Chance and Determinism

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On a very intuitive way of thinking, if it is already determined that some event will happen, then there is no non-trivial chance (no chance between 0 and 1) of it failing to happen, and if it is already determined that some event will not happen, then there is no non-trivial chance of it happening.[1] On this way of thinking, it does not make sense to claim both that it is already determined that Always Dreaming will win this year's Kentucky Derby *and* that the chance of Classic Empire winning instead is 1/2.

Nonetheless, it is becoming increasingly common for philosophers to claim that there are non-trivial chances in worlds where the fundamental dynamical laws are deterministic.[2] In such worlds, for any event e, at any time t, it is already (at t) either determined that e will happen or determined that e will not happen. But, according to these philosophers, there are at least some cases in such worlds where the chance (at t) of e happening is between 0 and 1. Call the chances that are supposed to exist in such worlds *deterministic chances*, and the philosophers who think that they do in fact exist *compatibilists about chance and determinism*, or just *compatibilists.*

This entry surveys some arguments that motivate compatibilists (section 1), with a focus on arguments that begin from the various roles that probabilities play in deterministic scientific theories—scientific theories with deterministic fundamental laws. I then discuss the extent to which deterministic chances, as established by such arguments, are compatible with existing metaphysical analyses of chance and with various pre-theoretic platitudes about the chance concept (section 2).

Before we begin, a note about terminology. Most discussions of chance begin by claiming that chances are objective probabilities. But what is meant by 'objective' in this definition is not

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[1] Lewis 1980, 1986; Popper 1982; Hajek 1996; Schaffer 2007.
[2] Loewer 2001, Ismael 2009, Hoefer 2007, Glynn 2010, Handfield and Wilson 2011, Emery 2015, Frigg and Hoefer 2015.

always clear. In what follows, I will assume that chances are objective probabilities in the sense that they are wholly determined by the world as it is independently of us and our epistemic position within that world. Chances, in other words, do not depend in on the sorts of beliefs and evidence that we have about the world, the types of creatures that we are, and the ways in which we reason.[3]

It is widely accepted that whatever chances are, they are to be contrasted with *individual credences* (the degrees of belief of some particular agent). And indeed the above way of understanding 'objective' captures this result. But—and this is more controversial—it also follows from the above way of understanding 'objective' that *rational credences* (the degrees of belief some agent *should* have) also do not count as genuine chances. While the degrees of belief that an agent should have will of course depend on what the world is like, they will also depend, at least in part, on the evidence that agent has, the sort of creature she is, and the kind of reasoning she is capable of engaging in. It will depend, in other words, on the epistemic position she occupies.[4]

In what follows, I will assume that in order to establish compatibilism about chance and determinism one must do more than establish that there are rational credences or evidential probabilities in worlds where the fundamental laws are deterministic. Compatibilism requires that we establish that there are probabilities that are wholly objective, in the sense described above, in such worlds. This assumption will play an important role in the discussion of arguments for compatibilism in the next section.

1 The case for deterministic chance

Why be a compatibilist? The type of argument I will focus on is this:

1. Non-trivial probabilities play role R in theory T (according to which the fundamental laws are deterministic).
2. In order to play role R, the probabilities in question must be objective.

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[3] Note that this understanding of 'objective' may need to be modified insofar as one is interested in objective probabilities of various doxastic states or epistemic positions. I set such worries aside.

[4] A more difficult question is whether evidential probabilities—the degree to which the evidence available from a certain epistemic position supports some proposition—are genuine chances. It will depend on what one means by evidence and whether the evidence available from a certain epistemic position depends on the nature of the agent that occupies it.

It follows from these two premises that there are chances in (at least some) worlds where the fundamental laws are deterministic (namely those worlds in which theory T is true).

The two deterministic theories that are most frequently discussed by compatibilists are Boltzmannian statistical mechanics and Bohmian mechanics.[5] I focus on versions of the above schema involving these two theories in sections 1.1 and 1.2 below. In section 1.3, I will briefly gesture toward a somewhat different, but importantly similar sort of argument for compatibilism.

1.1 Deterministic chance in Boltzmannian statistical mechanics

According to classical statistical mechanics, the fundamental laws are Newtonian and thus deterministic.[6] Given a complete specification of the initial state of a statistical mechanical system (i.e. given a complete specification of the position and momentum of each particle in the system at the inital time), those laws determine the behavior of that system at all other times.

A relatively standard Boltzmannian approach to statistical mechanics[7] adds to these fundamental laws a probabilistic postulate. For R an arbitrary region of phase space and r an arbitrary subregion of R, the rule says:

> *The Boltzmannian statistical postulate*. The probability that a system starts off in r, given that it starts off in R, is just the measure (on the Liouville measure) of the points within R that are also within r.

Where the Liouville measure is the measure that is uniform over phase space with respect to position and momentum.[8]

The Boltzmannian statistical postulate allows us to predict the microstate of a statistical mechanical system on the basis of its macrostate. Consider a gas enclosed in a box. There are ways of arranging the particles of the gas such that the gas is concentrated in one corner of the box. But—loosely speaking—there are far more ways of arranging the particles such that the gas

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[5] For a more detailed treatment of Boltzmannian statistical mechanics see chapter 7a in the present volume, and for a more detailed treatment of Bohmian mechanics see chapter 4d.

[6] *Pace* the concerns in Earman 1986 and Norton 2008. For further discussion see chapter 11b of this volume.

[7] Boltzmann argued for different approaches to statistical mechanics at different times in his career (see chapter 7a in the present volume), and interpretations of each of the various approaches differ. As is relatively standard in the literature on deterministic chance, I will focus specifically on the Boltzmannian approach as spelled out in detail in Albert 2000. For a discussion of probability in other versions of classical statistical mechanics see Sklar 1995.

[8] As discussed in Uffink 2017, 4.1, a measure that is uniform over phase space with respect to energy generates a probabilistic rules that makes incorrect predictions.

is roughly evenly distributed throughout the box. (More carefully, if B is the region of phase space that corresponds to the initial macrostate of the box, the measure (on the Liouville measure) of the points within B that correspond to the gas being concentrated in the corner is very small compared to the measure of the points within B that correspond to the gas being roughly evenly distributed.) So the Boltzmannian statistical postulate tells us that it is very likely that the initial state of the gas is such that it is roughly evenly distributed throughout the box.

The Boltzmannian statistical postulate, combined with the fundamental laws, also allows us to predict the behavior of a statistical mechanical system over time, given only a specification of its macrostate. For R1 and R2 arbitrary regions of phase space, it follows from the Boltzmannian statistical postulate that the probability that a system that starts off in R1 will evolve into R2 is just the measure (on the standard Lebesgue measure) of the points in R1 that evolve into R2 according to the fundamental dynamical laws. Let H be the region of phase space that corresponds to the initial macrostate of a gas that starts off confined to one half of an empty box. There are points within H that lead to the gas remaining concentrated in that half of the box, or even contracting to occupy a smaller volume. But the measure of such points is tiny compared to the measure of the points within H that lead to the gas expanding to occupy the available volume. It follows from the Boltzmannian statistical postulate that it is extremely likely that the gas will expand to occupy the available volume.

Of particular note is that fact that the Boltzmannian statistical postulate allows us to predict the data that was previously predicted by the second law of thermodynamics. It allows us to predict the fact that we rarely observe *anti-entropic behavior*—behavior in which a closed (or nearly-closed) system evolves from a higher entropy state into a lower entropy state. Within any non-gerrymandered region of phase space—including those regions that correspond to the sorts of largely isolated, macrophysical systems that we interact with on any everyday basis—the measure (on the Liouville measure) of the points within that region will evolve into regions that correspond to an increase in the system's entropy is tiny. It follows from this fact, combined with the Boltzmannian statistical postulate, that it is extremely unlikely that we will observe anti-entropic behavior.

It is tempting to think that what has been said so far about the role that the Boltzmannian statistical postulate plays in generating predictions is sufficient to support an argument for compatibilism along the following lines:

3 Non-trivial probabilities determine what we ought to expect to happen in Boltzmannian statistical mechanics.

4 In order to determine what we ought to expect to happen, the probabilities in question must be objective.

But one should tread carefully here. Although premise 3 is uncontroversial, the plausibility of premise 4 depends crucially on what is meant by 'objective'. In particular, it is not clear that in order to determine what we ought to expect to happen, the probabilities need to be wholly objective in the sense described in the introduction. At least on the face of it, rational degrees of belief are good candidates for determining what we ought to expect to happen. And, as was argued in the introduction, rational degrees of belief are not wholly objective probabilities.

For this reason it is important to recognize that most philosophers who argue for compatibilism on the bases of the role that probabilities play in Boltzmannian statistical mechanics emphasize that the Boltzmannian statistical postulate does not only play an important role in generating predictions—it also plays a crucial explanatory role.[9]

Consider again the fact that we rarely observe anti-entropic behavior. Insofar as one considers just the fundamental dynamical laws of classical statistical mechanics, the absence of anti-entropic behavior is surprising. Those laws, after all, are *time-reversal invariant*—if it is nomologically possible for a system to evolve from state S1 to state S2, it is also possible for the system to evolve from S2 to S1. So if it is nomologically possible for a statistical mechanical system to evolve from a lower entropy state to a higher entropy state—as indeed it is; we observe such behavior all the time—then it is also possible for such a system to evolve from a higher entropy state into a lower one. So why don't we ever observe the latter sort of behavior? the Boltzmannian statistical postulate gives us a straightforward answer to this question: we don't ever observe such behavior because, although it is possible, it is extremely unlikely.

This further explanatory role gives rise to an argument for compatibilism based on the following premises.

5 Non-trivial probabilities explain relative frequencies in Boltzmannian statistical mechanics.

6 In order to explain these relative frequencies, the probabilities in question must be objective.

[9] See for instance Albert 2000, Goldstein 2001, Loewer 2001, Meacham 2005, Lyon 2007, North 2010, Emery 2015.

This argument, at first glance at least, is substantially stronger than an argument based on premises 3 and 4. First, notice that premise 6 is uncontroversial. It is one of the most basic assumptions that we make about the world that nothing about the evidence that we as inquirers have about the world, or about the types of creatures that we are and the ways in which we reason plays a role in explaining the behavior of statistical mechanical systems. Insofar as there are probabilistic explanations of statistical mechanical phenomena, therefore, the probabilities involved must be objective.

As for premise 5, some philosophers who are resistant to the idea of deterministic chances point out that there are alternative explanations available for the explananda in question. Perhaps most obviously, one can explain the lack of anti-entropic behavior in any particular system simply by pointing to the exact microphysical state that system started in, combined with the fundamental laws.[10] But it is clearly part of standard scientific practice both historically and today to use probabilistic explanations of the sort described by premise 5.[11] If nothing else, that ought to make acceptance of premise 5 the default view.

The two arguments set out above are not the only ways of constructing an argument from Boltzmannian statistical mechanics that appeals to some version of premises 1 and 2. Other reasons for thinking that the probabilities generated by the Boltzmannian statistical postulate are genuinely objective may include the role that probabilities play: (i) in determining the truth (or assertibility) conditions of counterfactuals,[12] (ii) in underwriting various laws,[13] (iii) in the confirmation of a theory,[14] and so on. I leave it to the reader to construct and evaluate arguments for compatibilism based on these further roles for Boltzmannian probabilities.

1.2 Deterministic chance in Bohmian mechanics

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[10] See Schaffer 2007 and Frigg 2008 p. 680 for explicit endorsements of this alternative strategy. A different way of providing an alternative explanation is to explain the behavior directly in terms of facts about the measure as in Maudlin's (2007a) typicality account.

[11] This assertion is found in Albert 2000, Loewer 2001, Meacham 2005, North 2010, and elsewhere. See Strevens 2000 for an argument that the explanatory power of the probabilities found in, e.g. Boltzmann's rule, is required in order to explain the adoption of statistical mechanics over rival theories in the late 19th century., It is perhaps also worth noting that using probabilities to explain relative frequencies in the way suggested by premise 5 is utterly prosaic. Think, for instance, of how natural it is to answer the question, "why don't we ever see a fair coin land heads 100 times in a row?" by pointing out that it is extremely unlikely for that sequence of flips to occur.

[12] See Albert 2000, 2011; Loewer 2007; Emery 2

[13] See Loewer 2004 and Glynn 2010.

[14] Ismael 2009 emphasizes the role that probabilities play in confirming deterministic theories.

According to Bohmian mechanics, the fundamental laws are Schrodinger's equation and the guidance equation. Taken together, these laws are deterministic. Given a complete specification of the initial state of a quantum system (i.e. given a complete specification of the initial position of each particle in the system and the initial wavefunction of the system), these laws allow us to predict the behavior of that system at all other times.

Standard approaches to Bohmian mechanics[15] add a probabilistic postulate to Schrodinger's equation and the guidance equation. For C an arbitrary region of configuration space, and c an arbitrary subregion of C, the postulate says:

> *Bohmian statistical postulate*. The probability that a system starts off in c, given that it starts off in C, is just the measure (on the standard quantum measure) of the points within C that are also within c.

Where the standard quantum measure for a system that has initial wave function ψ is given by $|\psi|^2$.

The Bohmian statistical postulate allows us to predict the exact configuration of the particles in a quantum system based on less specific information about the configuration of those particles and the wavefunction of that system. Consider, for instance, a single particle that starts off located somewhere within region R and that has an initial wavefunction that is symmetric over the x-axis, which bisects R. It follows from the Bohmian statistical postulate that the probability that the particle starts off located above the x-axis is 1/2. If the initial wavefunction had instead been such that its amplitude was much higher above the x-axis than below the x-axis, then the probability that the particle started off located above the x-axis would have been very high.

The Bohmian statistical postulate also allows us to predict and explain the behavior of quantum mechanical systems based on a less than complete specification of the system's initial state. Let C1 and C2 be arbitrary regions of configuration space. It follows from the Bohmian statistical postulate that the probability that a system that starts in C1 at t1 will evolve into C2 at t2 is just the measure (on the standard quantum measure at t1) of the points in C1 that evolve into C2 according to the fundamental dynamical laws.

But of particular importance is the fact that the Bohmian statistical postulate allows us to predict the data that in the standard quantum mechanical formalism is predicted by Born's Rule.

[15] See for instance Durr et al 1991, Albert 1992, and chapter 4d in the present volume.

Born's Rule. The probability that a system with wave function ψ at t will be found in configuration c if we perform a measurement on it at t is given by $|\psi(c)|^2$.

This is because the fundamental dynamical laws of Bohmian mechanics are such that if the probability that a system will be found in some configuration c at some time t_o is $|\psi_{t_o}(c)|^2$, then for all t, the probability that a system will be found in c is $|\psi_t(c)|^2$. It follows from this fact, combined with the Bohmian statistical postulate, that the relative frequencies of the outcomes of various experiments will match the probabilities given by Born's rule.

As with the probabilities in Boltzmannian's rule, it is tempting to try to construct an argument for compatibilism just based on the role that the Bohmian statistical postulate play in generating these sorts of predictions. Such an argument would look like this:

7 According to Bohmian mechanics, non-trivial probabilities determine what we ought to expect to happen.

8 In order to determine what we ought to expect to happen, the probabilities in question must be objective.

But once again, one needs to tread carefully. Although premise 7 is uncontroversial, insofar as we adopt the understanding of 'objective' outlined in the introduction, there is no reason to endorse premise 8. Rational credences can determine what we ought to expect, and on that understanding of 'objective', rational credences are not genuinely objective probabilities.

For this reason, it is important that one also consider the role that the Bohmian statistical postulate plays in explaining the behavior of quantum mechanical systems. Insofar as one just considers the fundamental laws of Bohmian mechanics, the utility of Born's rule is surprising. There are initial arrangements of particles that, when combined with the fundamental laws, lead to configurations to which Born's rule assigns very low probability. But we rarely see such configurations. Why not? The Bohmian statistical postulate provides us with a straightforward answer to this question: we rarely see such configurations because, although they are possible, they are unlikely.

This further explanatory role for the probabilities in the Bohmian statistical postulate gives rise to the following argument for compatibilism:

9 According to Bohmian mechanics, non-trivial probabilities explain the behavior of quantum mechanical systems.

10 In order to explain the behavior of quantum mechanical systems, the probabilities in question must be objective.

Here premise 10 is uncontroversial. As for premise 9, it is not entirely clear that it is standard scientific practice to use probabilities to explain frequencies in Bohmian mechanics, if only because few practicing physicists endorse Bohmian mechanics and few physics texts discuss the theory in detail. Nonetheless this premise presumably inherits some plausibility from the very same arguments that can be mustered to support premise 5 above. Insofar as this sort of probabilistic explanation is legitimate—and preferable to alternatives—in statistical mechanics, presumably the same is true in Bohmian mechanics.

As was discussed with respect to Boltzmannian probabilities, there are also other roles that the probabilities in the Bohmian statistical postulate are supposed to play and that are plausibly such that any probabilities that play that role must be wholly objective. These include the roles that Bohmian probabilities may play in determining the truth (or assertibility) conditions of counterfactuals, in confirming the theory, and so on. But once again, I leave it to the reader to investigate those further arguments in detail.

1.3 Arguments from the irrelevance of the fundamental laws

A somewhat different type of argument for compatibilism that is worth discussing here starts from the observation that non-trivial probabilities play a certain role *whether or not* the underlying laws are deterministic, and then continues by claiming that in order to play that role the relevant probabilities must be objective. This sort of argument is sometimes put forward with respect to various roles that probabilities play in evolutionary theory (Sober 2010), but is also often put forward with respect to the roles that probabilities play in more prosaic contexts, like various kinds of gambling set-ups (Handfield and Wilson 2011).

I mention these arguments here mainly to point out the ways in which the very same considerations that were discussed in sections 1.1 and 1.2 will bear on these arguments. Along these lines it is worth nothing that the most obvious ways to construct such an argument will appeal to the roles that such probabilities play in prediction or explanation. So it seems plausible that the very same sorts of motivations and concerns that motivate the introduction of deterministic chance in Boltzmannian statistical mechanics and Bohmian mechanics will be relevant here.

In addition notice that in the case of gambling set-ups, at least, the relevant deterministic chances can also be derived by placing a relative natural measure over the space of possible initial states of the system and interpreting that measure as a probability measure. For instance, for a fair coin, initial conditions that lead to heads and initial conditions that lead to tails are relatively evenly distributed throughout the state space and within any non-gerrymandered region of that space, roughly half of the possible initial conditions will be such that they lead to the coin landing heads.[16] It follows that insofar as you put a relatively natural measure over the space of possible initial conditions and interpret that measure as a probability measure, the probability of a fair coin landing heads will be 1/2. So it seems plausible that any metaphysical analysis of deterministic chance that is able to handle the chances in Boltzmannian statistical mechanics and Bohmian mechanics will also be able to handle chances insofar as they arise in various gambling set-ups.

2 Two worries about deterministic chance

Now that we have a sense of the arguments that motivate compatibilism, we can address two common worries about deterministic chance. The first is a worry about whether we can understand deterministic chance in terms of any of the familiar metaphysical analyses of chance. The second is whether deterministic chance violates some sort of platitude about the chance concept.

2.1 Metaphysical analyses of deterministic chance

Can we give an analysis of deterministic chance in terms that are familiar from the debate over the metaphysics of chance in general? If not, advocates of deterministic chance may be required to give either a novel or a disjunctive account of chance (according to which deterministic chances are distinctively different sorts of entities from other chances).[17] Perhaps an account of

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[16] As discussed in chapter 11b in the present volume this observation was originally due to Poincare.

[17] As an example of a metaphysical analysis of deterministic chance which is not obviously amenable to also handling indeterministic chance, and thus gives rise to a disjunctive account of chance as a whole, see Strevens 1999, 2013. Further discussion can also be found in chapter 11b of this volume.

one of those two types is ultimately necessary, but at the very least it would be a significant cost.[18] Luckily for compatibilists, though, it looks as though deterministic chances as discussed in section 1 can be accommodated by several of the leading contenders for metaphysical theories of chance.

Perhaps most obviously, deterministic chances can be easily accommodated insofar as one adopts some kind of frequency analyses of chance.[19] In particular, consider an *actual frequency analysis* of chance, according to which the chance of event of type E is just the actual relative frequency with which events of type E actually occur. In order to give this sort of analysis of deterministic chances as they arise in, for instance, Boltzmannian statistical mechanics one need merely establish that the actual relative frequency with which the events described in the Boltzmannian statistical postulate is given by the Liouville measure over the relevant region of phase space.

The actual frequency analysis of chance, of course, faces many objections.[20] One worry that might seems especially pressing in the present context is that such an analysis robs chances of their explanatory role. Insofar as chances just are relative frequencies, they cannot explain those relative frequencies; after all, nothing can explain itself. This seems especially worrisome since the explanatory role played by the probabilities in, e.g. the Boltzmannian statistical postulate, was a key reason for thinking those probabilities were genuine chances.

It is not clear, however, that this worry about the explanatory power of actual frequentist accounts of chance in general is much of a worry for actual frequentist accounts of deterministic chance. It depends, in particular, on what sorts of relative frequencies we are trying to explain. Insofar as one is a frequentist one cannot, for instance, use the Boltzmannian statistical postulate to explain the relative frequency with which systems that start off in some region of phase space R also start off in some subregion r. To do so would be to use one and the same fact to explain itself. But one can use the Boltzmannian statistical postulate to explain the relative frequency with which systems that start off in R1 at t1 evolve into R2 at t2. In that case the explanandum and the explanans (which will appeal to the relative frequency within which systems that start off R1 start off in some particular subregion of R1) are distinct.

A different sort of worry that arises for an actual frequentist analysis of deterministic chance is that such an analysis seems unsuited to theories like Boltzmannian statistical mechanics or Bohmian mechanics insofar as those theories are supposed to describe the evolution of the universe as a whole. In order for an actual frequentist to make sense of the Boltzmannian and

[18] Not everyone cares about these costs. For instance Strevens's (2011) microconstant chance is an analysis of deterministic chance that makes such chances distinct from indeterministic chance.

[19] For more on frequency interpretations of chance see chapter 11b in this volume.

[20] See Hajek 1997 and chapter 11b in this volume.

Bohmian statistical postulate as applied to the universe as a whole, they would need to make sense of a probability distribution over the initial state of the universe in terms of the actual relative frequency with which the universe starts off in various initial conditions. But on a natural way of thinking, there is just a single universe and the universe has a single initial state. So the actual relative frequency with which the universe starts off in any particular initial condition is either 0 or 1.

In response to this worry frequentists have two options. First they can focus solely on relatively closed sub-systems of the universe, like everyday statistical mechanical systems and gambling devices. Insofar as one restricts ones interest to such systems, one need not make sense of the actual relative frequency of various initial conditions of the universe, only of the actual relative frequency of various initial conditions of these isolated systems. Second, they can insist that what is meant by 'the universe' in theories that describe the evolution of the universe as a whole is not everything that there is (and was and will be). Perhaps, for instance, the universe is just one of many closed systems, as in some contemporary multi-verse or "bubble universe" views. Such a view would leave room for the relative frequency with which universes start in a certain kind of initial condition to be between 0 and 1.

A second prominent metaphysical analysis of chance is the *best systems analysis,* according to which chances are those probability distributions that appear in the best way of systematizing the occurrent (non-modal, non-dispositional, non-casual) facts about the world.[21] What exactly makes one way of systematizing the world better than another varies, depending on which version of the best systems analysis you consider. But in general the introduction of various probability distributions potentially provides a significant advantage in terms of informativeness[22] with little cost in terms of complexity.

Perhaps the best known analysis along these lines is due to Albert and Loewer.[23] According to their view—which they call the *mentaculus*—probabilistic postulates like the Boltzmannian or Bohmian statistical postulates derive from a single probability distribution over the possible initial states of the universe. In Boltzmannian statistical mechanics, for instance, the probability distribution is given by Liouville measure over the region of the initial state space of the universe that corresponds to the universe having very low entropy. They then argue that the best systemization of the occurrent facts about the world includes both the fundamental

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[21] See Lewis 1994.

[22] Specifically adding the right probability distribution can provide a significant advantage in terms of what Lewis (1994) called *fit*—the extent to which the theory assigns high probability to events that do happen and low probability to events that do not.

[23] See Albert 2000, 2011; Loewer 2004, 2009, 2012.

dynamical laws and this initial probability distribution. It follows, given a best systems analysis, that the probability distribution in question is a genuine chance distribution.[24]

The best systems analysis has no trouble making sense of a probability distribution over the initial state of the universe. It does, however, face worries about the explanatory power of chances. On Albert and Loewer's account, for instance, the relative frequency of, for instance, anti-entropic behavior plays a role in making the probability distribution over the initial state of the universe a part of the best systematization. Is it legitimate to also claim that the probability distribution over the initial state explains anti-entropic behavior? This is a difficult philosophical question which has seen significant recent attention in the context of the best systems analysis of laws.[25]

Finally, consider propensity analyses of chance, according to which the chance of a system in S1 at t1 evolving into S2 at t2 is given by the propensity (or tendency, or causal disposition) of systems in S1 evolving into S2 over the specified time interval.[26] Is it possible to give a propensity analysis of deterministic chance?

At first glance, it seems not. After all, propensities are diachronic and the chances that arise in the Boltzmannian and Bohmian statistical postulates are synchronic chances. But there is at least one clever way of understanding deterministic chances as diachronic, and thus leaving room for a propensity analysis—an approach found in Demarest 2016. Demarest agrees with Albert and Loewer about the structure of deterministic chance—all deterministic chances ultimately derive from a probability distribution over the possible initial state of the universe. But she disagrees with Albert and Loewer's analysis of that initial probability distribution as a chance distribution deriving from the best system. Instead Demarest thinks that the initial probability distribution is determined by a single chance event which brought the initial state into existence. This view is straightforwardly amenable to a propensity analysis of chance.

It should be clear, then, that there are options available for understanding deterministic chance that are in keeping with several of the leading metaphysical analyses of chance. These various analyses of deterministic chance may come with various costs, and substantive further philosophical work is required in order to establish their ultimate viability. But there seems little reason to think that advocates of deterministic chance will be required to give a novel or disjunctive account of chance.

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[24] Important criticisms of this approach include those found in Elga 2001, Frigg 2008, Frisch 2010, and Meacham 2011. Other versions of a BSA analysis of deterministic chance are found in Callender and Cohen 2009, Hoefer 2007 and Frigg and Hoefer 2015. This sort of view is also discussed in Maudlin 2007a, section 2.

[25] See Maudlin 2007b, Loewer 2012, and Lange 2013.

[26] For more on propensity analyses of chance see chapter 11b in this volume.

2.2 Deterministic chance and the chance platitudes

Some philosophers claim that deterministic chance violates important platitudes about the chance concept. I don't have space to go into all of the arguments of this form in detail, but here is one example that illustrates the sort of considerations at stake.

Consider the fact that there appears to be an important connection between chance and possibility along the following lines: if there is a non-trivial chance of something happening, it must be possible for that thing to happen and possible for it not to happen. If there is a 1/2 chance of Classic Empire winning the Kentucky Derby, for instance, it must be possible for Classic Empire to win and possible for him not to win.

Here is one way of capturing that platitude:

> *The chance-possibility platitude—incompatibilist's version.* If the chance, at world w, at time t, of proposition p is greater than zero, then there exists a world w' such that (i) w' matches w in laws, (ii) w' and w have the same micro-physical history up until time t, and (iii) p is true at w'.[27]

It follows straightforwardly from this version of the chance-possibility platitude that there are no non-trivial chances in worlds where the fundamental laws are deterministic. If the chance of some proposition p is non-trivial, then the chance of p is greater than zero and the chance of ~p is greater than zero. But if the laws of world w are deterministic then the micro-physical history up until time t and the laws either determine that p is true or determine that p is not true. If they determine that p is true, then every world w' that matches w in the law and in its microphysical history is a world in which p is true, and it follows that the chance of ~p is not greater than zero. If they determine that p is not true, then every world w' that matches w in the law and in its microphysical history is a world in which ~p is true, and it follows the chance of p is not greater than zero. Either way, the chance of p is not non-trivial.

The important thing to notice, however, is that the incompatibilist's version of the chance-possibility platitude is not the only version. The compatibilist who thinks that there are chances in Boltzmannian statistical mechanics, for instance, cannot adopt the incompatibilist's version of the chance-possibility platitude. But she can adopt the following version:

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[27] This principle is called the realization principle in Schaffer 2007. It's a stronger version of the basic chance principle found in Bigelow et al. 1993.

> *The chance-possibility platitude—BSM compatibilist's version*
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> If the chance, at world w, at time t, of proposition p is greater than zero, then there exists a world w' such that (i) w' matches w in laws, (ii) w' and w have the same macro-physical history up until time t, and (iii) p is true at w'.

Similarly, the compatibilist who thinks that there are chances in Bohmian mechanics cannot adopt the incompatibilist's version of the chance-possibility platitude. But she can adopt the following version:

> *The chance-possibility platitude—BM compatibilist's version*
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> If the chance, at world w, at time t, of proposition p is greater than zero, then there exists a world w' such that (i) w' matches w in laws, (ii) w' and w have the same wavefunction up until time t, and (iii) p is true at w'.

The challenge for anyone who wants to insist that deterministic chances are not genuine chances is to argue for the incompatibilist's version of the chance-possibility platitude over these alternative versions. At the very least, though, there is room for the compatibilist to claim that they have retained at least some aspect of the platitude in question.[28]

Similar points can be made regarding the supposed incompatibility of deterministic chance and the standard way of thinking about the connection between chance and credence (the *principal principle*)[29] and regarding the standard way of thinking about the connection between chance and laws.[30]

Here is a related worry that, while rarely made explicit in the literature, may be playing a significant role in motivating incompatibilism. It is very natural to think that the past is not chancy. That is to say, it is very natural to think that chance is always time-indexed, and for an arbitrary proposition p, if t is in the past, then the chance at t of p is either 0 or 1. But one consequence of giving up various pre-theoretic platitudes about chance, like the incompatibilist's version of the chance-possibility platitude, is that you leave open the possibility of non-trivial chances of events in the past. Consider, for instance, the BSM-compatibilist's version of the

[28] The debate over which version of the chance-possibility platitude is the correct version is discussed in more detail in Emery 2015.

[29] This sort of argument against deterministic chance clearly motivated Lewis 1986 and is explicit in Schaffer 2007 and Lyon 2011. Responses to it can be found in Meacham 2005, Hoefer 2007, and Handfield and Wilson 2011.

[30] See Glynn 2010.

chance-possibility platitude. This version leaves open the possibility that there will be non-trivial chance of micro-physical events in the past.

Insofar as this is going to be an objection to deterministic chance more must be done to argue that compatibilists should in fact accept non-trivial chances of past events, not just that they might have to do so. But it is also worth pointing out that on a very standard view about philosophy of time, and in particular on the sort of view that appears to fit best with contemporary physics, there are no objective or fundamental differences between times that are past, and those that are not. So anyone who builds their defense of incompatibilism on the claim that the past cannot be chancy (while the future may), has their work cut out for them not only in terms of spelling out further details regarding the nature and commitments of deterministic chance, but also in defending their view against the standard approach to philosophy of time.[31]

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