Synthese (2026) 207:226
https://doi.org/10.1007/s11229-026-05593-y

ORIGINAL RESEARCH

Productivity of interdisciplinary research as a challenge to Kuhn's account of incommensurability

Yotam Harel[1]

Received: 21 January 2025 / Accepted: 13 April 2026

Abstract

In this paper, Kuhn's (The structure of scientific revolutions, University of Chicago Press, 1970) image of science, as portrayed in his *The Structure of Scientific Revolutions*, is examined in the face of the recent interdisciplinary turn in scientific practice. It is argued that, considering the actual productivity of interdisciplinary research, Kuhn's characterization of different scientific traditions as incommensurable is outdated and largely false. This conclusion relies on the following argument: (P_1) If different scientific traditions are incommensurable, the productivity of interdisciplinary research must be extremely low. (P_2) The productivity of interdisciplinary research is not extremely low. Hence, different scientific traditions are not incommensurable. To clarify and defend this argument, Kuhn's account of incommensurability is clarified, as well as what interdisciplinary research is. It is argued that this account of incommensurability involves methodological, semantic, and perceptual aspects and that interdisciplinary research is research that is based on an integration of two or more disciplines focused on a common problem. Then, the argument's premises, P_1-P_2, are defended, and its conclusion is discussed. It is argued that if philosophers of science wish to remain scientifically-informed, they must abandon Kuhn's image of science where different scientific traditions are incommensurable. Instead, philosophers of science should embrace an image of science that grants the sciences a broader common basis than the one Kuhn grants.

Keywords Incommensurability · Interdisciplinarity · Interdisciplinary research · Thomas Kuhn

✉ Yotam Harel
yotam.harel@merton.ox.ac.uk

[1] University of Oxford, Oxford, UK

Published online: 13 May 2026

1 Introduction

For more than half a century now, Kuhn's (1970) image of science, as portrayed in his *The Structure of Scientific Revolutions*, has been significantly influencing – not to say dominating – the philosophy of science. One of the central tenets of this image is that different scientific traditions are *incommensurable* (see, e.g., Hoyningen-Huene, 1990, p. 483). And, one of the central merits of this image of science is that it was scientifically-informed in the sense of being based on an examination of the *actual scientific practice*.

In the last few decades, however, the scientific practice seems to have been changing fundamentally due to the emergence of a new kind of research – *interdisciplinary research*. That interdisciplinary research is on the rise is widely acknowledged (see, e.g., Mäki, 2016, p. 330), when some even venture to declare that science is currently in a state of a so-called "interdisciplinarity revolution" (Politi, 2019). Thomas Kuhn, though, passed away almost three decades ago so that he could not update his image of science in the face of this interdisciplinary turn in the scientific practice. This might raise the natural concern that the image of science advocated by Kuhn (1970) in his *The Structure of Scientific Revolutions* might not be up to date and, consequently, that we, philosophers of science, should update our image of science so as to take into account this interdisciplinary turn.

Mäki (2016) predicts that, considering this interdisciplinary turn, "[i]ssues of *incommensurability* will make a comeback, whether semantic, methodological or some other variety" (p. 338). My strategy in this paper, though, goes in an opposite direction: I argue that the productivity of interdisciplinary research shows that Kuhn's (1970) account of incommensurability is outdated and largely false when it comes to contemporary science; thus, I allow issues of incommensurability to make an extremely short comeback in this paper just to largely dismiss them from our image of science in the long term.

In this paper, then, the following argument will be presented:

(P_1) If different scientific traditions are incommensurable, the productivity of interdisciplinary research must be extremely low.

(P_2) The productivity of interdisciplinary research is not extremely low.

Hence, different scientific traditions are not incommensurable.

The paper, then, will be structured as follows. First, in Sect. 2, Kuhn's (1970) account of incommensurability will be clarified. Since incommensurability is a complex *concept*, the understanding of which is necessary for the clarification of the incommensurability *thesis*, this section will lengthily discuss the concept of incommensurability. In Sect. 3, what interdisciplinary research is will be clarified. Since this paper critically engages with Kuhn, its account of interdisciplinary research will be formulated in a manner relevant to Kuhn's position, in Kuhnian terms and sense. In Sect. 4, the argument will be presented and defended. In Subsect. 4.1, it will be argued that if different scientific traditions are indeed incommensurable, the productivity of inter-

disciplinary research must be extremely low. In Subsect. 4.2, it will be argued that the productivity of interdisciplinary research is not, in fact, extremely low. In Subsect. 4.3, the argument's conclusion, according to which different scientific traditions are not in fact incommensurable, will be thoroughly discussed. It will be argued there that this conclusion calls for somewhat radical reform in the image of science held by contemporary philosophers of science and that the new image of science embraced must grant the sciences a broader common basis than the one Kuhn (1970) grants. Finally, in Sect. 5, the paper will be briefly concluded.

2 Kuhn's original account of incommensurability

In this section, Kuhn's original account of incommensurability will be clarified. First, a selective intellectual history of the concept of incommensurability will be presented. Although Steinmetz (2004) holds that the history of this concept can be traced back to "18th- and 19th-century Romanticism, historicism, German historical economics, and ethnology" (p. 386), this paper will focus on its history within philosophy of science. In this deliberately selective context, this concept was introduced almost simultaneously, in 1962, by Kuhn (1970), in his *The Structure of Scientific Revolutions* (hereafter *SSR*), and by Feyerabend (1981), in "Explanation, Reduction, and Empiricism." With respect to the history of philosophy of science, it is common wisdom to state that "[d]uring the first half of the twentieth century, philosophy of science was dominated by empiricist models of science, such as logical positivism and Popperian falsificationism. By the end of the 1950s, however, a new 'historical' or 'post-positivist' movement in philosophy of science had begun to emerge" (Sankey, 1997, p. 425). Such a historical characterization of the philosophy of science often holds that due to the significance of Kuhn (1970) and Feyerabend (1981), "[t]he year 1962 marks a particularly significant point in the emergence of post-positivist philosophy of science" (Ibid.). Indeed, this narrative of the history of philosophy of science, which highlights the alleged death of logical positivism and the following birth of so-called "post-positivist" philosophy of science,[1] often holds Kuhn's (1970) *SSR*, together with Quine's (1951) "Two Dogmas of Empiricism", responsible for this post-positivist turn (see, e.g., Friedman, 1999, p. 1; Richardson, 1996, p. 2). And, specifically, it is said that "the incommensurability thesis is one of the leading claims of what came to be known as the *post-positivist* or *historical* philosophy of science" (Hoyningen-Huene & Sankey, 2001, p. vii).[2] So, according to this narrative, Kuhn's (1970) *SSR* and, specifically, its account of incommensurability, had a pivotal role in

[1] This popular narrative (advocated by, e.g., Friedman, 1999, pp. xii-xiii; Hanfling, 1996, p. 193; Richardson, 1996, pp. 1–3) is challenged by Laudan (1996), who argues that logical positivism's spirit, contra the popular narrative, is "very much alive (and by some accounts still well)" (p. 4). While I tend to agree with Laudan on this point, discussing it exceeds this paper's limited scope.

[2] It may be worth noting that Bird (2012) argues that incommensurability "is an important idea but… not a key idea [in *SSR*] (in the sense of a keystone that plays a crucial structural role)" (p. 870). However, I admit that when the notion of a "key idea" is only explained in metaphorical terms of a keystone, the distinction between important ideas and key ideas seems somewhat unclear.

the alleged death of logical positivism and the following birth of the so-called post-positivist philosophy of science.

Now, in order to clarify the concept of incommensurability, it must first be determined *which* version of this concept is at stake. This is because this concept has different versions. First, Feyerabend's version of this concept differs from Kuhn's (Sankey, 1993, p. 760). Second, there are different versions of this concept also *within* Kuhn's works over the years, as

> Kuhn's treatment of incommensurability divides into early and late positions, separated by a transitional stage. Originally, Kuhn's notion of incommensurability involved semantical, observational and methodological differences between global theories or paradigms. His initial discussion suggested that proponents of incommensurable theories are unable to communicate, and that there is no recourse to neutral experience or objective standards to adjudicate between theories. In subsequent efforts to clarify his position he restricted incommensurability to semantic differences, and assimilated it to Quinean indeterminacy of translation. During this intermediate stage Kuhn's treatment of the issues tended to be incomplete, often resulting in cursory discussion. However, in recent years he has begun to develop his position in more refined form. His present view is that there is translation failure between a localized cluster of interdefined terms within the languages of theories. (Ibid.)

In this paper, Kuhn's original account of incommensurability, that of *SSR*, will be at stake. This decision has two grounds. First, the account of *SSR* is selected here due to the unprecedented influence of this book on the philosophy of science. As Hoyningen-Huene (1990) puts it, Kuhn's *SSR* "marks a turning point in the history of philosophy of science. This is well-known and practically undisputed" (p. 481). Thus, considering the influence of this book on the philosophy of science, it is worth examining its account of incommensurability. Second, this account is worth examining for its great influence not only within, but also *outside*, philosophy of science: *SSR*'s account of incommensurability seems influential also in other disciplines, such as the social sciences (see, e.g., Collins, 2016, p. 253; Steinmetz, 2004, p. 386). For these reasons, and as one must select a version of this concept to clarify and work with, Kuhn's original account of incommensurability, that of *SSR*, which will be referred to as 'the original account' for brevity, will be clarified in what follows. However, it is worth acknowledging that this paper does *not* exhaust the various versions of the concept of incommensurability.

Before clarifying the original account, an important note must be considered. This paper does *not* aim to reinterpret the original account since it has been authoritatively interpreted by other scholars, prominent among them are Paul Hoyningen-Huene and Howard Sankey. Instead, this paper relies on past interpretations so as to clarify the original account with respect to this paper's purpose.

Now, the *concept of incommensurability* of the original account will be clarified. First, this concept is a *relational* concept – a *multi-place predicate* (Hoyningen-Huene, 1990, p. 483). It is thus senseless to state that "x is incommensurable," period. Rather, it can be stated that "x and y are incommensurable," that "x is incommensu-

rable in relation to *y*," and the like. All such statements share the logical form of *Ixy* (when '*I*' stands for incommensurable). Indeed, this relation can hold for more than two objects: For example, one can state that "*x*, *y*, and *z* are incommensurable," that is, *Ixyz*. *De jure*, this relation can hold for any finite set of *n* objects.

As to the *objects* that this predicate applies to, Kuhn (1970) says that

> the early developmental stages of most sciences have been characterized by continual competition between a number of distinct views of nature… What differentiated these various schools was not one or another failure of method—they were all "scientific"—but what we shall come to call their incommensurable ways of seeing the world and of practicing science in it. (p. 4)

Here, it seems that what is incommensurable are different *ways of seeing the world and of practicing science in it*. However, what these ways are is admittedly unclear at this point. Later, Kuhn explains that "[t]he normal-scientific tradition that emerges from a scientific revolution is not only incompatible but often actually incommensurable with that which has gone before" (p. 103). Indeed, Hoyningen-Huene (1990) argues that incommensurability applies to different traditions of normal science, which are usually separated by a scientific revolution (p. 483).[3] Therefore, it seems that the objects that incommensurability applies to are different (normal) *scientific traditions*.

There are, however, alternative objects that incommensurability is said to apply to, such as Kuhn's (notoriously ambiguous)[4] *paradigms* (Sankey, 1993, p. 762). 'Scientific traditions' are selected here for their being *prima facie* clearer and more adequate for this paper's purpose, but when referring to works that employ 'paradigm' rather than 'scientific tradition,' the reader may relate to these terms as roughly interchangeable in this paper's context only (to be accurate, it is its reception of a common 'paradigm' or 'disciplinary matrix' that transforms a group of scientists into a 'scientific tradition' [Kuhn, 1970, p. 19]).

Up to this point, it seems that according to the original account, 'incommensurability' is a *relation* that applies to different *scientific traditions* so that if t_i stands for scientific tradition *i*, it can be said that, say, "t_1 and t_2 are incommensurable," or in its logical form, It_1t_2. What is meant by this relation – by stating that t_1 and t_2 are incommensurable – has so far remained open. Now, this paper will simply attempt to clarify what is *meant by stating* that, say, t_1 and t_2 are incommensurable. Stating that some *x* and *y* are incommensurable, then, means that there are three relations, *methodological*, *semantic*, and/or *perceptual*, that obtain between *x* and *y* (Hoyningen-Huene & Sankey, 2001, p. ix). These relations will now be presented and clarified.

(1) *The methodological aspect*. As Kuhn (1970) puts it, "the proponents of competing paradigms will often disagree about the list of problems that any candidate

[3] Hoyningen-Huene admits that though "the concept of a tradition of normal science is controversial, [he] cannot address the complications involved" (Ibid.). In the same vein, this concept will not be discussed here any further.

[4] Kuhn's concept of a paradigm in *SSR* has been argued to be notoriously ambiguous (Masterman, 1970). Even Kuhn (1970) himself, in the postscript, seems to doubt his own use of 'paradigm' and, consequently, suggests 'disciplinary matrix' as a broader alternative (p. 182).

for paradigm must resolve. Their standards or their definitions of science are not the same" (p. 148). First, it seems that scientists from incommensurable scientific traditions disagree about the proper *list of problems* the tradition should resolve. Second, scientists from incommensurable scientific traditions also disagree about the proper *standards of resolving these problems* – about how to resolve these problems and evaluate competing solutions. It therefore seems that the "standards of theory appraisal are internal to [each] paradigm [and this] suggests a relativistic view of the epistemic merits of paradigms" (Sankey, 1993, p. 762).

(2) *The semantic aspect*. Kuhn (1970) argues that

> [s]ince new paradigms are born from old ones, they ordinarily incorporate much of the vocabulary and apparatus, both conceptual and manipulative, that the traditional paradigm had previously employed. But they seldom employ these borrowed elements in quite the traditional way. Within the new paradigm, old terms, concepts, and experiments fall into new relationships one with the other. The inevitable result is what we must call… a misunderstanding between the two competing schools. (p. 149)

It seems that each scientific tradition employs a different, in Sankey's (1993) terms, "conceptual apparatus" (p. 762). Each such *conceptual apparatus* consists of a set of *terms* and their corresponding *meanings* so that incommensurable scientific traditions may use the same term while allocating different meanings to it. Thus, Sankey calls this cleavage between different conceptual apparatuses "conceptual disparity" (p. 763), and Kuhn (1970) admits that "[c]ommunication across [incommensurable scientific traditions] is inevitably partial" (p. 149).

(3) *The perceptual aspect*. This is presumably the most puzzling aspect of incommensurability. In an attempt to explain it, Kuhn states that it is

> the… most fundamental aspect of the incommensurability of competing paradigms. In a sense that I am unable to explicate further, the proponents of competing paradigms practice their trades in different worlds… Practicing in different worlds, the two groups of scientists see different things when they look from the same point in the same direction. Again, that is not to say that they can see anything they please. Both are looking at the world, and what they look at has not changed. But in some areas they see different things, and they see them in different relations one to the other. (p. 150)

It seems that, according to Kuhn, scientists from incommensurable scientific traditions practice their science in different *worlds* in the sense of *perceiving* the same things differently. Hoyningen-Huene (1990), however, identifies an ambiguity in Kuhn's use of the term 'world:' In quite a Kantian sense, Hoyningen-Huene distinguishes between the *object-sided world* and the *world of appearances* in *SSR* (pp. 484–485). So, while there is an objective object-sided world, which explains how what scientists from incommensurable scientific traditions look at has not really changed, there is also the subjective world of appearances, whose structure is imposed by the scientists' conceptual apparatus. Thus, Hoyningen-Huene (1990) says that "concepts are

of human origin, i.e. *we* impose a structure on the world by means of these concepts" (p. 484) and, consequently, scientists from different scientific traditions perceive the world differently.

Having clarified these three aspects, that is, the relations that are said to obtain between incommensurable scientific traditions, the concept of incommensurability will now be explained. So, if one states that x and y are incommensurable, one actually means that scientists from x and y: (1) employ different *methodologies* in the sense that they endorse different *lists of problems* and different *standards of resolving these problems*; (2) employ different *conceptual apparatuses* in the sense that they might use the same *terms* while allocating different *meanings* to them; (3) *perceive* the *world of appearances* differently in the sense that they perceive the same things differently. Now, whether the relation between (1)–(3) is conjunctive or disjunctive does not make much practical difference, at least for this paper's purpose. This is because (1)–(3) seem dependent, to some extent, on one another: For example, it seems that, at least partly, it is *because* scientists from incommensurable traditions use different conceptual apparatuses that they perceive the world of appearances differently, as, again, "concepts are of human origin, i.e. *we* impose a structure on the world by means of these concepts" (Hoyningen-Huene, 1990, p. 484). It seems, then, that if one of the aspects obtains, other aspects tend to obtain as well.

Now, Hoyningen-Huene and Sankey (2001) stress the distinction between the *concept* and the *thesis* of incommensurability (p. viii). So, the concept of incommensurability of the original account has been thoroughly discussed. As to the thesis of incommensurability of the original account – this thesis simply says that indeed, *different scientific traditions are incommensurable*, under the meaning of the concept of the original account, which involves the three aspects discussed above. Thus, if t_i stands for scientific tradition i, and $t_{\neg i}$ stands for any other scientific tradition, the *incommensurability thesis* of the original account may be formulated as follows: $\forall t_i \forall t_{\neg i} I t_i t_{\neg i}$.

To sum up, according to the original account, 'incommensurability' is a *relational* concept that applies to *scientific traditions*. What is meant by stating that x and y are incommensurable is threefold: Roughly speaking, it is meant that x and y (1) employ different *methodologies*, (2) employ different *conceptual apparatuses*, and/or (3) *perceive* the world differently. The incommensurability thesis of the original account simply says that indeed, *different scientific traditions are incommensurable*, in the sense of the meaning of 'incommensurable' of the original account presented here.

3 Interdisciplinary research

In this section, what interdisciplinary research is will be clarified. However, as Mäki (2016) notes, "[i]nterdisciplinarity is dependent on disciplinarity, both conceptually and causally. The conceptual dependence is obvious: the concept of the former must be defined in terms of that of the latter" (p. 331). Thus, first, what disciplines are will be clarified. Only afterward, will it be possible to clarify what interdisciplinary research is.

A methodological note is worth considering at this point. Since this paper critically engages with Kuhn's original account of incommensurability, this paper's account of interdisciplinary research must be relevant to Kuhn's position. To do so, the concept of interdisciplinary research will be formulated here in Kuhnian terms and sense.

It seems that, according to Kuhn (1970), a discipline is a *scientific community* whose members share, *at each period of normal science*, a paradigm or, as Kuhn suggests modifying the terminology in the postscript, a *disciplinary matrix* (p. 182). According to Kuhn, "it is sometimes just its reception of a paradigm that transforms a group previously interested merely in the study of nature into a… discipline" (p. 19). Kuhn adds that "one of the things a scientific community acquires with a paradigm is a criterion for choosing problems… Other problems, including many that had previously been standard, are rejected as metaphysical, as the concern of another discipline" (p. 37).

However, in the postscript, Kuhn admits that when it comes to what the members of a certain discipline share, "my original text licenses the answer, a paradigm or set of paradigms. But for this use… the term is inappropriate" (p. 182). Instead, Kuhn suggests that what these members share is to be called a disciplinary matrix, which is "composed of ordered elements of various sorts, each requiring further specification. All or most of the objects of group commitment that my original text makes paradigms… are constituents of the disciplinary matrix" (Ibid.). So, a disciplinary matrix is *broader* than a paradigm, and this matrix is composed of several elements, including a shared paradigm, but also shared symbolic generalizations, commitments to metaphysical beliefs, values, and more (pp. 182–187).

Indeed, as Andersen (2016) indicates,

> [o]n Kuhn's account, scientists within a given specialty have been through substantially the same kind of training, and through this training they have required very similar and strong mental sets; what Kuhn referred to first as a paradigm and later as a disciplinary matrix… [T]he mastery of the disciplinary matrix in the form of concepts, generalization, values and exemplars, as well as the ability to apply it to recognize, define and creatively solve new research puzzles were seen as the core elements… [This] implied that… [a] discipline was a community of scientists with highly similar expertise based on their possessing more or less the same set of cognitive resources that enabled them to identify more or less the same problems and methods for their solution. (p. 2)

It seems, then, that a discipline is a scientific community that shares a disciplinary matrix thanks to the fact that the members of this community have been through the same *process of training and socialization*.[5] What remains to be settled is the relation between three concepts: *disciplines*, *scientific traditions*, and *disciplinary matrices*. This relation is best understood by examining Kuhn's (1970) characterization of disciplines' historical self-image:

[5] On more extreme and irrational accounts of disciplines, it is argued that due to this process of socialization, disciplines are to be described "in anthropological terms, as separate tribes with different cultures and languages" (Moran, 2010, p. 12).

> Textbooks thus begin by truncating the scientist's sense of his discipline's history and then proceed to supply a substitute for what they have eliminated… And no wonder that, as they are rewritten, science once again comes to seem largely cumulative. Scientists are not, of course, the only group that tends to see its discipline's past developing linearly toward its present vantage. (pp. 137–138)

It seems, then, that scientists from a certain discipline conceive the history of their discipline as a history of one, unified scientific tradition, although in actuality, the history of disciplines consists of some (normal) scientific traditions punctuated by scientific revolutions (Sankey, 1993, p. 761). In each such scientific revolution of a transition between t_i and $t_{\neg i}$, the disciplinary matrix is clearly changed, not to say completely redesigned. What remains from the discipline in the sense of its persistence over time despite the occurrence of scientific revolutions is twofold: a *name* shared by the discipline's members (who identify themselves as members of some discipline "*A*") and actual *institutional facts*, such as departments, positions, degrees, associations, and the like, all of which are associated with this name (Turner, 2000, p. 47).

This may become comprehensible using one of Kuhn's (1970) classic examples of a scientific revolution. Consider the transition from Newtonian to Einsteinian dynamics in Physics. Both *scientific traditions*, the Newtonian and the Einsteinian, are part of the same *discipline* – Physics. This is because, although this scientific revolution has fundamentally changed the *disciplinary matrix* of physics, there remains a scientific community of self-identifying physicists who still have their physics departments, positions for physicists, physics degrees, associations for physicists, and the like. Having clarified the relation between disciplines, scientific traditions, and disciplinary matrices, the explication of what a discipline (in Kuhnian terms and sense) is can be completed based on a distinction between *temporal perspectives*:

- *From a perspective of a certain period of normal science*, a discipline is a scientific community that shares a disciplinary matrix; in this sense, a discipline is by and large synonymous with a scientific tradition.
- *From a historically-informed perspective*, a discipline is a sequence of different (normal) scientific traditions punctuated by scientific revolutions, when in each scientific revolution the disciplinary matrix is fundamentally changed (see Fig. 1); what remains from the discipline in the sense of its persistence over time is a shared name and actual institutional facts associated with it.

Having clarified what disciplines are, the same will be done with respect to interdisciplinary research. However, a methodological warning is worth considering here. As explained by Hoffmann et al. (2013), although 'interdisciplinarity' has become a buzzword in the last decades, its exact meaning is still in flux (p. 1857). Thus, in the formulation of this concept, the paper attempts to consider the most popular account of interdisciplinarity, while avoiding over-specification of this concept. According to Holbrook (2013), then, "what we have now in the scholarly literature on [interdisciplinarity] is something approaching agreement on the use of the following terms: …

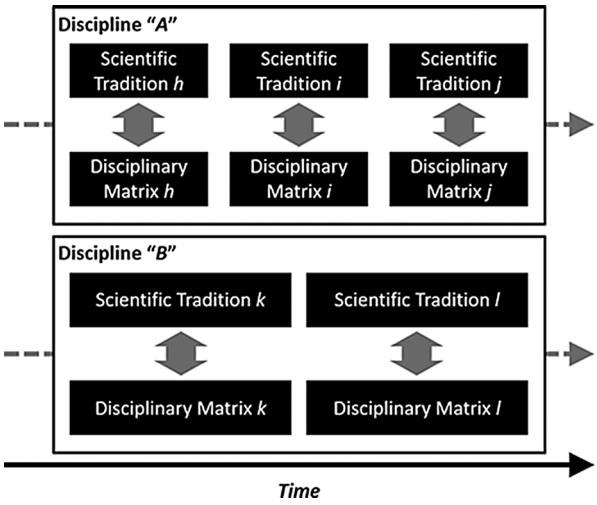

Fig. 1 Presents what disciplines are over time from a historically-informed perspective, including the relation between disciplines, scientific traditions, and disciplinary matrices

[interdisciplinarity] refers to the *integration* of two or more disciplines focused on a common (and, it is sometimes insisted, a *complex*) problem" (pp. 1866–1867).[6]

The components of this formulation will now be further specified and clarified. First, interdisciplinarity entails an integration of *two or more* ($n \geq 2$) *different disciplines*. Indeed, as Repko and Szostak (2017) explain, "[t]he prefix *inter* means 'between, among, in the midst,' or 'derived from two or more.' … So a starting point for understanding the meaning of *interdisciplinary studies* is between two or more fields of study" (p. 43).

Second, interdisciplinarity entails a focus on a common *problem*: Two or more disciplines must agree to focus on the same problem (which is often said to be complex). Repko and Szostak exemplify this point by stating that, for example, "urban riots are an interdisciplinary problem because they are an economic problem *and* a racial problem *and* a public policy problem… *[T]he focus is the problem or issue or intellectual question that each discipline is addressing*" (Ibid.). To clarify this example, the common problem is *urban riots*, and the disciplines that focus on this problem may be *economics*, *sociology*, and *public policy*.

Third, interdisciplinarity entails an *integration* of two or more disciplines focused on a common problem. Indeed, as stated in Klein (2010), "most definitions treat the *integration* of disciplines as the 'litmus test' of interdisciplinarity… [I]ntegration is the most common benchmark" (p. 17). Integration in interdisciplinary research amounts to more than mere collaboration (p. 19) as interdisciplinary integration has methodological and conceptual aspects (Aboelela et al., 2007, p. 341). Having clarified further what interdisciplinarity is, *interdisciplinary research* can now be formulated:

[6] Notice that Grüne-Yanoff (2016) argues for a broader concept of interdisciplinarity that does *not* entail integration.

Interdisciplinary Research: A research is interdisciplinary if and only if the research is based on an integration of two or more disciplines focused on a common problem.

4 Productivity of interdisciplinary research as a challenge to Kuhn's original account of incommensurability

Having set the grounds in Sects. 2–3, in this section, it will be argued that the productivity of interdisciplinary research challenges, to say the least, Kuhn's original account of incommensurability. Formally, the argument is as follows:

(P_1) If different scientific traditions are incommensurable, the productivity of interdisciplinary research must be extremely low.

(P_2) The productivity of interdisciplinary research is not extremely low.

Hence, different scientific traditions are not incommensurable.

Now, since the argument is logically impeccable, what remains is to establish its *premises*. Therefore, in the following subsections, P_1-P_2 will be established. First, in Subsect. 4.1, it will be argued that if different scientific traditions are indeed *incommensurable*, the productivity of interdisciplinary research must be *extremely low*. Afterward, in Subsect. 4.2, it will be argued that, based on cumulating evidence, it is clear that, nowadays, the productivity of interdisciplinary research is *not*, in fact, extremely low. Finally, in Subsect. 4.3, the argument's conclusion, according to which different scientific traditions are *not* incommensurable, will be thoroughly discussed.

4.1 Incommensurability and interdisciplinary research

In this subsection, it will be argued that if different scientific traditions are incommensurable, the productivity of interdisciplinary research must be extremely low. It must be noticed that this premise is understood here in light of the original account of incommensurability, that of Kuhn in *SSR*. To begin with, Politi (2017) argues that "it is not clear how interdisciplinarity would even be possible if it were true that different specialties were separated by incommensurability" (p. 302). Politi's claim seems to be in the right direction: It seems that if different scientific units (let these be specialties, scientific traditions, disciplines, and the like) are incommensurable, the productivity of interdisciplinary research (which entails integration between these units) must be extremely low, if such kind of research is even possible. However, Politi never explains in detail *why* it is so that incommensurable units virtually cannot conduct interdisciplinary research together. Thus, it will first be explained why it is so. Then, it will be shown that different *disciplines* are indeed *incommensurable units*.

However, before that, the notion of *productivity* must be clarified. Traditionally, this notion is used in economics to refer to the *efficiency of the conversion of inputs*

into outputs in production processes (Syverson, 2011). This means that productivity is a matter of degree, a comparable measure. Here, productivity is applied to academic research practices, and thus, how it will be used must be explained. Roughly speaking, it seems that the *input* or the "costs" of academic research are the overall time, effort, funding, equipment, institutional support, and the like employed to conduct it. On the other hand, the *output* or the "returns" of academic research are typically understood as the number of publications and their impact (commonly understood in terms of citations). 'Productivity,' then, will be understood here as the *ratio between academic research output and input*; the higher this ratio, the more productive the research. Notice, though, that in this subsection, we focus on the inputs of interdisciplinary research, assuming, for didactic purposes, that the outputs are fixed (so that an increase in the inputs means a decrease in productivity). Outputs will be discussed in Subsect. 4.2.

Now, according to the original account, if units x and y are incommensurable, some implications typically follow with respect to x and y, implications that negatively influence the possibility of x and y to conduct interdisciplinary research together:

(1) *Methodology*. If x and y are incommensurable, it follows that they do *not* agree on the *list of problems to be solved*. However, interdisciplinary research entails an agreement on a common problem to be solved. Hence, interdisciplinary research seems impossible as x and y cannot agree on a common problem to be solved. Even if reaching such an agreement is assumed to be somehow possible, it must result in long debates between the units, which must reduce the scientists' productivity as they would invest time and effort in convincing the other unit's scientists that their problem is worth solving instead of actually solving the problem. Moreover, if x and y are incommensurable, it also follows that x and y employ *different standards of resolving problems*. Hence, even if they somehow agree on the problem to be solved, an agreement on the correct solution might be almost impossible since each unit's scientists employ different standards of how to solve problems and evaluate competing solutions.

(2) *Semantics*. If x and y are incommensurable, it follows that each unit has a different *conceptual apparatus*, which consists of a set of *terms* and their corresponding *meanings*. However, interdisciplinary research entails *integration* between the units at stake. Hence, it seems that scientists from x and y will not properly understand each other due to frequent *communication failures*. It is, however, *de jure* possible that, for the sake of the research, scientists from one unit will "[learn] the language of another [unit] from within as a second-first language" (Holbrook, 2013, p. 1871). Even if scientists from one unit can learn the language of scientists from another unit,[7] it seems that this point necessarily makes interdisciplinary research much less productive. This is because learning a language is a challenging, time-consuming task, which does not directly contribute to solving the problem at stake.

(3) *Perception*. If x and y are incommensurable, it follows that scientists from each unit *perceive the world* (of appearances) *differently*. Hence, it seems that collabora-

[7] It still remains to determine which unit has to learn the other unit's language, which might ignite controversies; however, if each unit learns the other unit's language, the research will naturally be much less productive.

tion between scientists from these units might be impossible: They might disagree on the very content of *observations*, on what they perceive as part of their research's observations. As this sort of collaboration is a minimum requirement for interdisciplinary research (and not a sufficient one), which requires integration, this aspect of incommensurability also seems to make this kind of research much less productive, to say the least.

To sum up, it seems that if units *x* and *y* are incommensurable (in the sense of the original account), they can barely conduct interdisciplinary research together, if at all. This is due to methodological, semantic, and perceptual aspects of incommensurability that, even assuming that some of them can be overcome, must make the productivity of interdisciplinary research extremely low. This is because, if Kuhn's original account of incommensurability is correct, *interdisciplinary research incurs extremely high costs*, making the minimal inputs required for such research seem almost impossible to obtain. Thus, if interdisciplinary research is even possible, it is expected to generate relatively very few publications (i.e., *minimal output*), each of which requires extremely high costs in terms of time, effort, support, and the like (i.e., *enormous inputs*), and this would result in *extremely low productivity* overall.

What remains open, though, is whether different *disciplines* are indeed incommensurable units. Now, recall that in Sect. 3, two temporal senses of disciplines were suggested: (1) *from a perspective of a certain period of normal science*, and (2) *from a historically-informed perspective*. Since this paper is interested in interdisciplinary research, which must take place at a *certain period*, only the first sense is relevant here (the problem of conducting interdisciplinary research at times of a scientific revolution will have to be addressed elsewhere). In this sense, then, a discipline is a scientific community that shares a disciplinary matrix so that a discipline is by and large synonymous with a scientific tradition. Seemingly, this identification of a discipline with a certain scientific tradition (in periods of normal science) shows that different disciplines are incommensurable, as it has been shown, in Sect. 2, that according to the original account, different scientific traditions are incommensurable.

This way of putting it, however, might leave some scholars discontent. This is because, in their view, *competition between two units is a necessary condition for incommensurability*. As Politi (2017) puts it, "no matter *how* or *when* they have been differentiated, disciplines which are *now* different are not in a state of competition and, therefore, they are not incommensurable" (p. 309). And, according to this position, different disciplines are not in a state of competition as "their research is just about different things" (p. 306). Now, in order to make sense of this position, it may be illuminating to connect it with the original account of incommensurability. It can be argued that since different disciplines are not about the same "things," these disciplines do not disagree on the list of problems to be solved (see the methodological aspect). Instead, each discipline just minds its own business. Moreover, since these disciplines are about different things, there will not be any conceptual disagreements on the correct meaning of such and such term (see the semantic aspect). This is because these disciplines simply do not employ the same terms as they investigate different things. And, it can be argued, these disciplines will not suffer from the problem of perceptual disagreements (see the perceptual aspect) since they do not observe the same things – each discipline investigates another aspect of the world so that their

sights do not converge. Therefore, there would be no incommensurability between disciplines if, indeed, competition between two units were a necessary condition for incommensurability.

This position, however, employs a too-narrow concept of incommensurability that misses one of the most significant driving forces of incommensurability à la Kuhn's *SSR*: A demanding, long *process of training and socialization*. To clarify the argument, it may be useful to distinguish between two kinds of incommensurability: (1) *competitors' incommensurability* and (2) *non-competitors' incommensurability*. While the position presented above considers only the first kind as a genuine kind of incommensurability, it will be argued that the second kind, which is also compatible with Kuhn's original account, is both *a genuine kind of incommensurability and a threat to the productivity of interdisciplinary research*.

To begin with, the distinction between competitors' and non-competitors' incommensurability will be clarified. *Competitors' incommensurability* is the relation of incommensurability between two competing scientific traditions. These scientific traditions are competing in the sense that they profess to "scientify" (more or less) the same things. Typically, such incommensurability emerges between two scientific traditions that are divided by a scientific revolution *within* the same discipline. Figure 1 may be of help in clarifying this point: In this figure, for example, scientific tradition *h* and scientific tradition *i* are competitors within discipline "*A*" and are divided by a scientific revolution. A concrete example of this point is the incommensurability between Newtonian and Einsteinian dynamics in Physics: These scientific traditions are competitors within the same discipline that are divided by a scientific revolution.

Non-competitors' incommensurability, on the other hand, is the incommensurability between a scientific tradition *and a non-competing scientific tradition from another discipline* (or simply laymen who have gone through no process of scientific training and socialization). In this case, it will be argued, while there is no competition in the sense of the above, *the three aspects of incommensurability still largely obtain*. First, Fig. 1 may be of help in clarifying what is meant by scientific traditions from different disciplines: In this figure, for example, scientific tradition *h* and scientific tradition *k* belong to different disciplines (to discipline "*A*" and discipline "*B*" correspondingly). A concrete example of this state can be seen in the relation between, say, Newtonian dynamics in Physics and the neoclassical theory in Economics.

Now, it will be explained why the three aspects of incommensurability still largely obtain in the case of non-competitors' incommensurability. As Kuhn (1970) states,

> [w]hat were ducks in the scientist's world before the revolution are rabbits afterwards. The man who first saw the exterior of the box from above later sees its interior from below. Transformations like these, though usually more gradual and almost always irreversible, *are common concomitants of scientific training*… [S]cientific training is not well designed to produce the man who will easily discover a fresh approach… The group's members, as individuals and *by virtue of their shared training and experience, must be seen as the sole possessors of the rules of the game or of some equivalent basis for unequivocal judgments*. (italic added, pp. 111, 166, 168)

It is, indeed, widely recognized that one of the most significant driving forces of incommensurability according to Kuhn's original account, maybe even *the* driving force, is a demanding, long *process of training and socialization*. It is due to this process that scientists who have gone through a different process of training and socialization adhere to different *methodologies* (that is, consider different lists of problems and standards of resolving them as proper) and *conceptual apparatuses* (that is, embrace different sets of terms and their corresponding meanings),[8] and *perceive* the world differently. In this sense, with respect to a scientist from a certain scientific tradition, a scientist from *another* scientific tradition is considered a layman just as someone who has gone through no process of scientific training and socialization: Both lack the relevant skills and do not know the tradition's "rules of the game" (Kuhn, 1970, p. 168). It is thus clear why Holbrook (2013) states that

> [i]f we apply Kuhn's… views to interdisciplinary communication, what emerges is a very strong requirement for [interdisciplinarity] that recognizes the reality of incommensurability. Essentially, one would have to adopt the point of view of a different discipline in order for interdisciplinary communication to take place. One can imagine various options for accomplishing the adoption of a new disciplinary perspective. *The most obvious option, perhaps, would be to earn proficiency in another discipline, say by pursuing a second PhD*. (italic added, p. 1873)

The lack of competition between scientific traditions from different disciplines, then, does *not* cancel the incommensurability between them – it only has a different character – instead of being a relation between intellectual rivals, it is essentially the relation between a group of scientists and a group of laymen. Hence, according to Kuhn's original account, if a scientist from discipline "*A*" is willing to engage in interdisciplinary research with a scientist from discipline "*B*," the former must go through the demanding, long process of training and socialization common to *B* members so as to understand *B*'s "rules of the game" (that is, shared methodology, conceptual apparatus, and a way of perceiving the world). Holbrook indicates that, practically, the most obvious option would be to earn proficiency in another discipline, say, by pursuing a second PhD (Ibid.). Indeed, on Kuhn's image of science in *SSR*, *the productivity of interdisciplinary research, if the latter is even possible, must be extremely low* due to this kind of non-competitors' incommensurability that requires scientists from one scientific tradition to learn the disciplinary matrix of a scientific tradition from another discipline through a demanding, long process in order to overcome it and conduct interdisciplinary research together. Specifically, since this process, in terms of its costs, *is equivalent to obtaining a second PhD* (i.e., several years of consider-

[8] Notice that also in cases of non-competitors' incommensurability, there might be *communication failures* since scientists from different disciplines still have *folk meanings* of terms in mind. For example, although neoclassical economists do not employ 'space' in their ordinary scientific work, they still have some folk meaning of this term in mind. Thus, interdisciplinary research involving, say, neoclassical economists and Newtonian physicists is supposed to suffer from communication failures surrounding the use of 'space' as, while economists have some folk meaning of 'space' in mind, the physicists employ this term in a different, well-specified sense.

able effort, entailing funding and institutional support), if Kuhn's original account of incommensurability is correct, *we should expect that there would be very few, if any, interdisciplinary research publications,*[9] *and that the engagement in interdisciplinary research would be counterproductive overall for the participating researchers*.

4.2 The productivity of interdisciplinary research

In this subsection, it will be argued that the productivity of interdisciplinary research is not extremely low. Since productivity is a matter of degree, it may be more accurate to state that, to say the least, *interdisciplinary research is much more productive than we could expect had Kuhn's original account of incommensurability been correct*. Thus, to establish this premise, the *theoretically-expected productivity* of interdisciplinary research, entailed by Kuhn's original account, will be compared to the *actual productivity* of interdisciplinary research.

This premise, it must be recognized, *refers to a specific period*, and specifically to the past few decades, with an increasing focus on the present scientific practice. Establishing P_2, then, seems an easier task compared to establishing P_1 simply as the fact that interdisciplinary research has become relatively productive (and is probably becoming increasingly so) is well-accepted and patently supported by various empirical findings, which will be presented shortly. However, before that, a word on this paper's strategy may be needed.

Notice that Park (2016) argues that "[t]he interactions of ideas from different fields of Science are more typical and pervasive phenomena in present Science than in past Science" and states that interdisciplinary research is "an anomaly to Kuhn's account of Science" (p. 48). Despite being in the same direction as this paper's argument, Park's argument is grounded in different reasons. To establish his argument, Park advances an assortment of specific scientific examples of interdisciplinary interaction. Consider, for instance, the following example:

> [E]volutionary theory claims that marsupials flourished in South America millions of years ago. The theory of plate tectonics claims that South America, Antarctica, and Australia once formed a giant continent called Gondwanaland, and they drifted apart millions of years ago. Aware of these two theories, scientists speculated for years that marsupials migrated from South America to Australia via Antarctica, and inferred that there are marsupial fossils in Antarctica. A group of scientists discovered the marsupial fossils in Antarctica. Note that neither the biological theory nor the geological theory alone can explain the existence of marsupial fossils in Antarctica. Their existence can only be explained by the cooperation of the two theories. (p. 45)

This interesting scientific example of interdisciplinary interaction, so it seems, demonstrates the value of interdisciplinary interaction. Yet, while crucial to Park's argument, specific examples like the one above are not sufficient to establish this paper's

[9] Given that the very vast majority of academic researchers do *not* have a second PhD (nor did they invest an equivalent period of time, effort, and other related costs in studying another discipline "from within").

argument: This is because the latter is interested in the productivity of interdisciplinary research, but when it comes to such *specific examples*, one can suggest that conducting *that* research required enormous costs (i.e., time, effort, support, and the like), unless evidence to the contrary on the research process of that research is available. Thus, one might say that although there are *some* cases of interdisciplinary research that bore fruit, these were highly costly, and therefore, the productivity of interdisciplinary research can be extremely low after all. To establish this paper's argument, then, rather than building on such specific examples, it focuses on the *general trend* of the rise of interdisciplinary research and, through this general strategy, examines the actual productivity of interdisciplinary research.

Indeed, Mäki (2016) argues that "[i]nterdisciplinarity plays an increasingly central role in contemporary scientific research and its governance" (p. 329). Mäki also distinguishes between the *talk about* interdisciplinarity and the *practice of* interdisciplinarity in science but holds that "[e]ven if different, and sometimes independent, talk and practice share something important in common: presently they both grow" (p. 330). Indeed, it seems that both the talk about interdisciplinarity and the practice of interdisciplinarity in science grow (see Braun & Schubert, 2003 for empirical findings on the growth in the interdisciplinarity talk), but it may be useful to distinguish between two aspects of the output growth in the practice: growth in the *amount* of interdisciplinary research publications and in their *impact*. This is because research is not only expected to generate many publications but also to generate impactful ones. However, as explained in Subsect. 4.1, in order to measure productivity, it is not enough to examine the output alone; rather, academic productivity is the ratio between academic research output *and input*. Therefore, we must take into account the "costs" of conducting interdisciplinary research. In this subsection, then, it will be shown that empirical findings support that the productivity of interdisciplinary research is not extremely low, as is evident from (1) the *amount* of publications, (2) the *impact* of publications, and (3) the *inputs* employed. To say the least, interdisciplinary research, or so it will be argued, is much more productive than we could expect had Kuhn's original account of incommensurability been correct.

(1) As to the number of interdisciplinary publications, while it is admittedly difficult to assess their exact overall number as this number may vary depending on how 'interdisciplinarity' is operationalized, it is clear that there is a significant number of interdisciplinary research publications, also as a percentage of all publications. Larivière et al. (2015), for instance, assess that based on cited references, 9.2 million interdisciplinary research papers were published between 2000 and 2012, and that out of all the papers published in this period, 41.2% cited references from at least five different subdisciplines, which is a strong indicator of interdisciplinarity (p. 4). This means that even if Larivière et al.'s assessment is somewhat inflated, we may still estimate that, roughly, some good double-digit percentage of all publications are products of interdisciplinary research.

Moreover, cumulating evidence reveals significant growth in the number of interdisciplinary publications over the past decades. First, Hicks and Katz (1996) examine, among other things, whether science is becoming more interdisciplinary by comparing the number of papers published in single-field journals (i.e., not an indicator of interdisciplinarity) to those published in cross-field journals (i.e., an indicator of

interdisciplinarity), and examine 376,226 papers listing a U.K. address from 1981 to 1991. They find that "[t]he share of articles in single discipline journals decreased by 0.11% per year on average, while the share in transdisciplinary journals increased by 0.11% per year" (p. 387). Second, Porter and Rafols (2009) examine how the degree of interdisciplinarity changed in 1975–2005 over six research domains by computing bibliometric indicators. To measure interdisciplinarity, Porter and Rafols use various indicators such as the number of authors per paper and the number of cited disciplines. They conclude that "[t]he results attest to notable changes in research practices over this 30 year period, namely major increases in number of cited disciplines and references per article (both show about 50% growth), and co-authors per article (about 75% growth)" (p. 719).[10] It seems, then, that these empirical findings may serve as indications of the growth in the amount of interdisciplinary research outputs.

(2) As to the impact of interdisciplinary publications, evidence shows that interdisciplinary research has become relatively impactful. Larivière et al. (2015) examine the impact of interdisciplinary research, when their analysis of the impact of interdisciplinary papers is based on the citations they receive. Larivière et al. examine 9.2 million interdisciplinary research papers published in 2000–2012. They find that the "mean relative citation rate of all interdisciplinary subdiscipline pairs included in this study is 1.54. Out of all 161,994 interdisciplinary subdiscipline pairs, 69.9% are win-win relationships, 26.8% increased impact for one of the subdisciplines, and only 3.3% do not exceed expected citation rates in any of the two subdisciplines" (p. 4). They also find that "[t]he relative citation rate… of papers increases with the number of subdisciplines they cite, supporting the perceived success of interdisciplinarity" (p. 3). It seems, then, that research produced by authors from different disciplines and research citing various disciplines is more impactful, which serves as strong evidence of the relatively high impact of interdisciplinary research.[11]

(3) As to the inputs, that is, the "costs" of interdisciplinary research, these include time, effort, funding, equipment, institutional support, and the like. Unfortunately, at least to the best of this author's knowledge, no empirical research has measured all of these costs. However, some kinds of costs are known to be typically associated with interdisciplinary research. First, Bromham et al. (2016) show that interdisciplinary research has consistently lower funding success, also when other causal factors are taken into account. Lynch (2006) adds that it is sometimes difficult to find competent and willing collaborators (p. 1121). Moreover, varying publication norms make it more challenging to determine a publishing protocol (Campbell, 2005, p. 575; Lynch,

[10] They note, on the other hand, that "in most fields, [an] Integration score… show[s] a more modest growth (mostly around 5%)" (p. 721). They explain that it is so because this integration score considers the "distance" between disciplines on a "science map," where the more distant the disciplines, the more significant the integration according to this measure. However, it is unclear why this distance should be taken into account in this sense.

[11] One might suggest, then, that the productivity of interdisciplinary research is not extremely low not *because* it does not require the enormous inputs entailed by Kuhn's position, but *because* it is extremely more impactful than "normal" disciplinary research (in this case, the actual productivity of interdisciplinary research could have been compatible with the original account). However, this hypothesis can be dismissed since, as a matter of fact, the "impact gain" of interdisciplinary research is *not* so significant (Leahey, 2018, p. S57), and it could not offset the extremely high costs of such research had Kuhn been correct.

2006, pp. 1121–1122). For example, "the value of a multi-authored publication in a medical journal is not necessarily the same in epidemiology as in sociology, where the emphasis is traditionally on single authorship" (Lynch, 2006, p. 1121). And, of course, it often takes time and effort to learn the other discipline's relevant knowledge, concepts, and methods in the specific research context (Ibid.).

Now, recall that, as Subsect. 4.1 explains, *if* Kuhn's original account of incommensurability is correct, we should expect that there would be very few, if any, interdisciplinary research publications, and that the engagement in interdisciplinary research would be counterproductive overall for the participating researchers. However, as we have already seen in (1) above, there *is*, in fact, a significant number of interdisciplinary research publications, also as a percentage of all publications. This, in itself, is sufficient to render Kuhn's original account untenable since it is clear that the very vast majority of academic researchers do *not* have a second PhD (nor did they invest an equivalent period of time, effort, and other related costs in studying another discipline "from within"), and yet, some good double-digit percentage of all publications are products of interdisciplinary research.

Now, the question is how (1)-(3) affect the overall productivity of academic researchers engaging in interdisciplinary research. *Despite* the additional costs incurred in interdisciplinary research and detailed in (3) above, it appears that researchers engaged in interdisciplinary research are *not*, in fact, extremely unproductive. Leahey (2018) examines how conducting interdisciplinary research influences the productivity of academic researchers in terms of their number of publications and their impact based on their publication records as of 2005. Had Kuhn's position been correct, we could have expected that the productivity of those academics engaged in interdisciplinary research would be extremely low and that they would have very few publications. However, out of three operationalizations of interdisciplinarity employed by Leahey, only one of them, resorting to the perceived "distance" between the disciplines, was associated with a merely slight decrease in the number of publications (and even in this case, the decrease is almost entirely offset by a respective increase in impact in terms of citations number, in line with (2) above [a decrease of 9.6% in the number of publications throughout career is mitigated by a respective 6.2% increase in the number of citations; see p. S57]). More importantly, according to two other operational measures of interdisciplinarity, *no* decrease in the number of publications was observed. In fact, when one of these operationalizations was used, an *increase* in the number of publications was observed, while retaining the "impact gain" (p. S58). In this case, interdisciplinary research has *only* positive influence on productivity, without trade-offs.

Anyway, even if one insists on picking on the first operationalization where a slight decrease in the number of publications was observed, it is clear that conducting interdisciplinary research is by no means as costly as Kuhn's original account entails. This fact is particularly striking considering that many of the additional costs incurred in interdisciplinary research and detailed in (3) above are *not at all related to the alleged methodological, semantic, and perceptual cleavages entailed by the*

incommensurability thesis;[12] rather, many of these costs result from institutional barriers (e.g., funding and publication norms). All this body of evidence, so it seems, strongly supports that the productivity of interdisciplinary research is not, in fact, extremely low so as to establish P_2. More specifically, *interdisciplinary research is much more productive than we could expect had Kuhn's original account of incommensurability been correct*. This is evident from the abundance of interdisciplinary research publications (compared to the minority of academic researchers having a second PhD or investing an equivalent period of time, effort, and other related costs in studying another discipline "from within") and the fact that engagement in interdisciplinary research is not counterproductive overall for the participating researchers, maybe not even more costly.

Allegedly, though, there is a way out for Kuhn's proponents: They might argue that all of these findings do not document *genuine* interdisciplinary research but only *pseudo* interdisciplinary research, a term employed to describe cases that do not amount to integration between the disciplines (see Klein, 2010, p. 17 for an elaboration on this terminology). This, however, does not seem to amount to a genuine objection: Although it is impossible to ensure that every research output counted in the papers cited above as evidence for interdisciplinarity involves integration, the indicators employed in Hicks and Katz (1996), Porter and Rafols (2009), Larivière et al. (2015), and Leahey (2018) as indicators of the practice of interdisciplinary research seem to make sense. It is only plausible that research involving integration between disciplines will be more likely to be published in cross-field journals, to be conducted by many authors coming from many disciplines, or to cite sources from various disciplines. Thus, this objection, especially when it comes from the side of contemporary Kuhn's proponents, seems like a desperate attempt to sacrifice reality for the sake of saving the theory.

4.3 Toward an updated image of science

The argument, if correct, has so far led us to the conclusion that, considering a careful examination of the actual state of contemporary science, different scientific traditions are *not* incommensurable[13] (in the sense of the original account of incommensurability, that of Kuhn in *SSR*).[14] What must be taken into account is that this argument asks *to defeat Kuhn* (or, more precisely, his contemporary successors, as it will soon be explained) *using his own weapon: an examination of the actual scientific practice*.

[12] Indeed, Leahey (2018) shows that for interdisciplinary researchers, "working repeatedly with a similar set of collaborators reduces the productivity penalty" (p. S58), implying that finding competent and willing collaborators is one of the most significant costs of interdisciplinary research, *not* necessarily the costs Kuhn's position entails.

[13] It is worth noting that some have already argued that different scientific traditions (or paradigms) are not, in fact, incommensurable (see, e.g., Franklin, 1984), but this has been done on other grounds.

[14] The original account consists of a *concept* of incommensurability and an incommensurability *thesis*. It is worth noting that a possible response to this paper's argument may be to embrace a *weaker* concept of incommensurability so that the incommensurability thesis will be tenable with respect to the empirical findings presented here (that is, a concept of incommensurability for which P_1 is false). This response, however, will not be developed here.

This paper took seriously a significant trend in contemporary science – interdisciplinarity – and examined what implications its productivity has for the image of science held by philosophers of science. This strategy is in line with Mäki (2016), who states that "the contents of general philosophy of science should be reconsidered and revised, based on the new more local information that will have been generated [in philosophies of special sciences and philosophy of interdisciplinarity]" (p. 335). Indeed, what is advocated in this paper is that we, philosophers of science, should update our *image of science*, considering the recent interdisciplinary turn in scientific practice.[15] The inevitable consequence of such a scientifically-informed philosophy of science, it is argued, is the rejection of Kuhn's original account of incommensurability, as, at least in contemporary scientific practice, it seems that different scientific traditions are not incommensurable.

Some points about this update of our image of science are worth noting. First, it is *not* argued that Kuhn was wrong in *SSR*. Rather, it is argued that his many *contemporary successors* are *now* wrong. This is because in *SSR*, Kuhn naturally had in mind the scientific practice that preceded the interdisciplinary turn, which is a young phenomenon of the last few decades. Hence, Kuhn's image of science may have been correct at that time, but it is argued that this image is outdated and largely false with respect to contemporary science. This call for a reform in the image of science held by philosophers of science is quite radical considering *SSR*'s enormous influence on philosophers of science, also nowadays. This influence can barely be overstated (see Wray, 2012 for an assessment of this influence). So, to the extent that interdisciplinarity is indeed a revolution within science (Politi, 2019), it should also revolutionize philosophy of science as far as the latter wishes to remain scientifically-informed.

Second, the fall of Kuhn's image of science may give rise to an *old-new* spirit in the philosophy of science: To the inquiry of the *common basis of the special sciences*, guided, maybe, by an interest in a refashioned version of the unity of science thesis (which is sometimes perceived as a regulative ideal [Kitcher, 1999]). This spirit is *old* in the sense that back in the first half of the twentieth century, the logical positivists investigated what they conceived as concepts that are common to all the sciences, let these be confirmation, theory, or observation. It is *new*, however, in the sense that the image of science as an interdisciplinary enterprise does *not* necessarily ask to break down disciplinary boundaries in the sense of reducing all the special sciences to a unified science. Rather, it is interested in concepts underlying interdisciplinary research, such as integration, collaboration, and communication, to understand how, while maintaining the different disciplines, interdisciplinary research is possible (and can be facilitated). By rejecting Kuhn's account of incommensurability in *SSR*, however, this old-new spirit in the philosophy of science will have to grant the sciences some broader common basis than the one Kuhn grants in *SSR*, and this basis seems to be worth examining.

[15] What is implied by this position is that science is a dynamic enterprise that can change fundamentally and that we, philosophers of science, must remain aware of such fundamental changes in scientific practice.

5 Conclusion

It is argued here that if philosophers of science wish to remain scientifically-informed, they must abandon Kuhn's (1970) image of science where different scientific traditions are seen as incommensurable. This is due to two premises. First, it is argued that if different scientific traditions are indeed incommensurable (in Kuhn's, 1970 sense), the productivity of interdisciplinary research must be extremely low. However, it is also argued that the productivity of interdisciplinary research is not extremely low. Hence, we must reject the belief that different scientific traditions are incommensurable nowadays. Instead, it is argued that a new image of science should be embraced, an image that grants the sciences a broader common basis than the one Kuhn grants.

Acknowledgements I am indebted to Alexander Prescott-Couch for helpful discussions, anonymous reviewers for many helpful comments, and Nehama Baker for proofreading.

Author contributions Not applicable.

Funding Funding from the Rhodes Scholarship, Merton College, and the Faculty of Philosophy at the University of Oxford is gratefully acknowledged.

Data availability Not applicable.

Declarations

Competing interests The author has no relevant financial or non-financial interests to disclose.

References

Aboelela, S. W., Larson, E., Bakken, S., Carrasquillo, O., Formicola, A., Glied, S. A., Haas, J., & Gebbie, K. M. (2007). Defining interdisciplinary research: Conclusions from a critical review of the literature. *Health Services Research*, *42*(1p1), 329–346. https://doi.org/10.1111/j.1475-6773.2006.00621.x

Andersen, H. (2016). Collaboration, interdisciplinarity, and the epistemology of contemporary science. *Studies in History & Philosophy of Science Part A*, *56*, 1–10. https://doi.org/10.1016/j.shpsa.2015.10.006

Bird, A. (2012). *The structure of scientific revolutions* and its significance: An essay review of the fiftieth anniversary edition. *The British Journal for the Philosophy of Science*, *63*(4), 859–883. https://doi.org/10.1093/bjps/axs031

Braun, T., & Schubert, A. (2003). A quantitative view on the coming of age of interdisciplinarity in the sciences 1980-1999. *Scientometrics*, *58*(1), 183–189. https://doi.org/10.1023/A:1025439910278

Bromham, L., Dinnage, R., & Hua, X. (2016). Interdisciplinary research has consistently lower funding success. *Nature*, *534*(7609), 684–687. https://doi.org/10.1038/nature18315

Campbell, L. M. (2005). Overcoming obstacles to interdisciplinary research. *Conservation Biology*, *19*(2), 574–577. https://doi.org/10.1111/j.1523-1739.2005.00058.x

Collins, H. M. (2016). The notion of incommensurability. In A. Blum, K. Gavroglu, C. Joas, & J. Renn (Eds.), *Towards a history of the history of science: 50 years since 'Structure'* (pp. 251–256). Max Planck Research Library for the History and Development of Knowledge (Edition Open Access).

Feyerabend, P. K. (1981). Explanation, reduction, and empiricism. In *Realism, rationalism and scientific method: Philosophical papers* (pp. 44–96). Cambridge University Press.

Franklin, A. (1984). Are paradigms incommensurable? *The British Journal for the Philosophy of Science*, *35*(1), 57–60. https://doi.org/10.1093/bjps/35.1.57

Friedman, M. (1999). *Reconsidering logical positivism*. Cambridge University Press.

Grüne-Yanoff, T. (2016). Interdisciplinary success without integration. *European Journal for Philosophy of Science*, *6*(3), 343–360. https://doi.org/10.1007/s13194-016-0139-z

Hanfling, O. (1996). Logical positivism. In S. Shanker (Ed.), *Philosophy of science, logic, and mathematics in the twentieth century* (pp. 193–213). Routledge.

Hicks, D. M., & Katz, J. S. (1996). Where is science going? *Science, Technology, and Human Values*, *21*(4), 379–406. https://doi.org/10.1177/016224399602100401

Hoffmann, M. H. G., Schmidt, J. C., & Nersessian, N. J. (2013). Philosophy *of* and *as* interdisciplinarity. *Synthese*, *190*(11), 1857–1864. https://doi.org/10.1007/s11229-012-0214-8

Holbrook, J. B. (2013). What is interdisciplinary communication? Reflections on the very idea of disciplinary integration. *Synthese*, *190*(11), 1865–1879. https://doi.org/10.1007/s11229-012-0179-7

Hoyningen-Huene, P. (1990). Kuhn's conception of incommensurability. *Studies in History and Philosophy of Science Part A*, *21*(3), 481–492. https://doi.org/10.1016/0039-3681(90)90006-T

Hoyningen-Huene, P., & Sankey, H. (2001). *Incommensurability and related matters* (Vol. 216). Springer Netherlands. https://doi.org/10.1007/978-94-015-9680-0

Kitcher, P. (1999). Unification as a regulative ideal. *Perspectives on Science*, *7*(3), 337–348. https://doi.org/10.1162/posc.1999.7.3.337

Klein, J. T. (2010). A taxonomy of interdisciplinarity. In R. Frodeman, J. T. Klein, & C. Mitcham (Eds.), *The Oxford handbook of interdisciplinarity* (1st ed., pp. 15–30). Oxford University Press.

Kuhn, T. S. (1970). *The structure of scientific revolutions* (2nd ed., enl.). University of Chicago Press.

Larivière, V., Haustein, S., & Börner, K. (2015). Long-distance interdisciplinarity leads to higher scientific impact. *PLoS One*, *10*(3), e0122565. https://doi.org/10.1371/journal.pone.0122565

Laudan, L. (1996). *Beyond positivism and relativism: Theory, method, and evidence*. Westview Press.

Leahey, E. (2018). The perks and perils of interdisciplinary research. *European Review*, *26*(S2), S55–S67. https://doi.org/10.1017/S1062798718000261

Lynch, J. (2006). It's not easy being interdisciplinary. *International Journal of Epidemiology*, *35*(5), 1119–1122. https://doi.org/10.1093/ije/dyl200

Mäki, U. (2016). Philosophy of interdisciplinarity. What? Why? How? *European Journal for Philosophy of Science*, *6*(3), 327–342. https://doi.org/10.1007/s13194-016-0162-0

Masterman, M. (1970). The nature of a paradigm. In I. Lakatos, & A. Musgrave (Eds.), *Criticism and the growth of knowledge* (pp. 59–89). Cambridge University Press.

Moran, J. (2010). *Interdisciplinarity* (2nd ed.). Routledge.

Park, S. (2016). To be scientific is to be interactive. *European Journal of Science and Theology*, *12*(1), 39–50.

Politi, V. (2017). Specialisation, interdisciplinarity, and incommensurability. *International Studies in the Philosophy of Science*, *31*(3), 301–317. https://doi.org/10.1080/02698595.2018.1463697

Politi, V. (2019). The interdisciplinarity revolution. *THEORIA. An International Journal for Theory, History and Foundations of Science*, *34*(2), 237–252. https://doi.org/10.1387/theoria.18864

Porter, A. L., & Rafols, I. (2009). Is science becoming more interdisciplinary? Measuring and mapping six research fields over time. *Scientometrics*, *81*(3), 719–745. https://doi.org/10.1007/s11192-008-2197-2

Quine, W. V. (1951). Main trends in recent philosophy: Two dogmas of empiricism. *The Philosophical Review*, *60*(1), 20–43. https://doi.org/10.2307/2181906

Repko, A. F., & Szostak, R. (2017). *Interdisciplinary research: Process and theory* (3rd ed.). Sage Publications.

Richardson, A. W. (1996). Introduction: Origins of logical empiricism. In R. N. Giere, & A. W. Richardson (Eds.), *Origins of logical empiricism* (Vol. 16, pp. 1–13). University of Minnesota Press.

Sankey, H. (1993). Kuhn's changing concept of incommensurability. *The British Journal for the Philosophy of Science*, *44*(4), 759–774. https://doi.org/10.1093/bjps/44.4.759
Sankey, H. (1997). Incommensurability: The current state of play. *Theoria*, *12*(30), 425–445.
Steinmetz, G. (2004). Odious comparisons: Incommensurability, the case study, and "small N's" in sociology. *Sociological Theory*, *22*(3), 371–400. https://doi.org/10.1111/j.0735-2751.2004.00225.x
Syverson, C. (2011). What determines productivity? *Journal of Economic Literature*, *49*(2), 326–365. https://doi.org/10.1257/jel.49.2.326
Turner, S. (2000). What are disciplines? And how is interdisciplinarity different? In P. Weingart, & N. Stehr (Eds.), *Practising interdisciplinarity* (pp. 46–65). University of Toronto Press.
Wray, K. B. (2012). Assessing the influence of Kuhn's structure of scientific revolutions. *Metascience*, *21*(1), 1–10. https://doi.org/10.1007/s11016-011-9603-8