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Ravens and Strawberries: Remarks on Hempel's and Ramsey's Accounts of laws and scientific explanation

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Abstract

Hempel never met Ramsey, but he knew his work. In his 1958 *The Theoretician's Dilemma: a study in the logic of theory construction*, Hempel introduces the term *Ramsey sentence*, referring to Ramsey's attempt in *Theories* to get rid of theoretical terms in formal accounts of scientific theories. In this paper, I draw the attention to another connection between Ramsey's and Hempel's works. Hempel's Deductive-Nomological (DN) account of scientific explanation resembles very closely Ramsey's account of a certain type of conditional sentences. In the first part of the paper, by introducing a fictional story, I highlight the similarities and differences between the two. In the last part of the paper, I claim that the most relevant difference between Ramsey and Hempel can be used to offer original solutions to Hempel's Raven Paradox. Two possibilities are presented, arguing that the second, which requires a reconsideration of the formalisation of laws, is the most promising.

Keywords Ramsey · Hempel · Laws of nature · Scientific explanation

1 Introduction

It is well known that the work of Frank Ramsey was appreciated and discussed in Vienna, among the members of the Vienna Circle. Ramsey's contribution to the debate on the foundations of mathematics was of particular interest to the Circle. In 1929, Ramsey's name appeared in the Circle's manifesto, listed among the scholars close to the Circle's aims, and Ramsey himself travelled to Vienna several times.

Hempel never met Ramsey, but he knew his work. He heard of Ramsey's paper *Theories* (1929) in 1946 in a Braithwaite's lecture (for this and other Ramsey's biographical information, see Misak (2020)). And indeed, in his 1958 *The Theoretician's Dilemma: a study in the logic of theory construction*, Hempel introduces the term *Ramsey sentence*, referring to Ramsey's attempt in *Theories* to get rid of theoretical terms in formal accounts of scientific theories. According to Hempel (1958, 80)

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the Ramsey sentence 'is perhaps the most satisfactory way of conceiving the logical character of a scientific theory'.

The aims of this paper are to show that other connections between Hempel's and Ramsey's works can be found, and argue that these can be used to say something relevant about Hempel's paradox of the ravens. First, I draw a comparison between Ramsey's account of generalisations and conditionals, and Hempel's view of laws and scientific explanation. Ramsey's account of conditionals I here consider is not the one usually ascribed to him, which relies on conditional probability. Rather, I focus on a less-known approach by Ramsey, which applies to counterfactuals and makes use of generalisations. Second, I argue, by focusing on Hempel's ravens paradox, that Ramsey's account of laws could suggest an original analysis of the paradox and under-explored solutions to it. Given the similarities between Ramsey and Hempel, these solutions to the paradox would not require to change the general framework, but they would ask for a different characterisation of laws of nature. Indeed, despite Ramsey's and Hempel's accounts are in general alike, there is one relevant difference: according to Ramsey, but not for Hempel, laws and generalisations over infinite domains are not propositions – for they are neither true nor false.

The paper is thus structured: in Section 2, I introduce a fictional story, *Ravens & Strawberries*, that describes a case of Hempel's ravens paradox by modifying an example by Ramsey. In Sections 3 and 4, I draw the comparison between Ramsey's and Hempel's accounts of laws of nature and generalisations. Then, I outline the similarities between Hempel's famous Deductive-Nomological model (DN-model) of scientific explanation, and Ramsey's account of conditionals and scientific theories. In Section 5, I return to the story I presented in Section 2, analysing it to identify the source of our discomfort towards the conclusion of the example. I argue that the problem is Hempel's Equivalence Condition. After this diagnosis, I outline two possible solutions to escape the paradox inspired by Ramsey's late account of laws. The first solution is more radical and requires discarding the possibility that two logically equivalent propositions can ever be confirmed by the same instance. However, this clear-cut position is not essential for resolving the paradox, nor it is necessary to deny the propositional status of the laws of nature, as Ramsey does. Therefore, I advocate for the second option, which entails rejecting contraposition for conditional sentences and replacing the material implication used by Hempel with a non-classical conditional operator. Finally, I show that contraposition is problematic not only for the paradox of the ravens, but also for theories of explanation in general, even those that do not adhere to the covering-law model account. I end Section 5 by drawing the moral from the story presented in 2. Section 6 concludes.

2 Ravens & Strawberries

Let us start by the following fictional story. The situation is inspired by an example by Ramsey, but, unlike the original, the following version presents a case of Hempel's ravens paradox.

> In a very far land, there is a population of ravens whose individuals resemble all the other ravens in all respects, except for a specific eating habit: the ravens of this

> population do not eat strawberries, they never did. Apparently, they had no reason for this, they have never tried strawberries, so why should they not eat them? Like all ravens, the ones belonging to this population are very smart. But these particular individuals are so intelligent and rational that they reason according to classical logic and are logically omniscient. These amazing birds believe the generalisation (1) 'All the things that are not poisonous are not strawberries'. This generalisation has been confirmed by the ravens' experience: all the non-poisonous things they ate were never strawberries. These ravens believe that a law of the type '*A* entails *B*' is confirmed by a fact *a*, if *a* is *B* whenever it is *A*. Furthermore, they also believe that whatever confirms a proposition also confirms any other proposition that is logically equivalent to it. And since these ravens are logically omniscient and reason according to classical logic, they also believe (2) 'All strawberries are poisonous'. Indeed, generalisation (2) is logically equivalent to generalisation (1) – it is its contrapositive. They believe generalisation (2) and they do so because they believe it to be confirmed, even if they have never eaten a strawberry, since (2) is logically equivalent to (1).

This story is a rearrangement of a fictional scenario Ramsey (1931b, 253), discusses at the end of the paper. The original version presents humans that have never eaten strawberries thinking they are poisonous, but not as a case of the paradox of the ravens. This example is used by Ramsey to show that the counterfactuals we accept and the inferences we make do not depend on facts, but on the habits for forming beliefs that we have. Hence, the strawberry-abstainers' belief that had they eaten strawberries they would have been poisoned is not false, strictly speaking. The abstainers' problem is not that they believe something false. The mistake the strawberry-abstainers make, according to Ramsey, is that they have adopted a rule without testing it, namely without actually eating strawberries. Testing, making experiments, eating strawberries is needed to improve the evaluation of these rules and make it more accurate, i.e. to increase 'the weight of one's probability' (Ramsey, 1931b, 253).

The story here presented is inspired by Ramsey's strawberry abstainers, but it exhibits the same pattern of Hempel (1945a, b) ravens paradox. I use this story as the starting point for the comparison between Ramsey and Hempel. The comparison will lead to a discussion of the paradox and to a little explored solution to it, which relies on an alternative, Ramsey-inspired characterisation of laws. In order to do that, we first need to see how Hempel and Ramsey respectively view laws of nature.

3 Ramsey and Hempel on laws

Ramsey (1931b) lays out his new characterisation of generalisations over an infinite domain as rules for judging. Here, Ramsey rejects the view that he previously held, up to 1927 at least (cf. Ramsey, 1927), that generalisations like 'all men are mortal' are infinite conjunctions.[1] According to Ramsey, generalisations like 'All men are mortal',

[1] This rejection sets forth Ramsey's turn towards finitism and intuitionism in mathematics, see Majer (1989, 1991); Misak (2020); Sahlin (1990). It is interesting to notice that Ramsey extends the finitist view to empirical generalisations.

that he calls 'variable hypotheticals', cannot be infinite conjunctions, for they cannot even be written, or uttered, or used as such. If they were conjunctions, knowing that 'all men are mortal' is true would imply to know that every man that lived, lives and will live, was, is and will be mortal – which clearly goes far beyond our capabilities of finite beings. The generality of the enunciation implies, so to say, the habit to make the same judgement every time certain (the same) situations occur. Indeed, for Ramsey, variable hypotheticals are constituted by a habit of a belief and by the generality of the enunciation.

Variable hypotheticals 'form the system with which the speaker meets the future' (Ramsey, 1931b, 241), they are rules for forming beliefs and making inferences (like judging an x mortal, every time I judge that x to be a man), but even performing actions. They are formalised as universal conditional statements, $\forall x(\phi(x) \rightarrow \psi(x))$.[2] Similarly, Hempel, like many scholars at that time (e.g. Goodman, 1947), holds that laws have universal ('purely universal') conditional forms (cf. Hempel, 1942 and Hempel and Oppenheim, 1948).

Ramsey's variable hypotheticals are of two types: laws and chances. If the generalisation states that there is a probability k lower than 1 that something happens given that something else occurs (e.g. 'if A then probability k for B'), the variable hypothetical is called *chance*. Chances can be seen as idealised conditional degrees of belief in B given A. Laws, in turn, are chances where the probability value k is equal to 1 – a 'law is a chance unity' (Ramsey, 1931b, 251). From these chances and laws together with an agent's factual knowledge, the actual beliefs and degrees of belief of the agent are deduced (cf. Ramsey, 1931a). Analogously, Hempel and Oppenheim (1948) distinguish between laws and statistical laws, which are, so to say, 'less' universal and express a statistical connection between the antecedent of the generalisation and its consequent.

Variable hypotheticals include laws of nature, but also other types of laws or generalisations outside scientific contexts, as some of the examples in Ramsey (1931b) suggest.[3] Similarly, Hempel's account of laws of nature (their logical and empirical features) also applies to generalisations outside science, such as to what he calls 'laws of history' (Hempel, 1942).

Variable hypotheticals, both laws and chances, are crucial in supporting conditionals, especially counterfactuals (cf. Sisti, 2022).[4] Here, I will talk mainly of counterfactuals, for it is relevant for the comparison with Hempel, but keep in mind that, for Ramsey, the same account applies to other conditionals as well. According

[2] I use Greek letters for generalisations and laws, unless the predicates involved are further specified, as in Hempel's paradox of the ravens (see Section 5). As a side note, despite Ramsey uses classical logic notation, I changed the original notation and replaced $\supset$ – which I will use here whenever I refer to material implication – with $\rightarrow$, to underline that these generalisations are not propositions, hence not material conditionals.

[3] For instance, in discussing variable hypotheticals, Ramsey (1931b, 247) presents a scenario where two people disagree about the potential consequences of eating a cake. According to Ramsey, this disagreement stems from their differing beliefs about the variable hypotheticals involved. Hence, variable hypotheticals are not limited to science.

[4] With 'supporting a conditional' I mean that there is a certain law (or laws) that contributes to making a given counterfactual true (or acceptable, depending on the theory). The exact characterisation of the 'support' depends on the theory – e.g. in Goodman (1983) counterfatcuals are supported by laws because laws are part of set of the *cotenable* propositions added to the antecedent of the counterfactual.

to Ramsey, counterfactuals are instances of variable hypotheticals (cf. Ramsey, 1991 and Ramsey, 1931b). However, the instance is not the conditional as it is uttered, but it presupposes implicit information that the speaker has and that, together with the antecedent of the conditional, implies the consequent. So a conditional 'if A then B' really is 'if $A \wedge R$ then B', where R is the implicit information that the speaker presupposes. R must be true and can contain only conjunctions. Furthermore, R usually refers to events earlier than those described in the consequent of the conditional. Hempel and Oppenheim (1948) also hold, in line with Chisholm (1946) and Goodman (1947), that a distinctive trait of laws is that, unlike accidental generalisations, they support counterfactuals.[5]

As already said, variable hypotheticals are generalisations that we trust as guides, rules for making inferences, forming new beliefs, acting. They express ideal degrees of belief and, for this reason, they determine the agent's expectations too. A variable hypothetical is not just 'a summary of certain facts', but it is also 'an attitude of expectation for the future' (Ramsey, 1931b, 255, fn. 5). Thus, Ramsey speaks of 'forecasting theory of science' (as opposed to descriptive), recalling the idea that laws should predict future events. According to Hempel's *symmetry thesis*, prediction and explanation have the same logical form – see Section 3.

There are many similarities between Ramsey's account of laws and Hempel's, which is not very surprising since analogous or very similar characterisations of laws were (and still are) quite widespread, e.g. the already mentioned (Goodman, 1947), and Chisholm (1946).

There is, however, one, but huge difference between the two accounts of laws: according to Hempel, laws appearing in a scientific explanation must be true – hence they are proper propositions. Hempel and Oppenheim (1948) and Hempel (1942) list four requirements that the elements of an explanation must satisfy in order to have a sound explanation. Concerning laws, we have that they must be actually used in the explanation, they must have empirical content and they must be *true*. On the other hand, Ramsey's variable hypotheticals are not propositions, they 'express cognitive attitudes without being propositions; and the difference between saying yes or no to them is not the difference between saying yes or no to a proposition' (Ramsey, 1931b, 241-2). This feature is fundamental in Ramsey's late account of generalisations, for it signals a turn with respect to his previous (and common at that time) view (i.e. generalisations as infinite conjunctions). Ramsey's non-propositional account of laws violates Hempel's *empirical requirement* for scientific explanation, since Ramsey's laws are neither true nor false.

In the next section I discuss the similarities between Hempel's famous account of scientific explanation – the deductive-nomological model (DN-model) – and Ramsey's account of conditionals. Of course, this latter is properly not an account of explanation, but it shows striking similarities with the DN-model. Moreover, it is evident that what Ramsey (1931b) has in mind concerns also scientific theories, as reflected in his discussions on his account of laws and the referenced type of scientific theory (e.g.

[5] A curious coincidence: Chisholm (1946) is the first, in the contemporary literature on conditionals, to mention Ramsey and, specifically, Ramsey's footnote in Ramsey (1931b), which has then been taken as a source of inspiration for different theories of conditionals, under the name *Ramsey test*, cf. Harper (1975).

Ramsey 1931b, 255 fn.5), along with his distinction between primary and secondary systems within scientific theories (Ramsey 1931b, 248 fn.1; 254 fn.4).

4 Ramsey and Hempel on explanation

Hempel's DN-model is well-known, so I will introduce it later. I will now focus on Ramsey's system of variable hypotheticals and their relationship with conditionals (counterfactuals), and degrees of belief. In the following excerpt, Ramsey (1931a, 207) holds that variable hypotheticals – laws and chances – form a

> deductive system according to the rules of probability, and the actual beliefs of a user of the system should approximate to those deduced from a combination of the system and the particular knowledge of fact possessed by the user, this last being (inexactly) taken as certain.

Let us see how these ideas could work with conditionals. In the case of a conditional, the user's factual knowledge Ramsey refers to can be seen as the additional information R, and the antecedent of the conditional (this one supposed or known to be true). R and the antecedent A instantiate the antecedent of a variable hypothetical in the system, so that the user of the system infers the consequent of the conditional (instance itself of the consequent of that variable hypothetical).

Consider a variable hypothetical like $\forall x(\phi(x) \rightarrow \psi(x))$ and suppose that an agent has it in her system, i.e. she believes it. Suppose further that she knows that $\phi(a)$, where $\phi(a) = A(a) \wedge R_1(a) \wedge R_2(a)$, with $A(a)$ standing for the antecedent of a conditional and $R_1(a) \wedge R_2(a)$ as the additional implicit information. She concludes $B(a)$, instance of $\psi(x)$, after a generalisation she believes.

Conditionals are propositions in the sense that if we are interested in their truth-values, we have to look at the corresponding material conditional. However, very often, Ramsey (1991, 1931b) argues, their 'meaning' goes beyond the material meaning. For instance, in the context of the strawberry abstainers, Ramsey (1931b, 253) claims:

> if we regarded the unfulfilled conditional as a fact we should have to suppose that any such statement as 'If he had shuffled the cards, he would have dealt himself the ace' has a clear sense true or false, which is absurd.

It is not a fact that had the abstainers eaten strawberries they would not have had pain, for there is no way to actually establish the truth of the sentence. We might believe it, as in Ramsey's example, because it is a consequence of the laws we believe.

In Ramsey's account of conditionals, contraposition does not hold (see Ramsey (1991), 239, fn.6). According to Ramsey, two conditionals – the original and the contrapositive – do not have the same meaning; not in the sense that they do not have the same (classical) truth-conditions, but they convey different information and beliefs an agent might have. Therefore, despite being logically equivalent, a contrapositive conditional is not and should not be uttered in place of the original, pain the substantial change of meaning of the utterance. For contraposition to be valid, the additional information R that makes acceptable a conditional 'if A then B', where its explicit, extended version is 'if $A \wedge R$ then B', should be the same that makes 'if not-B then not-A' acceptable. It is easy to see that this cannot always be the case. In principle, the additional information R should be added to $\neg B$ – the antecedent of the contrapositive. The background idea is that in making an inference, the contextual information (in this case, R) must remain the same. However, there are counterexamples in real life and scientific contexts where 'if $A \wedge R$ then B' is accepted, but not 'if $\neg B \wedge R$ then $\neg A$'. Ramsey (1991, 239, fn. 6) discusses contraposition with the following example. He considers someone saying: 'if he came, he would anyhow have gone away right now'. Ramsey explains that replacing this utterance with the contrapositive 'if he were still here, he wouldn't have come' is clearly not possible in this circumstance. The failure of contraposition is even clearer if we take into account the additional information. For instance, someone could say: 'if I drink a soft drink, I don't drink Coke', where the trivial implicit information R is: 'Coke is a soft drink' – hence, the full conditional actually is 'if I have a soft drink and Coke is a soft drink, I don't drink Coke'. However, in the same circumstance (i.e. keeping R fixed) she is not prepared to assert, in place of the previous conditional: 'if I drink Coke and Coke is a soft drink, then I don't have a soft drink'.

The fact that an agent believes a generalisation does not *necessarily* imply that she believes also the contrapositive, for adoption of laws is (or, should be) determined by their reliability only, by how they work in leading us to true beliefs (cf. Ramsey, 1931c). Hence, it might be the case that the agent has evidence that '$\forall x(\phi(x) \rightarrow \psi(x))$ is reliable, for following it has led her to true beliefs. However, it could be that she has never experienced the contrapositve, namely she has never experienced x that are $\neg\psi$ and $\neg\phi$. So, according to this explanation, the contrapositive is not reliable for the agent, because she has never tested it.

The structure of Ramsey's account recalls the covering-law model of scientific explanation, and Hempel's DN-model in particular. In the DN-model, the *explanandum*, namely the phenomenon to be explained, can be seen as Ramsey's consequent $B(a)$, that is deduced from the *explanans*. Hempel's explanans is constituted by a set of antecedent conditions $C_1, ..., C_n$ – i.e., Ramsey's antecedent $A(a)$ and $R(a)$ – and a set of laws $L_1, ..., L_k$ – i.e., Ramsey's variable hypothetical $\forall x(\phi(x) \rightarrow \psi(x))$.[6]

Furthermore, Hempel endorses the *symmetry thesis*: scientific explanation and prediction have the same logical structure. Similarly, in Ramsey, laws are not only a collection of facts but they determine expectations for future events. A scientific theory must not only describe facts, but also predict them (descriptive vs. forecasting theory of science, as seen in the previous section). Since Ramsey uses the label 'forecasting theory of science' and acknowledges the role of laws in determining expectations (in other words, in deriving from them the agent's degrees of belief in future events), it

[6] In Hempel we have a set of laws, whereas in Ramsey's account of conditionals, each conditional seems to be an instance of *one*, specific variable hypothetical. However, in the passage quoted above, Ramsey speaks of beliefs deduced from 'a combination of the system', potentially composed of more than one single variable hypothetical, with the user's factual knowledge. Again, Ramsey's system composed of variable hypotheticals can be identified with Hempel's set of laws in the explanans, whereas the user's factual knowledge with Hempel's antecedent conditions. In this reconstruction, then, Hempel's explanandum is the belief of the user deduced from Ramsey's system, where this belief could even be the consequent of a conditional.

is reasonable to assume, I believe, that for Ramsey too, as it is for Hempel, the logical structures of explanation and prediction are the same. According to Hempel, the difference between explanation and prediction consists in the truth values of the propositions involved in the argument, whether they are already settled or not (the events described might not have occurred yet), or known or not. For instance, in explanations, the phenomenon described by the explanandum has (usually) already occurred – hence the proposition describing it is true. The situation is the same, namely, we have an explanation, when both the explanandum and the explanans assert known facts (propositions in the explanations are all true). In Ramsey, when both the antecedent and the consequent of a conditional are known to be true, the conditional is often expressed using 'because' instead of 'if' (cf. Ramsey, 1931b, 248), as it is often the case in a proper explanation. In Hempel's account of predictions, the propositions in the explanans refer to events known (i.e. the sentences in the explanans are true) whereas the phenomenon of the explanandum has not occurred yet. The situation in Ramsey is pretty much the same: whenever you know that the antecedent of a conditional is true, you derive the degree of expectation (i.e. of belief) in the consequent from the combination of the system of variable hypotheticals and your factual knowledge (that is the antecedent of the conditional that you know to be true, plus some other implicit, but related, true information). The only major difference between the two accounts is that in Hempel, but not in Ramsey, the laws in the system must be true.[7]

Established these similarities and differences, we can now go back to the story about ravens and strawberries and see how Ramsey's account of laws can help us to explain (and hopefully block) the paradox.

5 Back to *Ravens & Strawberries*

Among the contributions Hempel made to contemporary philosophy of science, the paradoxes of confirmation are some of his most influential ones. In this paper, I focus on the paradox of the ravens. The aim is to show that Ramsey's account of laws of nature can suggest a promising and original solution to this paradox. I do so by analysing the ravens' behaviour in the *Ravens & Strawberries* story I introduced at the beginning of the paper. I argue that Ramsey's recommendations for his original example of the strawberry abstainers smoothly apply to this ravens version. These recommendations suggest a different characterisation and formalisation of laws.

Now, let us briefly recall Hempel's ravens paradox. The paradox arises because of two (apparently) plain assumptions: the *Nicod's Principle* (henceforth NP) and the *Equivalence Condition* (EC). NP asserts that a law of the type 'A entails B' is confirmed by a fact if the fact is B whenever it is A; it is disconfirmed by the fact if the fact is A but not B. EC states that whatever confirms (disconfirms) one of two logically equivalent propositions also confirms (disconfirms) the other. However, these two assumptions together lead to a paradox. First, assume the existence of four objects:

[7] Ramsey's view as here outlined is compatible with what Ramsey says also in Ramsey (1931d, 231) about his *Ramsey sentence* for scientific theories.

- *a* that is a black raven;
- *b* that is black but not a raven;
- *c* that is not black and not raven;
- and *d* that is not black but a raven.

According to NP, the generalisation ‘All ravens are black’, formalised as $\forall x(R(x) \supset B(x))$, is confirmed by object (*a*) that is a black raven, disconfirmed by the object which is a raven but is not black (*d*), and left untouched by the other two objects (*b* and *c*).[8] By NP, the generalisation ‘All non-black objects are non-ravens’, formalised as $\forall x(\neg B(x) \supset \neg R(x))$, is confirmed by object (*c*) that is not black and is not a raven, disconfirmed by the raven which is not black (*d*), and left untouched by the two other objects (*a* and *b*). Notice that this latter generalisation is obtained by contraposition from ‘All ravens are black’. According to classical logic, the two generalisations are logically equivalent, hence, following EC, they must be confirmed by the same instances: all the objects that are not ravens and are not black confirm the generalisation ‘All ravens are black’ – even a white shoe. However, by NP, this is not the case.

According to Hempel, two logically equivalent propositions *must* be confirmed by the same facts. Therefore, a white shoe confirms ‘All non-black objects are non-ravens’, but it also confirms ‘All ravens are black’, no matter how counter-intuitive this may sound. Several explanations of the paradox have been offered. It could be, Hempel suggests, that we are surprised by the fact that a white shoe confirms the generalisation ‘All ravens are black’ for quantitative reasons. Namely, we know that the things that are non-black and non-ravens are considerably more than the black ravens. Hence, in a sense, a non-black non-raven count less than a black raven as evidence in favour of the generalisation.

Some scholars have suggested that what Hempel’s confirmation lacks is an account of the background information we might have, like the size of the classes we are considering. One solution proposed by Glymour (1980) is to move from a two-place confirmation relation to a three-place confirmation relation.

Other explanations of the paradox suggest that the evidence provided by the singular non-black and non-raven object is so much smaller than the one provided by a black raven that it appears irrelevant (*comparative Bayesian’s solution*). Another solution (*quantitative Bayesian solution*) argues that a non-black non-raven object confirms the generalisation ‘all ravens are black’ to such a small extent, so close to 0, that is negligible (see Fitelson and Hawthorne (2010) for an overview of Bayesian solutions to the paradox). Alternative solutions identify in one of the two principles, EC and NP, the culprit causing the paradoxical conclusion (for instance, Good, 1967 offers a counterexample to NP).

Now, given the similarities and the relevant differences of Hempel’s and Ramsey’s accounts of laws, I suggest, in what follows, that Ramsey’s view can offer an analysis and suggest an explanation, and hence a solution, to the paradox. The solution, however, requires to change the characterisation of laws and the application of EC. I show how this works by going back to the *Ravens & Strawberries* story.

[8] The generalisation is here formalised using the material implication because this is how Hempel formalises laws.

5.1 Analysis of *Ravens and Strawberries*

Recall the story of the particular population of ravens that are strawberry-abstainers: they have never eaten strawberries believing that they are poisonous. They believe ‘all strawberries are poisonous’, formalised as $\forall x(S(x) \supset P(x))$. We may wonder how these ravens have arrived at this generalisation, since they have never eaten a strawberry – i.e. they have never directly tested the hypothesis. In other words, they have never taken into account instances of the antecedent of the conditional ‘If I x is a strawberry then x is poisonous’ – more precisely, something like ‘if I eat an x and x is a strawberry then I will have a stomach ache’.

Let us unfold their reasoning. These ravens adhere to both NP and EC, and reason accordingly. Following NP, they believe the generalisation ‘all non-poisonous x are non-strawberries’ to be confirmed – whenever they ate something that was not poisonous it was not a strawberry. Furthermore, they know that the generalisation ‘all non-poisonous x are non-strawberries’ is logically equivalent to ‘all strawberries are poisonous’. In addition, they adhere to EC. Consequently, they conclude that the evidence confirming ‘all strawberries are poisonous’ confirms also ‘all non-poisonous x are non-strawberries’.

In the story, these ravens are masters of classical logic and reason according to Hempel’s dictate: they believe in the generalisation ‘all non-poisonous objects are non-strawberries’, and consider anything that does not cause them stomach ache as evidence for the generalisation ‘all strawberries are poisonous’. So what is that makes us suspicious about the ravens’ conclusion?

In Ramsey (1931b) original example, the strawberry abstainers are humans who have never eaten strawberries, believing them poisonous. According to Ramsey, the issue with the abstainers’ behaviour is that they rely on a generalisation they have not tested, i.e., one lacking supporting evidence. In Ramsey’s original story, we have no problem condemning the abstainers as irrational. On the other hand, the situation described in the story here presented, *Ravens & Strawberries*, is more complicated, for the ravens are (by assumption) *perfectly* rational. Nonetheless, we feel uncomfortable, to say the least, with the ravens’ conclusion.

To understand our discomfort, we may try to follow Ramsey’s analysis of his example and apply it to our ravens. Despite these ravens being perfectly rational, it seems that what puzzles us is still the fact that a generalisation is believed without directly testing it. Thanks to EC, as long as two generalisations are logically equivalent, almost everything could be confirmed without testing. So, the ravens’ conclusion ‘all strawberries are poisonous’ appears somehow unwarranted, based only on their experience of non-poisonous non-strawberries. The problem is that the ravens are making judgements on strawberries from their branches, to rephrase Watkins (1957). After all, this is not surprising, since the present story is a case of Hempel’s raven paradox: just as we feel doubtful about a white shoe confirming that all ravens are black, so we feel perplexed by a non-strawberry confirming that all strawberries are poisonous.

Now that the source of our uneasiness has been identified, the challenge of finding a solution remains.

5.2 Possible solutions

Despite the ravens' rational behaviour, a sense of unease lingers. As mentioned at the beginning of Section 5, several explanations and solutions to Hempel's original raven paradox have been suggested, which can be adapted to address the version of the paradox presented in this paper. Here, I opt for a less explored approach that involves a different formalisation of laws, aligning with Ramsey's later intuitions on generalisations. This approach is motivated by the similarities and the crucial difference between Ramsey's and Hempel's views outlined in the previous sections.

In the narrative featuring ravens and strawberries, the root of our surprise at the ravens' conclusion lies in the counterintuitive process of confirmation they employ to establish the generalisation 'all strawberries are poisonous'. Typically, both in everyday life and scientific settings, empirical generalisations are formed and confirmed through induction, wherein evidence is gathered in their favour. In contrast, the ravens reach their generalisation deductively, by reasoning classically: $\forall x(\neg P(x) \supset \neg S(x)) \models_{CL} \forall x(S(x) \supset P(x))$. The issue appears to be EC. Confirmation seems not to be an extensional concept, as it should not be the case that two logically equivalent propositions must *always* be confirmed (or disconfirmed) by the same instances.

Now, there are two options: either the problem lies with EC outright, meaning that generalisations, even if classically equivalent, are *never* confirmed by the same instances. Alternatively, EC may not apply in the specific cases of the ravens. From this perspective, the problem is the validity of contraposition. Laws and generalisations should not be formulated as material conditionals, but rather in a way that renders conditional formula and its contrapositive non-equivalent, and thus no longer confirmed by the same instances. Both options also require a reconsideration of the notion of confirmation and of its invariance with respect to classical logical equivalence.[9]

The first direction appears more aligned with Ramsey's late account of generalisations as variable hypotheticals. If generalisations are not propositions, then it is never the case that two classically equivalent hypotheses are confirmed (or disconfirmed) by the same instances. In this reading, confirmation becomes a hyperintensional notion.[10] However, despite being the closest to Ramsey's intuition, I do not intend to pursue this approach for primarily two reasons. First, Ramsey's position is too strong. Denying the status of propositions to generalisations is controversial, as it contradicts the widespread idea that a fundamental characteristic of a law is to be true. While truth could potentially be substituted with other concepts, such as acceptability, this would blur the distinction between laws and other generalisations, making it somewhat

[9] There are proposals that limit the application of EC by explicitly redefining confirmation. For instance, Scheffler and Goodman (1972) introduce the notion of 'selective confirmation', taking into account Popper's view that falsification is more conclusive than confirmation for the evaluation of scientific hypotheses. Selective confirmation does not satisfy EC.

[10] See Nolan (2014) for the idea that a hyperintensional treatment of objective confirmation is promising.

arbitrary.[11] The second reason is that such a stringent commitment is not necessary for resolving the paradox. Preventing the puzzling conclusion that a non-strawberry must confirm the generalisation 'All strawberries are poisonous' does not demand assuming that it is *never* the case that two equivalent propositions are confirmed by the same instances.

The second option requires reformulating laws to prevent the application of EC in contexts such as those of the ravens (both Hempel's ravens and the scenario considered here). Specifically, the idea is to block the paradox by invalidating contraposition.[12] While not a novel idea, it remains underexplored. Farrell (1979) substitutes classical logic with a three-valued logic called F_3, where contraposition does not hold. Therefore, EC does not apply in the case of the ravens, as the two generalisations are no longer equivalent. In a broader sense, this second approach consist of treating conditionals, universal conditionals included, in a non-classical manner and confirmation as an intensional concept – see Fitelson (2006) for problems of classical entailment in theories of confirmation.

The debate on conditionals is pervasive in philosophy, and since the beginning of the last century, non-classical accounts have flourished. Starting from the so-called paradoxes of material implications – inferring a conditional from the falsity of the antecedent or the truth of the consequent –, many classically valid inferences have faced scrutiny. Contraposition is one of these, and it is often deemed invalid in contemporary accounts of conditionals. Therefore, several options are available. One possibility, which embodies the idea that confirmation is an intensional notion, is the 'variably strict conditional' by Stalnaker (1968) and Lewis (1973), using possible world semantics. In both accounts, a conditional 'if p then q' is true if and only if in the closest possible world(s) where the antecedent p is true the consequent q is also true.[13] This approach preserves EC, albeit with a non-classical definition of logical equivalence. Crucially, however, contraposition is invalidated, hence the paradox of the ravens is avoided.

More generally, contraposition appears to be a controversial inference pattern even beyond the raven paradox, in theories of scientific explanation. Many theories of explanation, including the covering-law model, impose requirements concerning counterfactuals. As we have seen, in Hempel's account of explanation, one criterion for identifying laws is their support for counterfactuals. Similarly, in more contemporary views of explanation, counterfactuals play a crucial role. for instance, since the

[11] Cartwright (1980) argues against the necessity of *true* laws in covering-law accounts of scientific explanation. Ramsey's position is philosophically extremely interesting, as a proof of a law, as collecting evidence, can potentially have no limit and proceed to the infinite – see Sprenger (2011) on this. Consequently, the truth value of a generalisation may never be definitively established. However, it is improbable that scientists actually reason like this. It is hard to think that Newton thought that his laws of motions were 'acceptable' (perhaps even to a high degree) and not simply 'true'.

[12] Recall that contraposition is not valid in Ramsey's account of conditionals, see Section 4.

[13] While Stalnaker's and Lewis' accounts diverge on the validity of conditional excluded middle – valid for Stalnaker but not for Lewis – Stalnaker's framework can be encompassed within Lewis' by introducing certain assumptions. When the conditional is not counterfactual, the closest world where the antecedent is true is the actual world itself. Both Stalnaker's and Lewis' semantics address counterfactuals and indicatives, the two categories currently used to classify conditional sentences. Although initially formulated for propositional logic, Lewis (1973) suggests a way to extend it to first order logic.

highly influential account of causal explanation by Woodward (2003), contemporary theories of explanation – whether mechanistic, causal, topological, etc. – usually incorporate conditions regarding counterfactuals. As Kostić & Khalifa (2021, 14152) put it, 'many hold that explanations' capacity to support change-relating counterfactuals, or answer "what-if-things-had-been-different questions," distinguishes them from other scientific representations'. Kostić and Khalifa (2021) discuss the directionality of explanations, namely, the idea that in an explanation, if X explains Y, then $\neg Y$ does not explain $\neg X$. They argue that any theory of explanation involving a counterfactual requirement (such as 'had a been F' (rather than F), then b would have been G' (rather than G)') is necessarily directional, for 'logically speaking, contraposition is not a valid inference-rule for counterfactual conditionals' (p. 14159). So, any theory of explanation that involves counterfactuals does not validate contraposition. Indeed, Kostić and Khalifa (2021, 14162) conclude that explanations in general do not validate contraposition: 'the directionality requirement is itself an expression that, unlike material conditionals, explanations do not obey the inference-rule called "contraposition": from "if X, then Y" infer "if not-Y, then not-X".'

Finally, returning to the covering-law model of explanation, abandoning material implication might offer additional advantages. For instance, it would prevent the interdefinability of a conditional and a disjunction, thus blocking the confirmation of generalisations like 'All x are either non-ravens or black' by a white shoe. Furthermore, in the variably strict conditional account, as in many non-classical account for conditionals, the resulting logic is non-monotonic. Hence, if adopted, the variably strict conditional could overcome one of the problem ascribed to predictivism, which Hempel endorses. In Hempel's model, a prediction has the same logical structure of an explanation, i.e., that of a classical deduction. Hence, a valid predictive model is insensitive to the addition of any proposition, even completely unrelated, to the premises – i.e. the validity of the prediction is not altered. This, of course, is an undesired feature for a theory of prediction.[14]

The trade-off of embracing the proposed solution to the paradox (while also avoiding the other unpleasant consequences of material implication, as discussed) is the loss of the classical logical consequence, which is typically the preferred choice, especially for modelling scientific theories with a considerable mathematical apparatus. This often leads to the loss of other classically valid inference rules, beyond contraposition and monotonicity, such as transitivity. However, in these non-classical logics for conditionals, some other weaker forms of the mentioned inferences might be valid, like rational monotonicity ($p \rightarrow r, \neg(p \rightarrow \neg q) \therefore p \wedge q \rightarrow r$), cautious monotonicity ($p \rightarrow q, p \rightarrow r \therefore p \wedge q \rightarrow r$), weak contraposition ($r \wedge p \rightarrow q, \neg(r \rightarrow q) \therefore r \wedge \neg q \rightarrow \neg p$) or forms of weak transitivity (such as $p \rightarrow q, q \rightarrow r, \neg(q \rightarrow \neg p) \therefore p \rightarrow r$). Supposing we all agree that contraposition and monotonicity are not ideal, the question then becomes which inference patterns should be regarded as valid in an account of scientific explanation.

[14] Similarly for explanations: given a valid explanation, it is always possible to add unrelated propositions to the premises without affecting the validity of the conclusion (and hence of the whole explanation).

5.3 The moral of the story

The unease with the ravens' case arises from the incorrect application of EC to two laws that should not be regarded as equivalent. Ramsey's perspective extends this, suggesting that there is not a clear sense in which laws can be considered true or negated. Truth is not a prerequisite for being a law. Nonetheless, to solve the raven paradox, it's not required to presume that laws can never be deemed 'true' in a specific sense, although this sense may differ from that in which a material implication is considered true.

According to Ramsey (1931b), laws and empirical generalisations are (or should be) believed when proved reliable, rather than solely because of their logical features. The generalisations made by the ravens about their eating habits, such as 'all strawberries are poisonous', lack reliability because they have never been tested and hence they have not been shown to consistently lead to true beliefs. As Ramsey (1931b, 253) puts it: 'if q is relevant to p, it is good to find out q before acting in a way involving p. [...] They [the strawberry abstainers] knew, so they thought, what the issue of the experiment would be and so naturally couldn't bother to do it.' Testing hypotheses is necessary to increase (or decrease) our confidence and hence refine reliability.

6 Conclusion

There are striking similarities between Ramsey's and Hempel's accounts of laws, conditionals and explanation. In this paper, I began with a fictional story about ravens and their eating habits concerning strawberries, inspired by a scenario (Ramsey, 1931b) presents at the end of the paper. The story serves as a version of Hempel's raven paradox and as the starting point of the comparison between Ramsey's account of conditionals, and Hempel's deductive-nomological model of scientific explanation. Many similarities emerged: explanation, as well as the acceptance of a conditional, involves the actual knowledge of the agent and some generalisations that 'cover' some facts, namely some generalisations under which some events may be subsumed and which accepted conditionals may instantiate. However, there is one big, crucial difference between Hempel and Ramsey: according to the former, laws are propositions and must be true in scientific explanations. Instead, late Ramsey rejects the propositional account of laws and generalisations, putting forth a characterisations of generalisations as rules for forming judgements.

Once the similarities and differences between Ramsey and Hempel were identified, I reconsidered the story about ravens and strawberries. Following Ramsey's suggestions on his own example, the problem of the ravens in the fictional story presented here seems the fact that they have arrived at a generalisation without testing it but only following Hempel's dictates for confirmation (and hence classical logic). Similarly, for Hempel's original paradox of the ravens. In light of Ramsey's late account of generalisations and laws, I suggest that the source of our feeling of discomfort towards the ravens' conclusion can be identified in EC. More precisely, in the use of classical logic to formalise laws and hypotheses. This choice implies the validity of contraposition, an inference rule highly discussed in contemporary literature on conditional sentences. Along these lines, two possible solutions to the *Ravens & Strawberries* case, as well as to Hempel's paradox, are then considered. In the first, confirmation is a hyperintensional notion; in the second, intensional. I argue that the second option is overall preferable, for it does not require rejecting EC, but simply redefining logical equivalence, and it is sufficient to avoid the paradox. Finally, I show that changing the material formalisation of laws comes with some other advantages for the covering-law models and other accounts of scientific explanation.

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References

Cartwright, N. (1980). The truth doesn't explain much. *American philosophical quarterly, 17*(2), 159–163.

Chisholm, R. M. (1946). The contrary-to-fact conditional. *Mind, 55*(220), 289–307.

Farrell, R. J. (1979). Material implication, confirmation, and counterfactuals. *Notre dame journal of formal logic, 20*(2), 383–394.

Fitelson, B. (2006). The paradox of confirmation1. *Philosophy compass, 1*(1), 95–113.

Fitelson, B. & Hawthorne, J. (2010). How bayesian confirmation theory handles the paradox of the ravens. In Eells, E. & Fetzer, J. H., (Eds), *The Place of Probability in Science: In Honor of Ellery Eells (1953-2006)*, pp. 247–275. Springer

Glymour, C. N. (1980). *Theory and evidence*. Princeton University Press.

Good, I. J. (1967). The white shoe is a red herring. *British journal for the philosophy of science, 17*(4), 322.

Goodman, N. (1947). The problem of counterfactual conditionals. *The journal of philosophy, 44*(5), 113–128.

Goodman, N. (1983). *Fact, fiction, and forecast*. Harvard University Press.

Harper, W. L. (1975). Rational belief change, Popper functions and counterfactuals. *Synthese, 30*(1/2), 221–262.

Hempel, C. G. (1942). The function of general laws in history. *Journal of philosophy, 39*(2), 35–48.

Hempel, C. G. (1945a). Studies in the logic of confirmation (i.). *Mind*, 54(213), 1–26

Hempel, C. G. (1945b). Studies in the logic of confirmation (ii.). *Mind*, 54(214), 97–121
Hempel, C. G. (1958). The theoretician's dilemma: A study in the logic of theory construction. *Minnesota studies in the philosophy of science, 2*, 173–226.
Hempel, C. G., & Oppenheim, P. (1948). Studies in the logic of explanation. *Philosophy of science, 15*(2), 135–175.
Kostić, D., & Khalifa, K. (2021). The directionality of topological explanations. *Synthese, 199*, 14143–14165.
Lewis, D. K. (1973). *Counterfactuals*. Blackwell.
Majer, U. (1989). Ramsey's Conception of Theories: an Intuitionistic Approach. *History of philosophy quarterly, 6*(2), 233–258.
Majer, U. (1991). Ramsey's Theory of Truth and the Truth of Theories: a Synthesis of Pragmatism and Intuitionism in Ramsey's Last Philosophy. *Theoria, 57*, 162–195.
Misak, C. (2020). *Frank Ramsey: A Sheer Excess of Powers*. Oxford University Press.
Nolan, D. (2014). Hyperintensional metaphysics. *Philosophical studies, 171*(1), 149–160.
Ramsey, F. P. (1927). Facts and propositions. *Proceedings of the aristotelian society, supplementary volumes, 7*, 153–170.
Ramsey, F. P. (1931a). Chance. In R. Braithwaite (Ed.), *Foundations of mathematics and other logical essays.* London: Kegan Paul, Trench, Trubner, & Co.
Ramsey, F. P. (1931b). General Propositions and Causality. In R. Braithwaite (Ed.), *Foundations of mathematics and other logical essays.* London: Kegan Paul, Trench, Trubner, & Co.
Ramsey, F. P. (1931c). Knowledge. In R. Braithwaite (Ed.), *Foundations of mathematics and other logical essays.* London: Kegan Paul, Trench, Trubner, & Co.
Ramsey, F. P. (1931d). Theories. In R. Braithwaite (Ed.), *Foundations of mathematics and other logical essays.* London: Kegan Paul, Trench, Trubner, & Co.
Ramsey, F. P. (1991). The Meaning of Hypothetical propositions. In M. C. Galavotti (Ed.), *Notes on philosophy, probability, and mathematics.* Naples: Bibliopoli
Sahlin, N.-E. (1990). *The philosophy of frank ramsey*. Cambridge University Press.
Scheffler, I., & Goodman, N. (1972). Selective confirmation and the ravens: A reply to Foster. *The journal of philosophy, 69*(3), 78–83.
Sisti, C. (2022). Ramsey's lost counterfactual. *History and Philosophy of Logic*, pp. 1–16
Sprenger, J. (2011). Hempel and the paradoxes of confirmation. In Gabbay, D. M., Hartmann, S., & Woods, J., (eds), *Inductive Logic*, volume 10 of *Handbook of the History of Logic*, North-Holland. pp. 235–263
Stalnaker, R. (1968). A theory of conditionals. In N. Rescher (Ed.), *Studies in logical theory (American Philosophical Quarterly Monographs 2)* pp. 98–112. Oxford: Blackwell.
Watkins, J. W. N. (1957). Between analytic and empirical. *Philosophy, 32*(121), 112–131.
Woodward, J. F. (2003). *Making things happen: A theory of causal explanation*. New York: Oxford University Press.