is allowed to violate the laws of nature—by travelling faster than the speed of light, say—then the answer may well be 'yes'.

So the immediate question that arises with respect to the connection between chance and possibility is: what sorts of facts should we be holding fixed? If there is non-trivial chance of Sally attending the party, then it must be possible for her to attend the party, and for her not to attend—but possible in what sense? Different ways of drawing the distinction between chance and epistemic probability amount to different ways of answering this question.

Take, for example, the view that the past is not chancy—the view that the chance of any proposition wholly about the past being true is either zero or one. According to that view, if there is a non-trivial chance of something happening, then it is possible for that thing to happen, and for that thing not to happen, even when holding fixed the facts about the past.

The claim that chances are incompatible with deterministic laws can be set out in a similar way.[15] According to the incompatibilist, if there is a non-trivial chance of something happening, then it is possible for that thing to happen and for that thing not to happen even when holding fixed all of the facts about the past and the laws of nature. Or, to present the claim in the form it takes in the recent literature on chance:

> **The incompatibilist's criterion:** If the chance, at world $\omega$, at time $t$, of proposition p is greater than zero, then there exists a world $\omega'$ such that (i) $\omega'$ matches $\omega$ in laws, (ii) $\omega'$ and $\omega$ have the same micro-physical history up until time $t$, and (iii) $p$ is true at $\omega'$.[16]

One of the things that is attractive about this criterion is that it seems to capture what is distinctive about the paradigm case. It was a central feature

chance and possibility. On their view, $A$ has some non-trivial chance of occurring if and only if the evidence that could be acquired about $A$ does not rule out that $A$ occurs.

[15] Incompatibilism will follow from the claim that the past is not chancy if you also think that the laws of nature are not chancy, but the latter assumption will be problematic for anyone who thinks that the laws supervene on particular matters of fact (i.e. for anyone who is a Humean in Lewis's sense). See (Lewis [1980]).

[16] This principle is called the realization principle in (Schaffer [2007]) and (Glynn [2010]). It's a stronger version of the basic chance principle found in (Bigelow *et al*. [1993]). For a discussion of why anyone who accepts the basic chance principle should also accept the realization principle, see (Schaffer [2007], p. 124).

of that case that all the facts about the history of Sally's world up to and including the moment that she utters (1), combined with the laws of nature, do not determine whether the next silver atom will be deflected up. There are possible worlds that match the entire history of Sally's world up until she utters (1) in which the next silver atom is deflected up, and possible worlds that match the entire history of Sally's world up until she utters (1) in which the next silver atom is deflected down, so the incompatibilist's criterion allows for the chance-interpretation of (1) to be true.[17]

Not so for (2) and (3). In the former case, the micro-physical history of Sally's world up until the point at which she utters (2) includes some fact about whether the last silver atom was deflected up. If the last silver atom was deflected up, then there is no possible world that matches the history of Sally's world up until the point at which she utters (2) in which it was deflected down. If the last silver atom was deflected down, then there is no possible world that matches the history of Sally's world up until the point at which she utters (2) in which it was deflected up. In neither case can there be no non-trivial chance of the last silver atom having been deflected up. So the chance-interpretation of (2) must be false. The same will be true of all claims about the non-trivial probability of some proposition about the past.[18]

In the latter case, for any particular ice cube placed in a glass of water, the micro-physical history of Sally-C's world up until the point at which she utters (3), plus the laws of nature entail that either the ice melts or that it does not melt. If the ice is going to melt, then there is no possible world that matches the history of Sally-C's world up until the point at which she utters (3) in which it does not melt. If the ice is not going to melt, then there is no possible world that matches the history of Sally-C's world up until the point at which she utters (3) in which it does not melt. In neither case is the chance of the next ice cube melting non-trivial. And since (3) says that there is some non-trivial probability of the next ice cube melting, the chance-interpretation of (3) must be false. The same will be true of all claims about the non-trivial probability of any proposition about a world that has deterministic fundamental laws.[19]

[17] It is important that the incompatibilist's criterion is only a necessary condition, not a sufficient condition. You can have genuine indeterminacy without any non-trivial chances if there aren't the right sorts of patterns in the events. The paradigm case was set up to exhibit precisely the right sort of pattern.

[18] More carefully, claims about chance can be time-indexed in two ways. First, each claim is indexed to a particular time of evaluation (when it is not made explicit, this is generally the time of assertion). Call the time of evaluation $t_e$. Second, each claim about chance may be about a particular time, call it $t_a$. For (2), $t_a$ is before $t_e$. That is, at the time of evaluation, we would say that the proposition to be evaluated is about the past, or about something that has already happened. For (1) and (3), $t_a$ is after $t_e$. That is, at the time of evaluation, we would say that the proposition to be evaluated is about the future or about something that has yet to happen.

[19] One possible exception to this claim is propositions about the initial conditions of the universe. See Loewer ([2001]) and Maudlin ([2007b]) for arguments that chances in deterministic worlds

But notice that what the incompatibilist's criterion says about the chance-interpretation of (3) is due to a specific choice about what kind of past facts are relevant. Compare the incompatibilist's criterion presented above with the following alternative criterion:

> **The alternative criterion:** If the chance, at world $\omega$, at time $t$, of proposition $p$ is greater than 0, then there exists a world $\omega'$ such that (i) $\omega'$ matches ω in laws, (ii) $\omega'$ and $\omega$ have the same macro-physical history up until time $t$, and (iii) $p$ is true at $\omega'$.

Call the next ice cube that Sally-C places in a glass of water '*N*'. There are possible worlds that match Sally-C's world with respect to all of the macro-physical facts up until the time she utters (3) and the laws of nature, in which *N* melts. There are also possible worlds that match Sally-C's world with respect to all of the macro-physical facts up until the time she utters (3), and the laws of nature, in which *N* doesn't melt. According to the alternative criterion then, the chance-interpretation of (3) may well be true.

So the incompatibilist faces the following challenge: The incompatibilist's criterion and the alternative criterion give different results. If we are going to adopt one instead of the other, we need to come up with a good reason why. We need to identify some important difference between these two criteria, a difference that justifies our using the former instead of the latter and shows why the former instead of the latter is the best candidate for capturing the intuitive connection between chance and possibility. In the next section, I will argue that this cannot be done. Given a certain well-supported assumption about the structure of spacetime, any reason for adopting the incompatibilist's criterion over the alternative criterion is a reason for adopting a stronger criterion, and that stronger criterion is implausible—it says that there are no non-trivial chances, even in the paradigm case.

The compatibilist, as described above, however, will not face any similar challenge. On her view, the truth value of claims about chance is not always fixed, even after you specify a particular world and time of evaluation. They might be true when interpreted as claims about micro-chance and false when interpreted as claims about macro-chance, or vice versa. So the compatibilist need not argue for the alternative criterion over the incompatibilist's criterion (or vice versa); she can accept both, as long as the relevant sense of 'chance' is clarified in each. She will think, in other words, that if there is a non-trivial macro-chance of something happening, then it must be possible that it happens and that it doesn't happen, even while holding fixed all the facts about the

should be understood as probability distributions over the initial conditions of the universe. That sort of view is not open to anyone who thinks that chance must be dynamic, as nothing brings about the initial state of the universe.

macro-physical history of the world; and if there is a non-trivial micro-chance of something happening, then it must be possible that it happens and that it doesn't happen, even while holding fixed all the facts about the micro-physical history of the world.

## 4 Against the Incompatibilist's Criterion

Both the incompatibilist's and the alternative criterion rely on a claim about what is possible relative to a certain set of facts. According to the former, what is important is whether an outcome is possible, given the set of propositions that pick out the entire micro-physical history of the world up until t and the actual laws of nature. According to the latter what is important is whether an outcome is possible, given the set of propositions that pick out just the macro-physical history of the world up until t and the actual laws of nature. In neither case, however, is what is important whether an outcome is possible, given the set of propositions that pick out the entire history of the world and the actual laws of nature.

Any good reason for using the incompatibilist's criterion instead of the alternative criterion will therefore rely on there being an important difference between restricting our attention to just facts about the present and the past, on the one hand, and restricting our attention to just facts about the macro-physical level, on the other hand. I will argue that there is no such difference. To restrict our attention to the facts about the past and present is just as arbitrary as restricting our attention to facts about the macro-physical world.

There is no question but that this is a surprising claim to make. Our pre-theoretic understanding of the world around us implies that the past and the present are importantly different from the future. But there are good reasons, both philosophical and scientific, to think that our pre-theoretic understanding is wrong.

The most straightforward reason to favour the incompatibilist's criterion over the alternative criterion is an ontological reason.[20] If you think the future does not exist, then you will think that the reason we ought to take into account the entire micro-physical history of the world, instead of just the macrophysical history of the world, when determining whether there is a non-trivial chance of something happening is simple: the latter leaves something out, whereas the former is complete.

To make the sort of view I have in mind explicit, assume for the moment that there is a unique way of separating spacetime into regions of space and

[20] Though this is the most straightforward reason, it is not a particularly popular one, for the reasons I provide below. Dealing with it in detail here is helpful, however, as it illustrates the general principles that are relevant in responding to other potential reasons for favouring the incompatibilist's criterion.

instants of time. We can divide metaphysical theories of spacetime into two camps: eternalist theories and anti-eternalist theories. According to both eternalist and anti-eternalist theories, although the future will exist, the future does not presently exist. The crucial difference between the two views is that according to eternalist theories the future also exists, where 'exists' is meant tenselessly. According to anti-eternalist theories, it does not.[21]

There are two main lines of objection to anti-eternalist theories. The first focuses on difficulties involved in spelling the view out in a philosophically rigorous manner. The view that the future does not exist but will exist seems to require that there is an objective flow of time, sometimes called objective becoming, which gives rise to notoriously tricky philosophical questions like: If there is objective becoming, then at the moment, the universe is smaller than it will be in the future; but if the universe is expanding, what is it expanding into? At what rate is it growing?[22]

More importantly, however, it seems that anti-eternalist theories are incompatible with our best contemporary scientific theories. In relativistic theories of spacetime, there is no absolute standard of simultaneity; there is no single correct answer to the question: are events $e_1$ and $e_2$ simultaneous?[23] Nor is there, in general, a single correct answer to the question: is event $e_1$ past, present, or future? To combine such theories with an anti-eternalist theory (according to which only the past and present exist) would yield the result that there is no single correct answer to the question: does event $e_1$ exist? But to endorse that sort of relativism about existence is absurd.[24]

[21] Anti-eternalist theories include presentism, according to which only the present exists, and what is sometimes called the growing block theory, according to which only the present and the past exist. If you are tempted to think there is not a genuine debate between the eternalist and the anti-eternalist, or to worry that there is something suspect going on with the tenseless use of 'exists', it helps to draw an analogy with the debate over the existence of concrete possible worlds. According to both the 'actualist' and the 'modal realist', merely possible worlds possibly exist, and merely possible worlds don't actually exist. What the two views disagree about is whether merely possible worlds exist *simpliciter*.

[22] For further discussion of these and other issues, see (Price [1996], Chapter 1; Markosian [1993]; Smart [1949]). A recent defence of the view that time passes can be found in (Maudlin [2007a])—but that view, notably, is silent on the question of whether the future exists; it requires merely that time have a unique direction. It is possible to have an eternalist theory that includes the objective flow of time—this is usually called the moving spotlight theory. The point here is just that eternalist theories do not require objective becoming, whereas anti-eternalist theories do.

[23] There is no privileged way, in other words, to separate four-dimensional spacetime into three spatial dimensions and one temporal dimension. There are instead many ways of separating regions of space from instants of time, each of which is called a 'reference frame'. Depending on how fast you are moving relative to other entities, different reference frames will be more or less natural choices for you to use when making calculations or in representing various states of affairs, but, according to these theories, no choice of reference frame is privileged.

[24] See (Sider [2003], Chapter 2) for more on this objection. This is a complicated issue and deserves more attention than I have space to give it here, especially as there are a few philosophers who have taken the position that in light of the conflict between the anti-eternalist theories and special relativity, we ought to revise special relativity. (Perhaps the best examples of this is found in (Prior [1996]).) The main worry for these revisionist view is that revising special

These considerations put us back where we started: what justifies choosing the incompatibilist's criterion over the alternative criterion? Both evaluate probabilities on the basis of what is possible, relative to some restricted set of propositions. In what sense is the set of propositions that includes the micro-physical history of the actual world up until some particular time of evaluation a better context against which to judge whether there is a non-trivial chance of something happening than the set of propositions that include just the macro-physical history of the actual world up until the relevant time? Because we live in an eternalist world, neither includes all of the propositions that are true of the actual world.

Crucially, the advocate of the incompatibilist's criterion cannot appeal to the simple fact that this criterion holds fixed more of the propositions that are true of the actual world than the alternative criterion does—and is in that sense more restrictive and thus stronger. If that is the motivation for adopting the incompatibilist's criterion, then, in light of the fact that we live in an eternalist universe, surely we ought to endorse the following criterion instead:

> **The eliminativist's criterion:** If the chance, at world $\omega$, at time $t$, of proposition $p$ is greater than zero, then there exists a world $\omega'$ such that (i) $\omega'$ matches $\omega$ in laws; (ii) $\omega'$ and $\omega$ have the same complete history through all time; and (iii) $p$ is true at $\omega'$.

By this standard there will be no non-trivial chance of any proposition being true in our world, whether it is about the past, present, or future. The complete history of the world either includes that event or does not include that event, and in either case there will be no non-trivial chance of that proposition being true. In other words, anyone who insists on using the eliminativist's criterion would be adopting a distinction that counts even the probabilities in the paradigm case as mere epistemic probabilities. At the very least, this kind of eliminativism about chance ought to be a last resort, to be adopted only after we are certain that there is no other way of drawing a metaphysically robust distinction between chance and epistemic probabilities.

The ontological motivation is not the only way of motivating the incompatibilist's criterion over the alternative criterion. The argument above shows that the problem with the latter criterion cannot be that it leaves out some facts about the actual world. The incompatibilist's criterion also leaves out some facts—facts about the future. But to say that both the future and the past

relativity will involve giving up a plausible sort of simplicity assumption, namely, that if we are choosing between two theories, both of which reproduce all the same empirical results, but only one of which requires an extra theoretical entity (in this case a preferred reference frame), we ought to prefer the theory that does not require the additional theoretical entity.

exist, as the eternalist does, is not to say that the future is no different than the past. Nor it is obvious that all facts are equally relevant when it comes to determining the chance of a particular event occurring. So perhaps the advocate of the incompatibilist's criterion can motivate her position by arguing that the alternative criterion, unlike the incompatibilist's criterion, leaves out a certain type of fact, one that makes an important difference in determining the chances.

Anyone attempting to make such an argument needs to meet two distinct challenges: First, she needs to identify a type of fact that is left out by the alternative criterion but not by the incompatibilist's criterion. Second, she needs to establish that there is good reason for thinking that the class of salient facts plays a distinctive and relevant metaphysical role—a role that cannot be played by the macro-physical facts alone.

It would, for instance, be a non-starter to say simply that the incompatibilist's criterion is preferable to the alternative criterion because the latter leaves out some facts about the fundamental level. After all, the incompatibilist's criterion also leaves out some fundamental facts—fundamental facts about the future. It will also not do to say only that that the incompatibilist's criterion is preferable to the alternative criterion because the incompatibilist's criterion leaves out some facts about the past. Saying only that much gives us no insight into why facts about the past play a distinctive role in determining which chances are trivial and which are not.[25]

Not much more illuminating is the claim that the incompatibilist's criterion is preferable to the alternative criterion because the latter leaves out some of the fixed facts. Given that the future exists, just like the past, what reason do we have for thinking that only the past facts are fixed? One could just stipulate that the term 'fixed' includes all and only the past facts (and, perhaps, facts derivable from the past facts using the laws of nature); but if this is just a stipulation, then, again, why think that this group of facts plays an important and relevant metaphysical role, one that cannot be played by the macro-physical past facts alone?

A more promising move is to appeal to the temporal asymmetry in causation. It is common to assume, either implicitly or explicitly, that causes must precede their effects. Assuming that causes always precede their effects, if you

[25] A similar point applies to the distinction, found in (Barnes and Cameron [2009]), between possible worlds and possible futures. On their view a possible future is just a world that matches the actual world with respect to all of the facts about the past. The introduction of this terminology allows us to identify a group of facts that is captured by the incompatibilist's criterion but not the alternative criterion (the latter leaves out some facts that are included in all of the possible futures). But this new piece of terminology alone does not give us any good reason for thinking that the facts that are held in common across all possible futures plays some important metaphysical role with respect to fixing the chances, a role that cannot be played by, for instance, the facts that are held in common across all macro-possible futures.

take into account the entire micro-physical history leading up to some event, you will have taken into account all of the potential causes of that event. So, according to this way of thinking, the incompatibilist's criterion is preferable to the alternative criterion because the latter leaves out some of the potential causes of relevant events.[26]

The first thing to say about this motivation is that once we fully internalize the discussion above about the implausibility of anti-eternalist theories, the temporal asymmetry of causation (the claim that causes always precede their effects) may be open to doubt. At the very least, given the implausibility of anti-eternalist theories, the temporal asymmetry of causation is something that we learn about the world, not something we know *a priori*. So it cannot be, for instance, that the incompatibilist's criterion is preferable to the alternative criterion because the latter leaves out some facts that, for all we know *a priori*, are causes of the relevant effect.

In any case, it is not clear why, when determining whether there is a non-trivial chance of something happening, we ought to be interested in the potential causes of the relevant events, as opposed to the actual causes. It is by no means obvious that the actual causes of any particular event will always include facts about the micro-physical level.

To put the point another way, the advocate of the view described above does not seem to be arguing for the incompatibilist's criterion so much as the causal criterion:

> **The causal criterion:** If the chance, at world $\omega$, at time $t$, of proposition p is greater than zero, then there exists a world $\omega'$ such that (i) $\omega'$ matches $\omega$ in laws; (ii) $\omega'$ and $\omega$ match in terms of all of the causes of events that appear in $p$; and (iii) $p$ is true at $\omega'$.

Unless one is an arch-reductionist about causation—that is, unless one thinks that one must always hold all of the facts about the micro-physical history of an event fixed to hold the causal facts about that event fixed—it is by no means obvious that the causal criterion and the incompatibilist's criterion amount to the same thing. That sort of arch-reductionism is a substantial commitment to take on to save the incompatibilist's criterion, especially before we have investigated other possible ways of drawing the distinction between chance and epistemic probability. For one thing, such arch-reductionism conflicts with any theory of causation according to which causes are required to be commensurate or proportional to their effects.[27] For another, it seems to be part of

[26] Thanks to Brad Skow for suggesting this line of thinking.

[27] On such theories what causes an ice cube in a glass of water to melt will be the initial macro-state of the system, not the initial micro-state, as the vast, vast majority of the information contained in the initial micro-state could have been different and the macro-physical behaviour of the ice remained exactly the same. See, for instance, (Yablo [1992]). A couple of points here: First, it is possible to read Yablo as giving not a metaphysical account of causation so much as a pragmatic

our pre-theoretic understanding of causation that there are patterns of causal dependence at various levels of description, including the macro-physical level (pool balls cause one another to accelerate, snowstorms cause car accidents, hunger causes people to head for the kitchen) and that when such patterns occur, it is possible for the micro-physical facts to vary without changing the causal facts. (Fundamental particle *p* might have had an ever-so-slightly different momentum, for instance, and yet the cue ball would still have caused the eight ball to go into the pocket.)

There is one final sort of motivation for the incompatibilist's criterion that I will consider. Maybe taking into account the complete micro-physical history up until some relevant time is the best we can do, not because of some independent metaphysical feature of the world, like that the future doesn't exist or that causes always precede their effects but because of some fact about us. Perhaps the reason why we should use the incompatibilist's criterion instead of the alternative criterion to pick out the objective probabilities is because we have a different sort of access to micro-physical facts than we do to facts about the future.

The problem with this motivation is that when you focus on the sort of micro-physical facts that actually play a role in theories like classical statistical mechanics, it is by no means obvious that we do have better access to these micro-physical facts than the kind of access we have to facts about the future. Even assuming that a glass of water with ice in it is an isolated system, in order to determine for certain whether the ice will melt, we would need to know the exact position and momentum of each of the fundamental particles in the glass, the water, and the ice at a single time.[28] Even with the best-equipped of physics laboratories at our disposal, this is not the sort of information that we actually have access to.

It is easy to imagine someone protesting that what is important is not the sort of information we actually have access to, but instead the sort of information that we could in principle have access to.[29] But in what sense of 'in principle' can we in principle come to know the exact micro-state of the system

account of what causal factors it is contextually appropriate to cite. Insofar as his article advocates the kind of view I have in mind here, he should not be read that way. Second, Yablo distinguishes between multiple causal notions, in particular, he distinguishes between causation and causal relevance, and only the former must be commensurate in the sense described above. In other words, the initial micro-state might still be causally relevant to the final macro-state even if it isn't the cause of the final macro-state. This raises the prospect that the causal motivation discussed in this section might be resurrected as the causal relevance motivation. But again, the advocate of such a view faces two challenges: first, show that facts about the future are not causally relevant, and second provide some argument for the claim that chances always depend importantly on everything that is causally relevant as opposed to only on those things that are actual causes.

[28] The problem is much, much worse, if the only truly isolated system is the entire universe.

[29] See (Ismael [2012], p. 425) for a defense of this position.

but cannot, even in principle, know what is going to happen in the future (except to the extent that it is determined by some past or present events)? There are physical facts about us, about what sorts of beings we are and how we are situated in spacetime that make it impossible for us to build a measuring device that delivers regular information about the future, and there are physical facts about us and how we are situated at the macro-physical level that make it impossible for us to build a measuring device that delivers regular information about the exact micro-state of everyday systems. If we are allowed to vary the former sort of fact, why shouldn't we be allowed to vary the latter? Put another way, it is of course possible that a different sort of being than us—the sort of demon that Maxwell once conjectured—would be able to determine the exact micro-state. But unless there is some important metaphysical distinction between the past and the present on the one hand, and the future on the other, then there is no obvious reason why there could not also be an analogous being—an Einsteinian demon, say—who would be able to determine the exact future state of the cup.

## 5 The Explanatory Criterion

The arguments in Section 4 leave us with two main options.[30] First, we can become eliminativists about chance. According to this way of thinking, relativistic theories have not only taught us something important about spacetime (that we live in an eternalist world) but also about chance (that there are no non-trivial chances in our world).

Second, we can reject the incompatibilist's criterion and take seriously the suggestion made in Section 3 that chances are relative not only to a world and a time of evaluation but also to a specification of whether they are being evaluated at the macro-physical or micro-physical level. Relative to the micro-physical facts, the chance of any event in a world where the laws are deterministic is either zero or one. Relative to the macro-physical facts, there may be non-trivial chances in such worlds. There is no reason we cannot endorse both of these claims, just as there is no reason we cannot endorse apparently conflicting claims about chance when those claims are interpreted as claims about the chance as evaluated at different times or in different worlds. The connection between chance and possibility is captured trivially by allowing for many different connections between different types of chance and corresponding types of possibility, as described at the end of Section 3.

If we are willing to relativize chance to a specification of macro- and micro-levels, the question arises: ought we to relativize it in other ways? In addition

[30] A third option being to adopt arch-reductionism about causation in order to save the incompatibilist's criterion.

to micro-chance and macro-chance, is there chemical chance and biological chance? And if so, why stop there? Why not think that for every set of facts, there is a probability function corresponding to the chance relative to those facts. Why not think, for instance, that in the case where someone tampered with Sally's experimental set-up in the way described in Section 2, the chance interpretation of (1) is still true as long as it is interpreted as a claim about the chance of the next silver atom being deflected up relative to what Sally knows. The chance of the next silver atom going down may be very low relative to the facts about how the experimental set-up is arranged, but why should that preclude the chance of the next silver atom going up from being very high relative to what Sally knows about that set-up? And if we are willing to adopt this last suggestion, if we are willing to say that so-called 'Sally-chance' is just as deserving of the name 'chance' as macro-chance or micro-chance, it is no longer clear that there is an important distinction between chance and epistemic probability at all.[31]

Here is another way of putting the worry. If the incompatibilist's criterion was our only hope for making a metaphysically robust distinction between chance and epistemic probability, then the two options left to us at the end of Section 4 present us with two horns of a dilemma: either we eliminate chance or run the risk of trivializing it.

It is important to establish, therefore, that the incompatibilist's criterion is not our only hope for making a metaphysically robust distinction between chance and epistemic probability, and thus that the dilemma above is one we can avoid. As it happens, there is another distinctive feature of the paradigm case that we have yet to consider: the explanatory role played by the probabilities that arise in that case.

Look again at the paradigm case. In that scenario, Sally observed a certain pattern in the results of her experiment: most (but not all) of the silver atoms

[31] The point here is not that there is no way of resisting these questions, only that they pose a *prima facie* worry. Glynn ([2010]), for instance, argues that chance should be relativized to each scientific level, and presumably no further. The success of that argument of course depends on developing a clear understanding of what counts as a scientific level. If such levels are just defined as sets of facts that are explanatorily closed, then the distinction between chance and epistemic probabilities on that view will likely end up being the same as the distinction I suggest below.

Handfield and Wilson ([forthcoming]) go a step further. On their view, chance is relativized to an 'evidence base'—a set of propositions that is determined by the context. Insofar as this view is meant to provide a distinction between chance and mere epistemic probability, all of the work is in determining which evidence bases generate genuine chance functions. The authors do not attempt to give necessary and sufficient conditions for when a particular evidence basis can generate genuine chance-functions (provided the right context), but they do argue that overly gerrymandered evidence bases do not generate genuine chance-functions. Neither do overly parochial evidence bases (evidence bases that include only propositions about a localized region of spacetime. The evidence basis that consists of all of the facts about the cards visible to a poker player according to the rules of the game does, however, generate a genuine chance-function.

were deflected up. On the basis of the frequency of the silver atoms being deflected up, she asserted (1), and we concluded that the chance-interpretation of (1) was true[32]:

(4) The chance that the next silver atom will be deflected up is very high.

But (4) is not the only sort of chance claim that Sally seems warranted to make in that scenario. In particular, (4) seems to follow from a more general claim which, given the observations she has made, is liable to be part of Sally's best theory about the experimental set-up:

(5) The chance of any silver atom in the experiment being deflected up is very high.

And (5) demonstrates that in addition to claims about frequency providing evidence for claims about chance, claims about chance can also, at least sometimes, explain claims about frequencies. In particular, (5) explains (6):

(6) Most of the silver atoms in the experiment have been deflected up.

That (5) explains (6) may not immediately obvious, but the argument for it is straightforward. First, notice that if (5) does not explain (6), then nothing does. It is part of the paradigm case that there is no feature such that all and only silver atoms that are deflected up have that feature before they are sent through the magnets. What else, then, could explain the fact that most of the silver atoms sent through the experiment are deflected up? What other sort of fact could be provided as answer to the question, 'Why have most of the silver atoms in the experiment been deflected up?' Second, notice that if nothing explains (6), then we have no reason for expecting the pattern described in (6) to continue. If it is just a massive coincidence that most of the silver atoms sent through the experiment have been deflected up, then we should not expect the next silver atom to be deflected up. But, we do expect the next silver atom to be deflected up, and most of the silver atoms after that. So we expect the pattern described in (6) to continue. So something explains (6). And the only possible explanation is (5).[33]

[32] This is not to say that frequencies are the only evidence we have for chance, nor is it to say that frequencies cannot sometimes provide misleading evidence about chances. It is a crucial part of our concept of chance that the relative frequency of some event can vary significantly from the chance of that event, though it is unlikely to do so.

[33] Crucially, I am not claiming that all facts cry out for explanation in the sense that (6) does. Contrast, for instance, the fact that most silver atoms are deflected up with the fact that one particular silver atom was deflected up. The argument above shows that we cannot leave the former fact unexplained, but does not address the latter fact.

The discussion here illustrates the complicated relationship between prediction and explanation in scientific theories. Predictions answer questions of the form 'Will *E* occur?', whereas explanations answer questions of the form 'Why does *E* occur?' But part of being a good explanation is also to underwrite certain sorts of predictions. A good answer to the question

The fact that (5) explains (6), combined with the fact that (5) describes what is supposed to be a paradigm case of chance, suggests the following criterion:

> **The explanatory criterion:** Suppose that events of type *E* are events that are independent of anyone's belief state. If (I) explains (II), then the chance-interpretation of (I) is true:
>
> (i) The probability of any event of type *E* is very high.
>
> (ii) The relative frequency of events of type *E* is very high.[34]

It is important to emphasize that the explanatory criterion as set out here does not obviously capture everything there is to say about the explanatory role that chances play. It is silent, for instance, on the question of whether the chance-interpretation of (I) also explains any particular instance of an event of type *E*.[35]

But even presented in this limited form, the explanatory criterion keeps us from sliding toward the kind of trivialization presented earlier in this section. Consider the case where someone has tampered with Sally's experimental set-up in the paradigm case by rotating the magnets by 180°, and suppose that (as is possible, because the laws in that case are indeterministic) most of the silver atoms continue to be deflected up. In that case there is an obvious sense in which it is still very likely for any next silver atom to be deflected up—for all that Sally knows, it is still very likely. But that fact does not explain the fact that most of the silver atoms continue to be deflected up. What Sally knows or does not know does not have any relevance at all to the behaviour of the silver

'Why does *E* occur?' should provide you with the ability to make various predictions about the conditions under which *E*-type events will occur in the future.

[34] The explanatory criterion obviously undermines a straightforward actual frequency interpretation of chance, according to which the chance of some outcome, *O*, occurring as a result of some set-up, *E*, is just the actual relative frequency with which outcomes like *O* result from set-ups like *E*. If (I) is just equivalent to (II), then (I) cannot explain (II). This is no real detriment to the criterion, as simple actual frequentism already faces significant objections. Perhaps the most straightforward and compelling objection to the view is the only already mentioned in Footnote 31 above: it seems possible for the actual relative frequency of some type of event to differ from the chance of that type of event. For instance, it seems possible, though unlikely, that a six could come up far more often than one sixth of the time, when rolling a fair die. This possibility is part of what we are trying to convey when we claim that the die is fair. For a comprehensive rehearsal of the arguments against actual frequentism see (Hajek [1996]). Hajek takes the fact that actual frequentists cannot account for the explanatory role that chances play as an argument against actual frequentism.

It is not obvious that the worry extends straightforwardly to more sophisticated versions of frequentism, like hypothetical frequentism (according to which probabilities are just the relative frequency that would occur if the experiment in question were repeated infinitely many times) or David Lewis's Humean theory of chance. Although it is a standard objection to Humean theories of laws that they do not explain their instances, Humeans have argued that laws, on their view, can still play an important explanatory role. See (van Fraassen [1989], pp. 48-51).

[35] A claim that is made in (Albert [2000]) and (Loewer [2001]). It is also silent on the question of whether very unlikely relative frequencies have any explanation.

atoms. So the explanatory criterion does not warrant the claim that the chance any silver atom being deflected up is still very high.

The criterion also apparently classifies at least some probabilities that arise in worlds where the fundamental laws are deterministic as chances. Consider again the world that Sally-C lives in, where the laws include the laws of classical statistical mechanics. In that situation, a fact about frequencies (that all of the ice cubes Sally has observed floating in glasses of lukewarm water have melted within the hour) plus a fact about the fundamental laws (that it is possible for ice cubes in lukewarm water not to melt, but instead get bigger, while the rest of the water around them boils) prompted Sally to assert:

(7) It is very likely, though not certain, that the next ice cube will melt.

And presumably also warrants her to assert:

(8) It is very likely, though not certain, that any ice cube in the experiment will melt.

According to the explanatory criterion, if (8) explains (9),

(9) Most of the ice cubes in the experiment have melted,[36]

then the chance-interpretation of (8) is true.

One initial reason for thinking that (8) does explain (9) is that exactly this sort of explanatory relationship is part of the standard presentation of classical statistical mechanics. After all, it is a central part of that theory that the fundamental laws allow for all sorts of strange behaviour that we never observe: ice cubes placed in lukewarm water can get bigger, broken coffee mugs can knit themselves back together and hop up off the floor, a banana left on the kitchen counter can get progressively less ripe, and so on. Which raises the question: why don't we ever observe such strange behaviour? The standard answer to that question is: although that behaviour is possible, it is extremely unlikely.[37]

[36] Presumably, if (8) explains (9), then (8) can also explain the stronger fact that all of the ice cube in the experiment have melted, as long as we assume that the probability described in (8) is high enough relative to the number of times the experiment has been run.

[37] See, for example, (Sklar [1993]; Albert [2000]; Loewer [2001]). Scientists often say something stronger: that on any particular occasion when ice melts, (8) explains why it melted. See, for example, (Albert [2000], pp. 64-5). A related claim is that only the explanatory power of claims like (8) can explain the historical facts regarding the adoption of statistical mechanics instead of alternative theories in the second half of the nineteenth century. For more, see (Strevens [2000], pp. 12-4), which is a concise version of the account found in (Brush [1983]).

One of the major projects in the foundations of statistical mechanics is to try to spell out what is going on at the fundamental level in virtue of which (8) is true. An overview of such attempts is found in (Uffink [2007]) and further discussion can be found in (Leeds [2003]). The attempt that is probably currently most popular among philosophers (found in Albert [2000]), begins with the observation that for a number of relatively simple systems, if you take phase space (the $6N$-dimensional space in which three dimensions correspond to the position of each particle in the system and three dimensions correspond to the momentum of each particle in the system) and you (i) place a uniform, normalized measure over any region that corresponds to a macro-state

Unlike in the paradigm case, there are alternative explanations for (9). In particular, one might try to explain (9) by citing only the initial micro-state of every observed ice cube in a glass of water, and the fundamental laws, as in (10):

(10) Every ice-cube-and-glass system observed so far started off in a normal micro-state (a state that leads deterministically to the ice melting within an hour).[38]

The recent literature on explanation contains a number of arguments for the conclusion that (8) is a better explanation of (9) than (10) is,[39] but notice that the explanatory criterion as stated above does not require any such argument. The criterion does not require that (8) must be the best explanation of (9), only that (8) be an explanation of (9), and there is good reason to think that these are two distinct conditions. Maintaining a robust distinction between the claim that $p_1$ explains $p_2$, on the one hand, and the claim that $p_1$ is the best explanation of $p_2$, on the other, is the best way of accommodating the apparent fact that what counts as the best explanation of something varies considerably with pragmatic features of the context without rendering the notion of explanation a wholly pragmatic one. It is the best way, in other words, to allow that although there may be not a single context-independent fact about

of the system and (ii) assume that the universe as a whole started off in a low-entropy state, then the measure of the normal micro-states (states that leads deterministically to thermodynamically acceptable behaviour) within that region will be one, and the measure of abnormal micro-states will be zero. Advocates of this view suggest that we assume that this result is true for all systems and interpret the relevant measure over phase space as a probability measure.

It is possible for someone to claim that this fact about the relative standard measure of normal to abnormal micro-states explains the fact that most ice cubes melt directly and non-probabilistically, but the advocate of such a view faces an significant challenge especially given that there is no one unique or uniquely natural way of putting a measure over phase space. (As discussed in, for example, (Uffink [2004], Section 4.1), a uniform, normalized measure placed over phase space yields different results if phase space is parameterized in terms of position and energy, instead of position and momentum.)

[38] I present (10) here because it is taken to be the standard micro-level explanation of (9). (See Woodward [2005]; Strevens [2008]; and Weslake [2010].) But there are good reasons for thinking that (10) doesn't explain (9) at all. For all (10) says, it could have been mere coincidence that each ice-cube-and-glass system started off in exactly the micro-state that it did. Given that (10) leaves it open that (9) is the result of that sort of coincidence, it gives us no reason at all for expecting (9) to continue. But, as with the fundamental-level explanations described above, it seems that part of what we are looking for when we are looking for an explanation of robust patterns like that documented in (9) is an explanation of not only why we have observed that pattern but also why we expect that pattern to continue. One way to avoid this worry is to replace (10) with the following claim: the universe as a whole started in micro-state $m$, and $m$, combined with the laws of nature, entails that all (or almost all) ice cubes placed in glasses of water begin in a normal micro-state. For reasons given in, for example, (Callender [2004]), it is plausible to think that claims about the initial state of the universe do not require further explanation.

[39] Again, see (Woodward [2005]; Strevens [2008]; Weslake [2010]).

what the best explanation is, there are still objective facts about what sorts of facts are explanations at all.[40]

So the mere existence of an alternative explanation, like (10), does not undermine the claim that (8) explains (9). What would suffice to undermine that claim would be a theory of explanation that explicitly ruled out (8) as an explanation of (9). One such theory is a deductive-nomological theory of explanation, according to which $p_1$ explains $p_2$ if and only if $p_1$, combined with some law of nature, entails $p_2$. Another such theory is one that combines the claim that all explanation is causal explanation with the kind of arch-reductionism about causation that was described in Section 4 (the view that causation always occurs at the fundamental level). But there are serious objections to both of these positions, objections which, at the very least make them initially unattractive.[41] It is up to the person who endorses one of these theories to provide a convincing argument for them. Until they do, the explanatory criterion suggests that we ought to be compatibilists about chance and deterministic laws.

## 6 Conclusion

Non-trivial chances arise even in worlds where the fundamental laws are deterministic. This kind of compatibilism—compatibilism about chance and deterministic laws—is not something that can only be established after adopting a detailed and controversial metaphysics of chance. Instead, it follows from two minimal assumptions: that the case presented in Section 2 is a paradigm case of chance and that we live in an eternalist world. To resist the argument from these minimal assumptions to compatibilism requires adopting substantial metaphysical commitments, the sorts of commitments that most of us would like to avoid if we could.

Rejecting the incompatibilist's constraint on chance does not mean, however, that there is no way of drawing a robust distinction between chance and epistemic probability. Careful attention to the paradigm case in Section 2 shows that chances play a distinctive explanatory role in that case: the high chance of a certain type of event happening explains the high relative frequency with which that type of event happens. More work needs to be done to set out the details of this explanatory role and to understand how it

[40] See (Sober [2010]) for an example of someone who rejects any important connection between chance and explanation because he is concerned about pragmatic factors in the latter. Sober does not distinguish, in that article, between the question of whether $p_1$ explains $p_2$ and the question of whether $p_1$ is the best explanation of $p_2$.

[41] Even Hempel ([1965]) (the *locus classicus* for a defence of deductive-nomological explanation) allows for forms of statistical explanation. Salmon ([1989]) includes a review of well-known counterexamples to the deductive-nomological view. See Sober ([1983]) for an argument that not all explanation is causal explanation.

generalizes to other cases, but even in the minimal form in which it is presented here, this explanatory criterion apparently allows for non-trivial chances in worlds where the fundamental laws are deterministic.

Compatibilism about chance has often been assumed to be a substantive and surprising result of certain metaphysical theories of chance. As the above arguments demonstrate, compatibilism ought to be the default view, the starting place from which our metaphysics of chance begins.

## Acknowledgements

Thanks to the many people who provided helpful feedback on earlier drafts, especially Ned Hall, Brad Skow, Bob Stalnaker, Caspar Hare, Roger White, Jim Binkoski, Alejandro Perez Carballo, and Paulina Sliwa.

*Department of Philosophy*
*Brown University*
*Providence, RI 02912, USA*
*nina_emery@brown.edu*

## References

Albert, D. [2000]: *Time and Chance*, Cambridge, MA: Harvard University Press.

Barnes, E. and Cameron, R. [2009]: 'The Open Future: Bivalence, Determinism, and Ontology', *Philosophical Studies*, **146**, pp. 291–309.

Bigelow, J., Collins, J. and Pargetter, R. [1993]: 'The Big Bad Bug: What Are the Humean's Chances?', *British Journal for the Philosophy of Science*, **44**, pp. 443–62.

Brush, S. [1983]: *Statistical Physics and the Atomic Theory of Matter from Boyle and Newton to Landau and Onsager*, Princeton, NJ: Princeton University Press.

Callender, C. [2004]: 'Measures, Explanation, and the Past: Should "Special" Initial Conditions Be Explained?', *British Journal for the Philosophy of Science*, **55**, pp. 195–217.

Eagle, A. [2011]: 'Deterministic Chance', *Noûs*, **45**, pp. 269–99.

Earman, J. [1986]: *A Primer on Determinism*, New York: Springer.

Elga, A. [2007]: 'Isolation in Folk Physics', in H. Price and R. Corry (*eds*), *Causality, Physics, and the Constitution of Reality*, Oxford: Oxford University Press, pp. 106–19.

Glynn, L. [2010]: 'Deterministic Chance', *British Journal for the Philosophy of Science*, **61**, pp. 51–80.

Hajek, A. [1996]: '"Mises Redux"-Redux: Fifteen Arguments against Finite Frequentism', *Erkenntnis*, **45**, pp. 209–27.

Handfield, T. [2012]: *A Philosophical Guide to Chance: Physical Probability*, Cambridge: Cambridge University Press.

Handfield, T. and Wilson, A. [forthcoming]: 'Chance and Context', in A. Wilson (*ed.*), *Chance and Temporal Asymmetry*, Oxford: Oxford University Press.

Hempel, C. [1965]: 'Aspects of Scientific Explanation', in his *Aspects of Scientific Explanation and Other Essays in the Philosophy of Science*, New York: Free Press.

Hoefer, C. [2007]: 'The Third Way on Objective Probability: A Skeptic's Guide to Objective Chance', *Mind*, **116**, pp. 463–549.

Jackson, F. and Pettit, P. [1992]: 'In Defense of Explanatory Ecumenism', *Economics and Philosophy*, **8**, pp. 1–21.

Ismael, J. [2012]: 'A Modest Proposal about Chance', *The Journal of Philosophy*, **108**, pp. 416–42.

Leeds, S. [2003]: 'Foundations of Statistical Mechanics—Two Approaches', *Philosophy of Science*, **70**, pp. 126–44.

Lewis, D. [1980]: 'A Subjectivist's Guide to Objective Chance', in his *Philosophical Papers*, Volume II, Oxford: Oxford University Press.

Loewer, B. [2001]: 'Determinism and Chance', *Studies in the History of Modern Physics*, **32**, pp. 609–20.

Markosian, N. [1993]: 'How Fast Does Time Pass?', *Philosophy and Phenomenological Research*, **53**, pp. 829–44.

Maudlin, T. [2007a]: 'On the Passing of Time', in T. Maudlin (*ed.*), *The Metaphysics within Physics*, Oxford: Oxford University Press, pp. 104–43.

Maudlin, T. [2007b]: 'What Could Be Objective about Probabilities?', *Studies in History and Philosophy of Modern Physics*, **38**, pp. 275–91.

Price, H. [1996]: *Time's Arrow and Archimedes' Point: New Directions for the Physics of Time*, Oxford: Oxford University Press.

Prior, A. [1996]: 'Some Free Thinking about Time', in J. Copeland (*ed.*), *Logic and Reality: Essays on the Legacy of Arthur Prior*, Oxford: Clarendon Press, pp. 47–51.

Salmon, W. [1989]: *Four Decades of Scientific Explanation*, Minneapolis: University of Minnesota Press.

Schaffer, J. [2007]: 'Deterministic Chance?', *British Journal for the Philosophy of Science*, **58**, pp. 113–40.

Sider, T. [2003]: *Four-Dimensionalism: An Ontology of Persistence and Time*, Oxford: Oxford University Press.

Sklar, L. [1993]: *Physics and Chance: Philosophical Issues in the Foundations of Statistical Mechanics*, Cambridge: Cambridge University Press.

Sober, E. [1983]: 'Equilibrium Explanation', *Philosophical Studies*, **43**, pp. 201–10.

Sober, E. [2010]: 'Evolutionary Theory and the Reality of Macro Probabilities', in E. Eells and J. H. Fetzer (*eds*), *The Place of Probability in Science*, New York: Springer.

Smart, J. [1949]: 'The River of Time', *Mind*, **58**, pp. 483–94.

Strevens, M. [2000]: 'Do Large Probabilities Explain Better?', *Philosophy of Science*, **67**, pp. 366–90.

Strevens, M. [2008]: *Depth: An Account of Scientific Explanation*, Cambridge, MA: Harvard University Press.

Uffink, J. [2007]: 'Compendium of the Foundations of Classical Statistical Physics', in J. Butterfield and J. Earman (*eds*), *Philosophy of Physics*, Amsterdam: North Holland, pp. 923–1047.

Uffink, J. [2004]: 'Boltzmann's Work in Statistical Physics', in E. Zalta (*ed.*), *Stanford Encyclopedia of Philosophy*, <http://plato.stanford.edu/archives/win2004/entries/statphys-Boltzmann/>.

van Fraassen, B. [1989]: *Laws and Symmetry*, Oxford: Clarendon Press.

Weslake, B. [2010]: 'Explanatory Depth', *Philosophy of Science*, **77**, pp. 273–94.

Woodward, J. [2005]: *Making Things Happen*, Oxford: Oxford University Press.

Yablo, S. [1992]: 'Mental Causation', *The Philosophical Review*, **101**, pp. 245–80.