The Case Study Method in Philosophy of Science: An Empirical Study

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Abstract: There is an ongoing methodological debate in Philosophy of Science concerning the use of case studies as evidence for and/or against theories about science. In this paper, I aim to make a contribution to this debate by taking an empirical approach. I present the results of a systematic survey of the PhilSci-Archive, which suggest that a sizeable proportion of papers in Philosophy of Science contain appeals to case studies, as indicated by the occurrence of the indicator words "case study" and/or "case studies." These results are confirmed by data mined from the JSTOR database on research articles published in leading journals in the field: *Philosophy of Science*, the *British Journal for the Philosophy of Science* (BJPS), and the *Journal for General Philosophy of Science* (JGPS), as well as the *Proceedings of the Biennial Meeting of the Philosophy of Science Association* (PSA). The data also show upward trends in appeals to case studies in articles published in *Philosophy of Science*, the BJPS, and the JGPS. The empirical work I have done for this paper provides philosophers of science who are wary of the use of case studies as evidence for and/or against theories about science with a way to do Philosophy of Science that is informed by data rather than case studies.

Keywords: case study; data science; metaphilosophy; philosophical methodology; scientific philosophy of science

1. Introduction

In the introduction to *The Structure of Scientific Revolutions* (1962), Kuhn (1996, p. 1) famously writes, "History, if viewed as a repository for more than *anecdote* or chronology, could produce a decisive transformation in the image of science by which we are now possessed" (emphasis added). Kuhn is right that to use the history of science merely as a repository for anecdotes

would be problematic. The reason for this is that anecdotes and stories are not reliable evidence for and/or against theories about science.[1] Almost every introductory textbook to logic and reasoning includes a warning about using anecdotes, stories, narratives, examples, and isolated cases as evidence for and/or against general conclusions. These textbooks tell students that such evidence is unreliable. From an anecdote, a story, an example, or an isolated case, no matter how vivid, no secure conclusions can be drawn. Here are a few examples from logic and reasoning textbooks to that effect (emphasis added):

> Another kind of evidence that is considered unreliable is *anecdotal evidence*. Suppose that you have cancer and a friend advises you that eating garlic can cure it. You decide to take this advice, and after eating a clove of garlic every day for a year, the cancer goes into remission. Did the garlic cure the cancer? Evidence of this sort is called *anecdotal*, and science usually rejects it. The trouble with *anecdotal evidence* is that it is too *isolated* to establish any causal connections (Hurley and Watson 2018, p. 648).

> It is a fallacy [...] to allow *a single vivid case* to outweigh strong statistical data. This mistake in reasoning can be called the *fallacy of misleading vividness* (Salmon 2013, p. 151).

> One typical form of *hasty conclusion* occurs when the arguer uses *anecdotal evidence*. Evidence is *anecdotal*, as contrasted with systematic, when it takes the form of

[1] According to the *Oxford English Dictionary*, an anecdote is "a short amusing or interesting story about a real incident or person." Synonyms include "story" and "narrative." Insofar as a case study from the history of science is an interesting story about a real incident or episode from the history of science, it might count as an anecdote, and hence anecdotal evidence, when used as evidence for and/or against theories about science. In philosophy, "anecdote" and "case study" are sometimes used interchangeably (see, e.g., Montero 2016, p. 6). As Pietsch (2016, p. 58) observes, "the problem of differentiating a meaningful case study from an anecdote" requires a general framework for the proper treatment of case studies.

> recounting *an experience*, often in *story* form, of one person or a few people (Johnson and Blair 2006, p. 70).
>
> Mistakes in causal reasoning are often made because of the uncritical acceptance of *anecdotal evidence*, *stories* citing *one or two cases* (Wall 2001, p. 36).
>
> A scientist who appreciates good evidence knows that having *anecdotal evidence* isn't as good as having a wide variety of evidence. [...] If you discount evidence arrived at by systematic search, or by testing, in favor of a few firsthand *stories*, you've committed the *fallacy of overemphasizing anecdotal evidence* (Dowden 1993, p. 366).

This characterization of the mistake in reasoning that occurs when using an anecdote, a story, or an isolated case as evidence for and/or against generalizations is shared by researchers beyond logic and philosophy. One can find it in introductory textbooks of archeology, psychology, and other social sciences as well. For example (emphasis added):

> Anecdotal evidence consists of personal *stories* about specific *incidents* and *experiences*. However, *anecdotal evidence is usually based on the equivalent of a single case study*, which is not an adequate sample, and there are no safeguards to reduce the distortions often found in self-report data. Many *anecdotes* are inaccurate, secondhand report of others' experiences (Weiten 2013, p. 75).
>
> The appeal [to anecdotal evidence] is a mistake because it violates the sufficiency criterion of a good argument (Gibbon 2014, p. 179).

Along the same lines, the *Oxford Dictionary of Public Health* (2017) defines "anecdotal evidence" as follows:

> Evidence derived from medical (or lay) histories, *unsupported by objective data*. Anecdotal evidence can be an important indicator of need for further study. This may be an anecdotal study, such as the medical histories of a series of *cases* of a rare condition, and may in turn suggest further investigation, such as a case control study. Examples include the case history series that preceded the first epidemiological studies of malignant neoplasm of the vagina in young women caused by prenatal exposure to diethylstilbestrol (DES) and of hemangiosarcoma of the liver in workers exposed to vinyl chloride. Anecdotal evidence influences policy making when *politicians play on emotions aroused by publicizing a single case to promote a particular cause*, such as investing in costly diagnostic equipment (emphasis added).

Accordingly, it appears to be a rather common view among researchers across various disciplines that evidence that consists of an anecdote, a story, or an isolated case is not good evidence for and/or against general conclusions. As Pietsch (2016, p. 58) puts it, "Many scientists regard case studies as merely anecdotal, serving at best a heuristic function for suggesting novel concepts and hypotheses."[2] For instance, even if I conduct a careful study of Keith Richards, which results in a detailed, nuanced, informative, sophisticated, and rich analysis of his life, his career, and his smoking habits, no conclusions about musicians and/or smokers in general would follow from it. This is because the following inference is both deductively invalid and inductively weak:

1. Keith Richards is a musician who smokes but does not have cancer.

[2] Of course, not only scientists but philosophers, too, have expressed concerns about the use of case studies as evidence for general conclusions. For example, Bishop and Trout (2002, p. S204) ask, "How much support does a single case study (or even a number of case studies) provide a general principle about the nature of science?" And Chakravartty (2017, p. 29) argues that "case studies [are ineffective] in settling debates about scientific ontology."

2. Therefore, musicians can smoke without getting cancer.

The premise of this argument not only does not entail the conclusion (which is why the argument is deductively invalid) but also does not make the conclusion more probable or likely to be true (which is why the argument is inductively weak) because Keith Richards may simply be an outlier. In fact, this argument is a variation on a textbook example of hasty generalization:

> "*I don't believe smoking causes cancer. My grandfather smoked until his nineties and just died of old age*." (Quoted from Bailin and Battersby 2016, p. 90. Italics in original.)

Any argument of the form "*a* is an *F* and a *G*; therefore, all *F*s are *G*s" or "*a* is an *F* and a *G*; therefore, most *F*s are *G*s" is fallacious. The problem with such arguments is that, no matter how detailed, nuanced, informative, sophisticated, rich, and meticulous the analysis of the case is, it is still an *isolated case*, which means that the conclusion is based on an inadequate sample size; in other words, "the generalization is too strong to be supported by the evidence offered" (Bailin and Battersby 2016, p. 90).

Similarly, no matter how detailed, nuanced, informative, sophisticated, rich, and meticulous my analysis of the so-called "Copernican Revolution" may be (see, e.g., Kuhn 1985), no general conclusions, of the form "All *F*s are *G*s," "Most *F*s are *G*s," or "*X*% of *F*s are *G*s," about revolutions in science would follow (either deductively or inductively) from it (Park 2018, pp. 61-64). As Pitt (2001, p. 373) puts it, "if one starts with a case study, it is not clear where to go from there--for it is unreasonable to generalize from one case or even two or three."[3]

In this paper, I set out to find out whether, and to what extent, philosophers of science use case studies as evidence for and/or against their theories about science in their research. According to Bishop and Trout (2002, p. S204), "Contemporary philosophers and historians of

[3] Farbach (2011), Park (2011), and Mizrahi (2013a) have made this criticism against the inductive version of the pessimistic induction, i.e., that it is an inductive generalization from an insufficiently large and diverse sample.

science who propose general hypotheses about how science works typically rely on case studies." Likewise, Bolinska and Martin (2019) observe that "philosophers [seek] historical support for their theories [about science]" through the use of case studies. For example, many philosophers have studied the case of Eddington's "measurements of starlight bending in response to the sun's gravitational field," which "validated predictions of Albert Einstein's general theory of relativity" and have deemed it "a clear case from which to draw more general conclusions about the scientific process" (Bolinska and Martin 2019). But what can an isolated anecdote, story, example, or case tell us about the scientific process in general? If logic and reasoning textbooks are right, not much. As Salmon (2013, p. 151) puts it, to draw general conclusions from "a single vivid case" is a mistake in reasoning, a "fallacy of misleading vividness."[4]

Throughout this paper, I will be concerned with the use of case studies as *evidence* for and/or against theories about science in Philosophy of Science.[5] One might think that case studies should not be used as evidence for and/or against theories about science, but that they still serve a purpose in Philosophy of Science, e.g., they can be used "primarily to generate, rather than to confirm, hypotheses" (McAllister 2018, p. 252). Here I am not concerned with

[4] Steel et al. (2017, p. 22) refer to this methodological concern with the method of case studies as the problem of "small samples," i.e., "a small number of cases are not a sufficient basis for generalization about science." They also identify the problem of "potential for bias," i.e., "Cases are often generated in a manner that does not adequately guard against biases in selection, emphasis, and interpretation."

[5] In other words, I am concerned with what Bolinska and Martin (2019) call "problems of method." They argue that methodological objections to the use of case studies as evidence in Philosophy of Science "do not identify special challenges that do not also apply to other epistemic practices." This is correct, of course, insofar as, no matter the epistemic domain, inferences of the form "*a* is an *F* and a *G*; therefore, all *F*s are *G*s" and "*a* is an *F* and a *G*; therefore, most *F*s are *G*s" are fallacious (with the exception, perhaps, of what Godfrey-Smith 2011 calls inductive inferences "based on causal structures and kinds"; see Mizrahi 2013a for discussion of such inductive inferences in Philosophy of Science, specifically, in the context of the scientific realism/anti-realism debate). Nevertheless, Bolinska and Martin (2019) think that "attention to the *ways* in which history is messy and in which philosophy is difficult can be resources for developing better historiographical and philosophical practices" (emphasis in original).

other uses of cases studies (e.g., pedagogical) except as evidence for and/or against theories about science in Philosophy of Science.[6]

Of course, to simply pick out a few research articles in Philosophy of Science and then check whether they make use of case studies as evidence for and/or against theories about science would be to make the mistake "of overemphasizing anecdotal evidence" (Dowden 1993, p. 366) or "misleading vividness" (Salmon 2013, p. 151). So instead, I rely on the data mining, corpus analysis, and data visualization methods of data science. I conduct a systematic survey of research in Philosophy of Science in order to find out whether, and to what extent, philosophers of science appeal to case studies in their scholarly work. My data, which are systematically mined from databases of research articles in Philosophy of Science, such as the PhilSci-Archive and JSTOR, suggest that philosophers of science do rely on case studies as evidence for and/or against their theories about science quite frequently. That is, scholarly work in Philosophy of Science regularly features appeals to case studies.

Before I present the empirical evidence that supports this claim (Section 3), I will explain the methods I have used in my empirical study of appeals to case studies in the Philosophy of Science (Section 2). Finally, I will discuss how work in the Philosophy of Science can benefit from the methods of data science, the very methods I use in this paper (Section 4).[7]

2. Methods

[6] For more on the non-justificatory roles that case studies might play in Philosophy of Science, see Morgan (2012) and Currie (2015).

[7] For more on the problems with using case studies as evidence for and/or against theories about science in Philosophy of Science, see Pitt (2001). Cf. Burian (2001). See also the essays collected in Sauer and Scholl (2016) and Bolinska and Martin (2019).

According to Knuuttila and Loettgers (2016, p. 151), "Philosophers of science make frequent use of case studies, and the use of case studies has become even more prevalent in recent years with the more marked practice-orientation of even mainstream philosophy of science." In order to find out whether philosophers of science appeal to case studies frequently, we need to conduct a systematic survey of research in Philosophy of Science. If philosophers of science use the words "case study" and/or "case studies" in their published work, then that would be a pretty good indication that they do make appeals to case studies. Accordingly, the words "case study" and/or "case studies" can be used as pretty good (though not perfect) indicator words for appeals to case studies in Philosophy of Science research in much the same way that words such as "therefore" and "consequently" are used as indicator words for arguments in logic textbooks.[8] This search methodology will pick out usage of the words "case study" and/or "case studies" in Philosophy of Science papers, and thereby indicate the presence of appeals to case studies.

We can use this search methodology, then, to find out whether, and to what extent, case studies are used as evidence for and/or against theories about science in Philosophy of Science. If we find that the words "case study" and/or "case studies" are frequently used in Philosophy of Science papers, then that would suggest that appeals to case studies are frequent in Philosophy of Science. On the other hand, if we find that the words "case study" and/or "case studies" are rarely used in Philosophy of Science papers, then that would suggest that appeals to case studies are rare in Philosophy of Science.[9]

Of course, as with any empirical methodology, there may be some false positives; in this case, instances of "case study" and/or "case studies" picked up by the search methodology where a case study is *not* used as evidence for and/or against theories about science. As mentioned

[8] See Ashton and Mizrahi (2018a) for a discussion of this methodology.
[9] For another application of this sort of methodology, see Ashton and Mizrahi (2018b).

above, the words "case study" and/or "case studies" are pretty good (albeit not perfect) indicators for appeals to case studies in Philosophy of Science research. In that sense, they are no different from argument indicator words like "therefore," "because," and the like. That is, just as the presence or absence of indicator words does not guarantee the presence or absence of arguments, the presence or absence of the words "case study" and/or "case studies" does not guarantee the presence or absence of appeals to case studies. Nevertheless, just as indicator words are pretty good indicators of the presence or absence of arguments, which is why logic textbooks instruct students to look for them, the words "case study" and/or "case studies" are pretty good indicators of the presence or absence of appeals to case studies. This is because research articles in Philosophy of Science, as philosophical work in general, contain arguments, and arguments are attempts to support conclusions on the basis of evidence. Accordingly, when philosophers of science use case studies, they are more likely than not to use them as evidence in their arguments. Now, the sort of conclusions philosophers of science tend to argue for, especially in General Philosophy of Science, are general conclusions about science, such as scientific realism, anti-realism, structural realism, instrumentalism, explanationism, falsificationism, constructive empiricism, etc.[10]

In other words, like all philosophers, philosophers of science make arguments in their published work. Since philosophy of science is *about* science, *by definition*, it means that philosophers of science tend to argue for meta-scientific conclusions. Such meta-scientific conclusions are general in nature insofar as they are supposed to apply to science as a whole. Therefore, when case studies are used in Philosophy of Science publications, they are probably

[10] Indeed, even beyond philosophy, we can be pretty confident that case studies are used to support generalizations, given that *by definition*, a case study is "a detailed account giving information about the development of a person, group, or thing, *especially in order to show general principles*" (*Cambridge Advanced Learner's Dictionary*).

used as evidence for meta-scientific conclusions that are supposed to apply to science as a whole (e.g., falsificationism, instrumentalism, etc.). As Bishop and Trout (2002, p. S204) put it, "Contemporary philosophers and historians of science who propose *general hypotheses about how science works* typically rely on case studies" (emphasis added).

For these reasons, although there are likely to be a few false positives, we can still be quite confident that the results will be representative of work in Philosophy of Science. For example, if the search methodology picks out instances of "case study" and/or "case studies" that refer to James B. Conant's use of case studies in his General Education course "Understanding Science" at Harvard University, we can still be pretty confident that these case studies will probably serve as evidence for and/or against a general conclusion about science. Indeed, as Daston (2016, p. 131) recounts, "His *case study* on the demise of the phlogiston theory in James Bryant Conant, ed., *Harvard Case Studies in the History of the Experimental Sciences* (Cambridge, MA: Harvard University Press, 1950) provided Kuhn with some of his most powerful *examples*" (emphasis added). Again, an example (or an isolated case), no matter how powerful or vivid, is not adequate evidence for a general theory about science, as Kuhn's theory of scientific change purports to be (Park 2018, pp. 61-64).[11]

Furthermore, false positives are likely to be publications in which philosophers of science discuss the method of case studies itself. In fact, the present paper is such a paper. Since there are only a handful of publications in Philosophy of Science that discuss the method of case studies

[11] According to the *Oxford English Dictionary*, a case study is "a particular instance of something used or analyzed in order to illustrate a thesis or principle." Since theses in Philosophy of Science tend to be general meta-scientific claims (e.g., structural realism, explanationism, etc.), we can be pretty confident that philosophers of science use case studies in an attempt to support such general, meta-scientific claims in their published work. As discussed in Section 1, those who are concerned with appeals to case studies in Philosophy of Science point out that one of the problems with this method is that a particular instance does not provide adequate support for a general meta-scientific thesis, which is the sort of theses philosophers of science typically argue for and/or against in their published works. See, e.g., Pitt (2001) and Faust and Meehl (2002).

itself, almost all of which are cited here, we can be pretty confident that false positives will be the rare exception rather than the rule.[12]

3. Results

3a. PhilSci-Archive

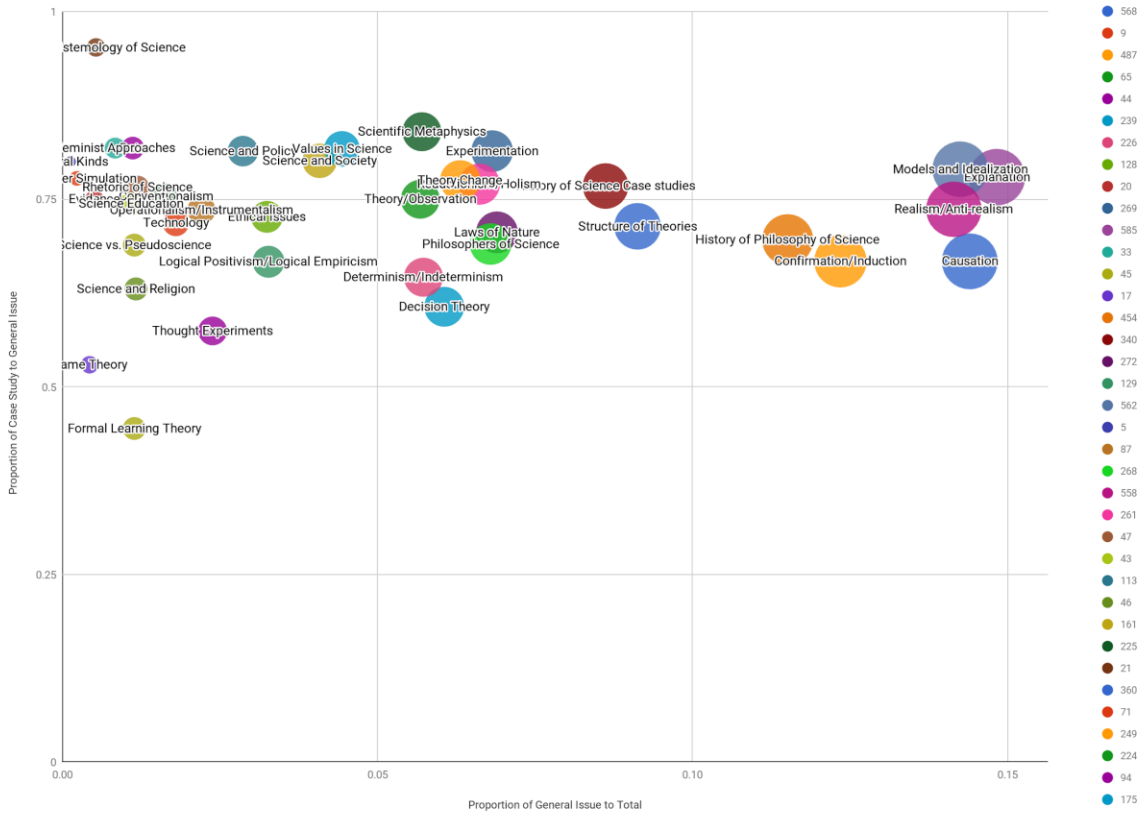
The PhilSci-Archive is "an electronic archive specifically tailored to and run by philosophers of science" (philsci-archive.pitt.edu/). The PhilSci-Archive's Board "is comprised of philosophers of science with recognized standing in the profession," which include members of the Governing Board of the Philosophy of Science Association, editors of the journal Philosophy of Science, and directors of the center for Philosophy of Science at the University of Pittsburgh (philsci-archive.pitt.edu/information.html). All of this suggests that the PhilSci-Archive is a suitable database for systematically surveying research in Philosophy of Science. Since the "PhilSci-Archive invites submissions in all areas of philosophy of science, including general philosophy of science, philosophy of particular sciences (physics, biology, chemistry, psychology, etc.), feminist philosophy of science, socially relevant philosophy of science, history and philosophy of science and history of the philosophy of science" (philsci-archive.pitt.edu), it is reasonable to regard it as a representative database of research in Philosophy of Science as a whole. However, some might worry that the PhilSci-Archive might not be representative of all the work that is being done in Philosophy of Science. For this reason, I have also mined data from Philosophy of Science journals through the JSTOR database (see Section 3b).

[12] To the best of my knowledge, recent papers that discuss the method of case studies in the Philosophy of Science include the following: Bishop and Trout (2002), Bolinska and Martin (2019), Burian (2001), Chang (2012), Currie (2015), Faust and Meehl (2002), Kinzel (2015), McAllister (2018), Morgan (2012), Pinnick and Gale (2000), Pitt (2001), Steel et al. (2017), and the papers collected in Sauer and Scholl (2016).

The PhilSci-Archive distinguishes between two Subject Areas broadly: General Issues in Philosophy of Science, such as Causation and Explanation, and Specific Sciences, such as Anthropology and Physics. Of all the papers currently (October 7, 2019) available in the "General Issues" subject area on the PhilSci-Archive (3,944 papers), 2,778 (70%) contain the indicator words "case study" and/or "case studies." There is also a "History of Science Case Studies" issue in the "General Issues" subject area on the PhilSci-Archive, which is itself a reason to think that appeals to case studies are rather widespread in Philosophy of Science. The "History of Science Case Studies" general issue contains more papers (340) than the other 38 issues in the "General Issues" subject area, with the exception of the following general issues: "Causation" (568), "Confirmation/Induction" (487), "Explanation" (585), "History of Philosophy of Science" (454), "Models and Idealization" (562), "Realism/Anti-realism" (558), and "Structure of Theories" (360). See Figure 1.[13]

Figure 1. General issues in proportion to the total number of papers in the "General Issues" subject area on the PhilSci-Archive and the proportion of those papers that contain the indicator words "case study" and/or "case studies" in each general issue

[13] The size of each circle in Figure 1 represents the number of papers in a general issue. The bigger the circle, the more papers in the general issue. The number of papers in each general issue is also listed on the right side of Figure 1.



As we can see from Figure 1, in almost all the general issues in the PhilSci-Archive from "Causation" to "Values in Science," there is a sizeable proportion of papers that feature appeals to case studies, as indicated by the occurrence of the indicator words "case study" and/or "case studies" in those papers (see Table 1). The general issue "Social Epistemology of Science" contains the highest proportion of papers that appeal to case studies (0.95), followed by "Scientific Metaphysics" (0.84), whereas the general issue "Formal Learning Theory" contains the lowest proportion of papers that appeal to case studies (0.44), followed by "Game Theory" (0.52).

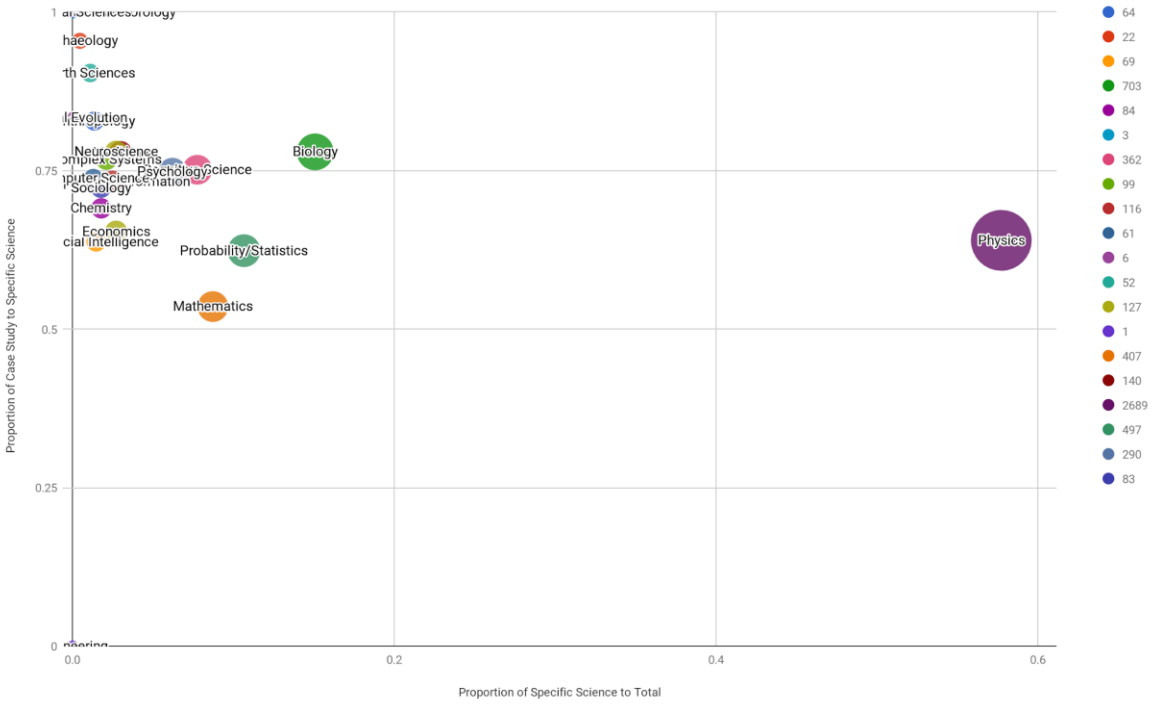
Table 1. Mean proportions of papers that contain the indicator words "case study" and/or "case studies" in the "General Issues" and the "Specific Sciences" subject areas on the PhilSci-Archive

	Mean	Median	SD	N
"Case Study" in "General Issues" papers on the PhilSci-Archive	0.73	0.74	0.09	38
"Case Study" in "Specific Sciences" papers on the PhilSci-Archive	0.73	0.74	0.04	22

Of all the papers currently (October 7, 2019) available in the "Specific Sciences" subject area on the PhilSci-Archive (4,659 papers), 3,095 (66%) contain the indicator words "case study" and/or "case studies." As we can see from Figure 2, in almost all the specific sciences in the PhilSci-Archive from "Anthropology" to "Sociology," there is a sizeable proportion of papers that feature appeals to case studies, as indicated by the occurrence of the indicator words "case study" and/or "case studies" in those papers (see Table 1). The specific sciences "Climate Science" and "Historical Sciences" contain the highest proportion of papers that appeal to case studies (1), followed by "Archeology" (0.95), whereas the specific science "Mathematics" contains the lowest proportion of papers that appeal to case studies (0.53), followed by "Probability/Statistics" (0.62). See Figure 2.[14]

Figure 2. Specific sciences in proportion to the total number of papers in the "Specific Sciences" subject area on the PhilSci-Archive and the proportion of those papers that contain the indicator words "case study" and/or "case studies" in each specific science

[14] The size of each circle in Figure 2 represents the number of papers in a specific science. The bigger the circle, the more papers in that specific science. The number of papers in each specific science is also listed on the right side of Figure 2.



3b. JSTOR

There is another way to gather data on the use of case studies as evidence for and/or against theories about science in Philosophy of Science. To double check the results from my systematic survey of the PhilSci-Archive, I have also looked at research articles published in leading journals in the field (Wray 2010): *Philosophy of Science*, the *British Journal for the Philosophy of Science* (BJPS), and the *Journal for General Philosophy of Science* (JGPS), as well as the *Proceedings of the Biennial Meeting of the Philosophy of Science Association* (PSA). According to Wray (2010, p. 429), "Much of the core research in philosophy of science has been published in five key journals that are either concerned exclusively with philosophy of science or give extensive coverage to topics in the philosophy of science: *Philosophy of Science*, *British Journal for the Philosophy of Science*, *Synthese*, *Erkenntnis*, and *Studies in History and Philosophy of Science*." Since my empirical study includes data from *Philosophy of Science* and the *British*

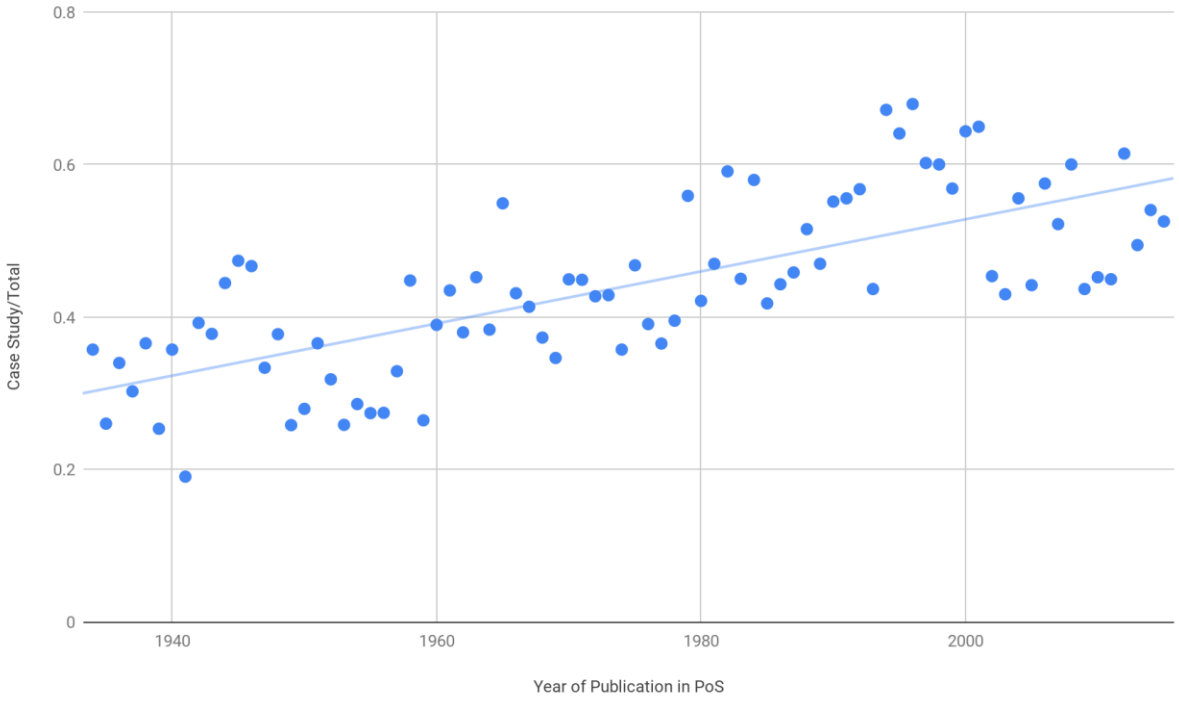
Journal for the Philosophy of Science, which are both concerned exclusively with Philosophy of Science and publish the core research in the field, we can be pretty confident that my data is representative of the field.

I have used JSTOR Data for Research (jstor.org/dfr/) in order to mine data from the aforementioned journals.

> Data for Research (DfR) provides datasets of content on JSTOR for use in research and teaching. Researchers may use DfR to define and submit their desired dataset to be automatically processed. Data available through the service includes metadata, n-grams, and word counts for most articles and book chapters, and for all research reports and pamphlets on JSTOR. Datasets are produced at no cost to researchers and may include data for up to 25,000 documents (JSTOR Data for Research 2017).

The first journal I have looked at is *Philosophy of Science*. I have searched for research articles that contain the indicator words "case study" and/or "case studies" relative to the total number of research articles published in *Philosophy of Science* between the years 1934 and 2015. Applying my search methodology and the technique of text mining, I have gathered data on appeals to case studies in *Philosophy of Science* research articles, which are summarized in Figure 3.

Figure 3. Proportion of "case study" research articles published in the journal *Philosophy of Science* between the years 1934 and 2015 (Source: JSTOR Data for Research)



The trend-line in Figure 3 suggests consistent use of case studies as evidence for and/or against theories about science, as indicated by the presence of the indicator words "case study" and/or "case studies" in research articles published in the journal *Philosophy of Science* between the years 1934 and 2015. The mean proportion of research articles that contain appeals to case studies published in the journal *Philosophy of Science* between the years 1934 and 2015 is 0.44 and the median is 0.43 (see Table 2).

Table 2. Descriptive statistics of "case study" research articles by journal (Source: JSTOR Data for Research)

	Mean	***Median***	***SD***	***N***
Philosophy of Science	0.44	0.43	0.11	82

BJPS	0.40	0.39	0.14	64
JGPS	0.48	0.48	0.14	26
PSA	0.70	0.69	0.06	13

Moreover, a regression analysis indicates that the upward trend-line in Figure 3 is statistically significant. A statistically significant equation was found ($F(1, 80) = 89.69$, $p < 0.00$), with an R^2 of 0.52. This result suggests that we should expect more appeals to case studies in research articles published in *Philosophy of Science* in the future. In other words, as far as research articles published in *Philosophy of Science* are concerned, the reliance on case studies as evidence for and/or against meta-scientific theories becomes significantly more widespread over the years.

In order to contextualize these statistical results, and make sure that the search methodology described in Section 2 picks out genuine instances of appeals to case studies, I have selected at random three instances of appeals to case studies from the *Philosophy of Science* dataset (emphasis added):

1. "In highly developed fields of science, there is often an intricate relationship between the hypothesis under investigation and the auxiliary theories. Consider the recent discovery of the top quark. This fundamental particle is suggested by the Standard Model of particle physics. But certain elements of this model also come in in the methods that were used to analyze the data collected by the instruments. These interrelationships are extremely complex and our model in strategy 3 is highly idealized. A *case study* in which a

Bayesian Network is constructed that models the scientific process *would lend support to* our analysis" (Bovens and Hartmann 2002, p. 66).

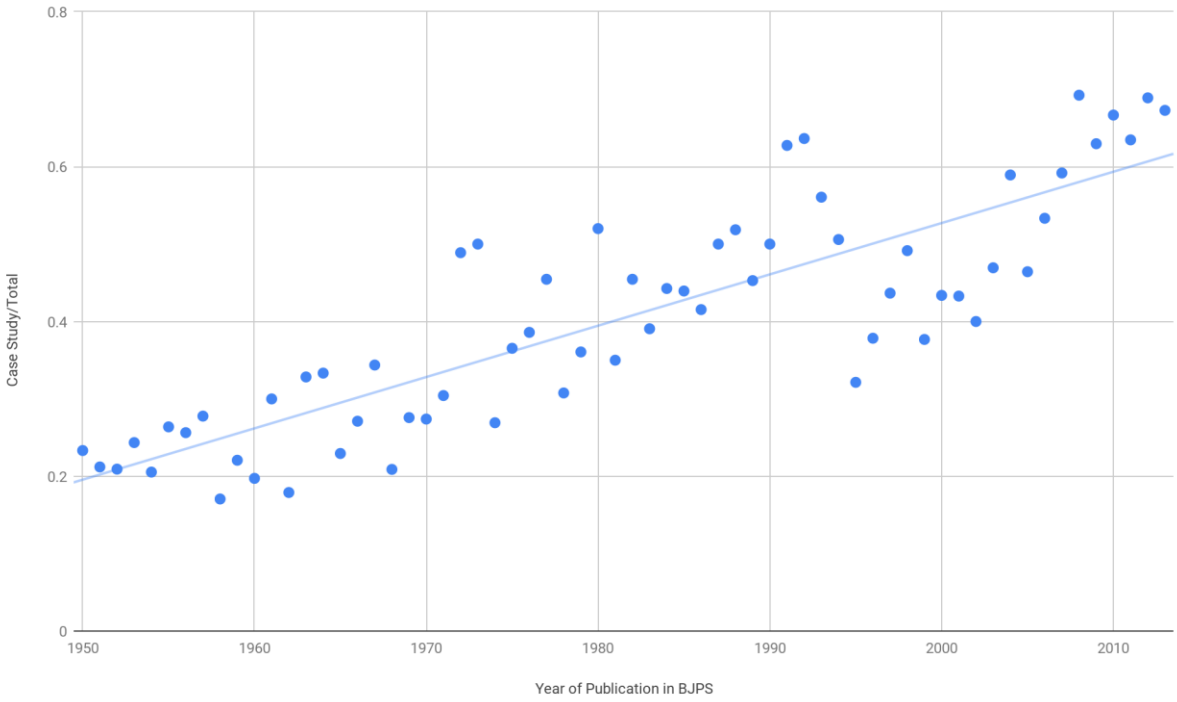
2. "this *case study* [namely, investigative systems biology] should have *broader relevance* for a philosophical understanding of simulation model-building practices *across a range of* modern simulation-driven scientific contexts" (MacLeod and Nersessian 2013, p. 537).
3. "The *case study* presented in this paper [namely, industry research on the giant magnetoresistance effect in the 1990s] *shows that* epistemic merits can also prosper in less sensational cases of industrial research" (Wilholt 2006, pp. 85-86).

In each of these instances, a case study is being used as evidence for and/or against meta-scientific theses. In the first example (1), the authors appeal to a case study as support (i.e., evidence) for a general theory about science (namely, some version of Bayesian confirmation theory). The same can be said about the second example (2). In (2), the authors use the case of investigative systems biology as a basis for drawing broader conclusions about scientific simulations. Finally, the third example (3) also features a case study being used as evidence for the general claim that private, application-driven scientific research has epistemic merit.

The next journal I have looked at is the BJPS. I have searched for research articles that contain the indicator words "case study" and/or "case studies" relative to the total number of research articles published in the BJPS between the years 1950 and 2013. Applying my search methodology and the technique of text mining, I have gathered data on the use of case studies as evidence for and/or against theories about science in BJPS research articles, which are summarized in Figure 4. Consistent with the aforementioned data from *Philosophy of Science*, research articles that contain the indicator words "case study" and/or "case studies" do make up a sizeable proportion of research articles published in the BJPS. The mean proportion of research

articles that contain appeals to case studies published in the BJPS between the years 1950 and 2013 is 0.40 and the median is 0.39 (see Table 2).

Figure 4. Proportion of "case study" research articles published in the BJPS between the years 1950 and 2013 (Source: JSTOR Data for Research)



Moreover, a regression analysis indicates that the upward trend-line in Figure 4 is statistically significant. A statistically significant equation was found ($F(1, 62) = 161.06$, $p < 0.00$), with an R^2 of 0.72. This result suggests that we should expect more appeals to case studies in BJPS research articles in the future. In other words, as far as research articles published in the BJPS are concerned, the reliance on case studies as evidence for and/or against meta-scientific theories becomes significantly more widespread over the years.

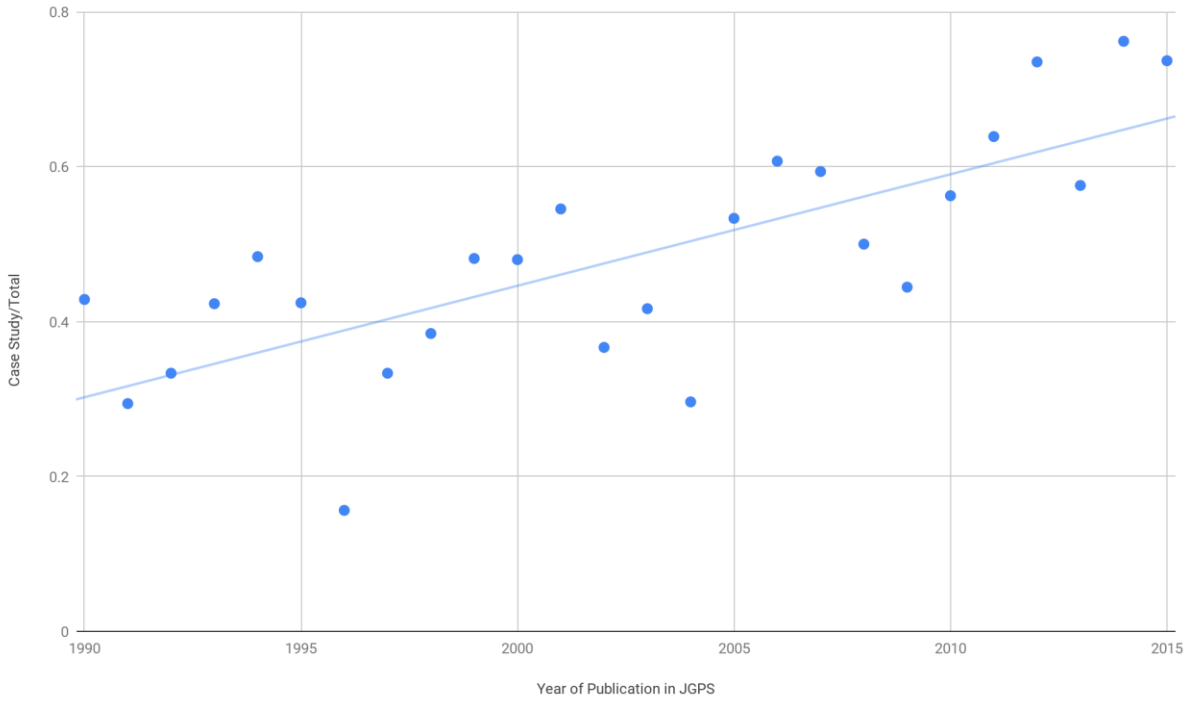
In order to contextualize these statistical results, and make sure that the search methodology described in Section 2 picks out genuine instances of appeals to case studies, I have selected at random three instances of appeals to case studies from the BJPS dataset (emphasis added):

1. "The *case study* that follows *forces the Naive Optimist to abandon her realism*--unless she is willing to be less naive, of course. We will *argue that attending to the details of this case* should lead the realist to qualify the connection between success and truth" (Saatsi and Vickers 2002, p. 34).
2. "My aim in this article was *to demonstrate that* the notion of structural representation is a central theoretical notion in the current computational approaches in cognitive neuroscience. The *argument rests on one case-study*, that of some computational work on the oculomotor integrator" (Shagrir 2012, p. 541).
3. "The modified models are often, although not necessarily, presented by different economists than the one(s) who proposed the original model (as shown below, this holds for our *case study*). In this sense, then, our *claim* is that theoretical model building in economics is to be understood as *collective derivational robustness analysis*" (Kuorikoski 2010, p. 549).

In each of these instances, a case study is being used as evidence for and/or against meta-scientific theses. In the first example (1), the authors appeal to a case study as evidence against a general theory about science (namely, some version of scientific realism). The same can be said about the second example (2). In (2), the author explicitly says that his argument rests on a case study. Finally, the third example (3) is also an example of a case study being used as evidence for a general claim about economics.

I have also looked at data from the JGPS. I have searched for research articles that contain the indicator words “case study” and/or “case studies” relative to the total number of research articles published in the JGPS between the years 1990 and 2015. Applying my search methodology and the technique of text mining, I have gathered data on the use of case studies as evidence for and/or against theories about science in JGPS research articles, which are summarized in Figure 5. Like the data from *Philosophy of Science* and the BJPS, the data from the JGPS also show that the use of case studies as evidence for and/or against theories about science is on the rise, as evidenced by the upward trend in Figure 5. The mean proportion of research articles that contain appeals to case studies published in the JGPS between the years 1990 and 2015 is 0.48 and the median is 0.48 as well (see Table 2).

Figure 5. Proportion of “case study” research articles published in the JGPS between the years 1990 and 2015 (Source: JSTOR Data for Research)



Moreover, a regression analysis indicates that the upward trend-line in Figure 5 is statistically significant. A statistically significant equation was found ($F(1, 24) = 30.61$, $p < 0.00$), with an R^2 of 0.56. This result suggests that we should expect more appeals to case studies in JGPS research articles in the future. In other words, as far as research articles published in the JGPS are concerned, the reliance on case studies as evidence for and/or against meta-scientific theories becomes significantly more widespread over the years.

In order to contextualize these statistical results, and make sure that the search methodology described in Section 2 picks out genuine instances of appeals to case studies, I have selected at random three instances of appeals to case studies from the JGPS dataset (emphasis added):

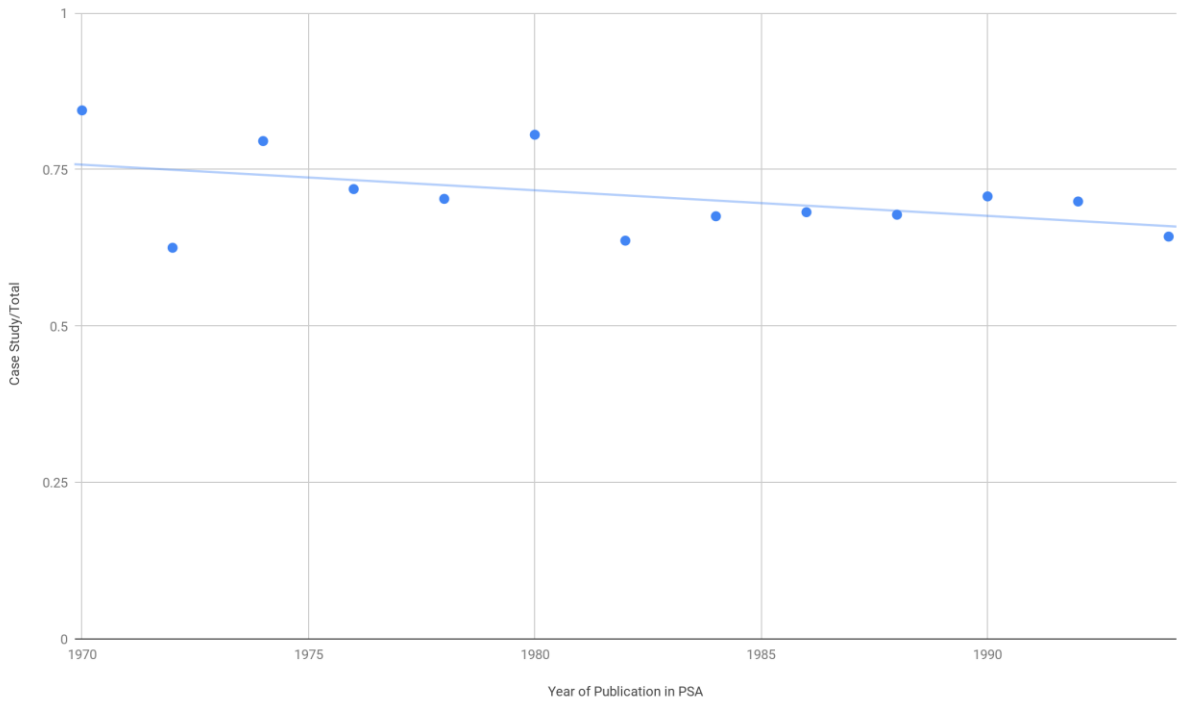
1. "Both aspects--the removal of a greater number of anomalies by a limited amount of assumptions and the explanation of phenomena previously regarded as anomalies by a theory not designed for this specific task--are hardly discussed at all in the relevant literature. The *case study*, however, *shows that* they might be very helpful for investigating the relation between anomalies, coherence, and truth" (Gähde 2012, p. 358).
2. "I seek to suggest some modifications or extensions to their [namely, de Regt and Dieks (2005)] original proposal on the basis of an important *historical case-study*: understanding in Newton's theory of universal gravitation. [...] I shall take stock of *the implications of the historical case-study* at hand for de Regt and Dieks' proposal by focusing on Christiaan Huygens' reception of the theory of universal gravitation" (Ducheyne 2009, p. 229).

3. “we believe that theories T_1 to T_4 do indeed represent good examples for a *case study* of theory underdetermination--at least in the sense of what in the final section 4 we propose to call *practical underdetermination*” (Lyre and Eynck 2003, p. 290).

In each of these instances, a case study is being used as evidence for and/or against meta-scientific theses. In the first example (1), the author appeals to a case study as evidence for (i.e., to show that) a meta-scientific thesis (namely, a general theory about theory change in science). The same can be said about the second example (2). In (2), the author uses a case study to draw broader implications vis-à-vis philosophical accounts of scientific understanding. Finally, the third example (3) is also an example of a case study being used as evidence for a general meta-scientific concept the authors call “practical underdetermination.”

Lastly, I have also looked at data from the Proceedings of the Biennial Meeting of the Philosophy of Science Association (PSA). I have searched for papers that contain the indicator words “case study” and/or “case studies” relative to the total number of papers published in the PSA between the years 1970 and 1994. Applying my search methodology and the technique of text mining, I have gathered data on the use of case studies as evidence for and/or against theories about science in PSA papers, which are summarized in Figure 6. Like the data from the journals *Philosophy of Science*, the BJPS, and the JGPS, data from the PSA also suggest that papers that contain the indicator words “case study” and/or “case studies” make up a sizeable proportion of PSA papers (see Table 2), as we can see in Figure 6.

Figure 6. Proportion of “case study” research articles published in the PSA between the years 1970 and 1994 (Source: JSTOR Data for Research)



Although research articles that feature appeals to case studies make up a sizeable proportion of PSA research articles--indeed, more so than in *Philosophy of Science*, the BJPS, and the JGPS (see Table 2)--a regression analysis did not find a statistically significant equation: ($F(1, 11) = 3.13$, $p < 0.1$), with an R^2 of 0.22. This result suggests that we should expect neither more nor less appeals to case studies in future PSA research articles. In that respect, it is important to note that PSA papers are now published in supplementary issues of *Philosophy of Science*, which is why the PSA dataset mined from the JSTOR database only contains papers from 1970 to 1994. As we have seen, as far as research articles published in *Philosophy of Science* are concerned, the reliance on case studies as evidence for and/or against meta-scientific theories does become significantly more widespread over the years.

In order to contextualize these statistical results, and make sure that the search methodology described in Section 2 picks out genuine instances of appeals to case studies, I have

selected at random three instances of appeals to case studies from the PSA dataset (emphasis added):

1. "While Ludwik Fleck's *Genesis and Development of a Scientific Fact* is mainly concerned with social elements in science, a central argument depends on his *case study* of the development of a serum test for syphilis, the Wasserman Reaction, which Fleck argues was the product of skill and of laboratory practice, not a simple discovery" (Stump 1988, p. 302).
2. "The Ox-Phos Controversy in bioenergetics serves as an integral *case study*" (Allchin 1992, p. 74).
3. "Using a research program in neuroendocrinology investigating a hormonal basis for sex-differentiated lateralization as a *case study*, the authors disagree concerning whether the first two criteria can be construed as criteria for good science" (Nelson and Nelson 1994, p. 120).

In each of these instances, a case study is being used as evidence for and/or against meta-scientific theses. In the first example (1), the author discusses Fleck's argument for the social elements that play a role in science from the historical case study having to do with the development of a serum test for syphilis. In (2), the author uses a case study, namely, the Ox-Phos Controversy in bioenergetics, to draw a distinction between two kinds of scientific experiments: what he calls "demonstrations" and "crucial tests." In (3), the authors use a case study to argue against Longino's account of "ontological heterogeneity" and "complexity of relationship" as criteria for good science.

To sum up, a systematic survey of the PhilSci-Archive reveals that a sizeable proportion of papers in Philosophy of Science feature appeals to case studies (Table 1), as indicated by the

occurrence of the indicator words "case study" and/or "case studies" (Figures 1 and 2). These results are confirmed by data mined from the JSTOR database on research articles published in leading journals in the field: *Philosophy of Science* (Figure 3), the BJPS (Figure 4), and the JGPS (Figure 5), as well as the PSA (Figure 6). Sizeable proportions of research articles published in each of these journals contain appeals to case studies, as indicated by the occurrence of the indicator words "case study" and/or "case studies" (Table 2). Moreover, the data show upward trends in appeals to case studies in research articles published in *Philosophy of Science*, the BJPS, and the JGPS. These statistically significant trends give us reasons to believe that the reliance on case studies as evidence for and/or against theories about science becomes significantly more widespread over the years.

4. Discussion

As discussed in Section 1, there are several problems with using case studies as evidence for and/or against theories about science in Philosophy of Science. In this paper, I have focused on methodological problems with appeals to case studies. As Bolinska and Martin (2019) point out, there are additional problems with appeals to case studies: what they call "problems of metaphysics" in addition to "problems of method."[15] Given these problems, it should be a cause for some concern to find out that a significant amount of work in Philosophy of Science engages in appeals to case studies. That is, to find out based on data systematically mined from the PhilSci-Archive and the JSTOR database, that a sizeable proportion of papers in the field feature appeals to case studies, and that reliance on appeals to case studies constitutes a significant trend

[15] See also Steel et al. (2017, p. 23) on "small samples, selection bias, emphasis bias, and interpretation bias," which are concerns that "create challenges for generalization from case studies."

in the leading journals in the field, should lead philosophers of science to seriously rethink their methods.

Surprisingly, the results of my empirical study provide no sign of a so-called "historical turn" in Philosophy of Science following the publication of Kuhn's *The Structure of Scientific Revolutions* in 1962. As mentioned in Section 1, Kuhn is widely credited for having initiated a so-called "historical turn" in Philosophy of Science. As Wray (2011, p. 87) puts it, "Kuhn was part of the vanguard that ushered in the historical turn in philosophy of science which looked to the history of science as a source of data for developing a philosophy of science" (emphasis added). However, the data I have systematically mined from the PhilSci-Archive and the JSTOR database do not bear this out. Instead, the results of my empirical study suggest that there has been a steady increase in appeals to case studies from the history of science since the 1940s (Figure 3) and 1950s (Figure 4), decades before the publication of Kuhn's *The Structure of Scientific Revolutions* (1962).

For those philosophers of science who are concerned about the use of case studies as evidence in Philosophy of Science, I would like to propose that there is a way to do Philosophy of Science without appealing to case studies.[16] That way is data science. Instead of appealing to case studies, philosophers of science who are concerned about the use of case studies as evidence for and/or against meta-scientific theses can harness the tools of data science to study the history of science in systematic and data-driven ways. As I have done in this paper, by applying the text mining, corpus analysis, and data visualization techniques of data science, philosophers of

[16] Full disclosure: I have used case studies as evidence for and/or against meta-scientific theses in my own work as well (Mizrahi 2013b). Since then, however, I have seen the error of my ways and I have changed my ways (for the better, one would hope).

science can mine data from databases of historical, philosophical, and scientific works, thus painting a picture of science and its history using big data instead of isolated case studies.

Of course, data science itself can be, and has been recently, an object of investigation for philosophers of science. According to Leonelli (2016, p. 1):

> Over the last three decades, online databases, digital visualization, and automated data analysis have become key tools to cope with the increasing scale and diversity of scientifically relevant information. [...] Some scientists and commentators have characterized this situation as a novel "data-driven" paradigm for research, within which knowledge can be extracted from data without reliance on preconceived hypotheses.

Leonelli (2016, p. 1) argues that "We are not witnessing the birth of a data-driven method but rather the rise of a data-centric approach to science." Be that as it may, there is no reason why the advent of data-driven or data-centric science cannot be studied by philosophers of science while the tools of data science are used by philosophers of science (who are so inclined) to study other aspects of science (or philosophy of science, as I have done in this paper). In fact, recently, a few philosophers of science have started to use the tools of data science with surprising results. For instance, by using text mining and corpus analysis techniques, Mizrahi (2016) finds some empirical evidence against the so-called "graveyard picture of the history of science," according to which the history of science is a graveyard of dead theories and abandoned theoretical posits. This "graveyard picture" is generally accepted by philosophers of science despite the fact that it is based merely on isolated cases studies of theories (e.g., the caloric theory of heat) and theoretical posits (e.g., phlogiston) that were discarded. In addition to the research conducted for the present paper, Mizrahi (2016) is another example of how using the tools of data science in Philosophy of Science can lead to interesting and illuminating results; in other words, how

"knowledge can be extracted from data without reliance on preconceived hypotheses" (Leonelli 2016, p. 1), such as the "graveyard" hypothesis.[17]

5. Conclusion

The aim of this paper has been to make a contribution to the ongoing methodological debate in Philosophy of Science concerning the use of case studies as evidence for and/or against theories about science by taking an empirical approach. I have presented the results of a systematic survey of the PhilSci-Archive. These results suggest that a sizeable proportion of papers in Philosophy of Science feature appeals to case studies, as indicated by the occurrence of the indicator words "case study" and/or "case studies." These results are confirmed by data systematically mined from the JSTOR database on research articles published in leading journals in the field: *Philosophy of Science*, the BJPS, and the JGPS, as well as the PSA. Sizeable proportions of research articles published in each of these journals contain appeals to case studies, as indicated by the occurrence of the indicator words "case study" and/or "case studies." Moreover, the data show upward trends in appeals to case studies in articles published in *Philosophy of Science*, the BJPS, and the JGPS. These statistically significant trends suggest that the reliance on case studies as evidence for and/or against theories about science becomes significantly more widespread over the years.

The way in which I have conducted my empirical study for this paper provides a methodological remedy for those who are concerned about the use of case studies as evidence for and/or against theories about science in Philosophy of Science. That is to say, philosophers of science who are concerned about the use of case studies as evidence for and/or against meta-

[17] For another example, see Fahrbach (2011).

scientific theses can use the very methods of data science I have used in this paper in order to study the history of science in systematic and data-driven ways. Rather than appeal to case studies, philosophers of science who are wary of appeals to case studies can use the text mining, corpus analysis, and data visualization techniques of data science to gather data from databases of historical, philosophical, and scientific works, and thereby paint a picture of science and its history using big data. My take home message to my fellow philosophers of science, then, is this: data science can be our friend!

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