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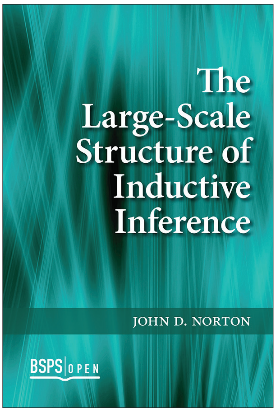

THE LARGE-SCALE STRUCTURE OF INDUCTIVE INFERENCE

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Mutually Supporting Evidence in Radiocarbon Dating

1. Introduction

Consider two ways that we can date artifacts and samples. First, traditional methods of historical analysis and archaeology enable us to date artifacts, and the counting of tree rings enables us to date wood from ancient trees. Second, radiocarbon dating provides another means of dating these samples. What results are two sets of propositions concerning the age of specific artifacts. In Section 4, the first are called *H* (historical), and the second are called *R* (radiocarbon).

Each type of dating can provide evidence for the other type. That is, relations of support between these two sets of propositions proceed in both directions, analogously to the relations of support between the stones on either side of an arch.

The second type *R* can support the first type *H*: if we are interested in checking the historical dating of some artifact, then we can send a sample to a radiocarbon laboratory for dating.

The first type *H* can support the second type *R*: radiocarbon dating itself requires empirical calibration to correct for many confounding variables, such as changes in levels of atmospheric carbon 14. Historically dated artifacts and wood dated by tree ring counting can be used in this calibration process. In it, the evidence of these other methods of dating provides support for the recalibrated radiocarbon dating of the samples.

When the two methods agree for some sample, we have support relations passing in both directions. However, the circumstances of the sample might incline us to emphasize only one direction.

In Section 2, I will review briefly how radiocarbon dating works, and in Section 3 I will describe the need for and methods of independent calibration of radiocarbon dating. Finally, in Section 4, I will review how relations of evidential support cross over among the type *H* and type *R* propositions, using the example of the dating of the shroud of Turin and associated control samples.

To speak of just two mutually supporting methods oversimplifies greatly in the interests of brevity. An appreciation of the richness of the interactions of many lines of evidence employed in radiocarbon dating has been provided by Alison Wylie in several works, including Wylie (2016). For a related analysis of radiometric dating in geology, see Alisa Bokulich (2020).

2. How Radiocarbon Dating Works

Consider some ancient artifact such as a scrap of linen from an Egyptian mummy's wrapping or a thread from a medieval cloak. How are we to know its age? In the 1940s, William Libby hit upon a method so ingenious and important that it earned him the Nobel Prize in chemistry in 1960.[1] These artifacts are all derived from carbon-based plants. These plants derived their carbon from the CO_2 in the atmosphere. Virtually all of the atmospheric carbon is the stable isotope ^{12}C, "carbon 12." However, a tiny portion is a radioactively unstable ^{14}C. This tiny portion is decaying exponentially, with clocklike regularity, with a half-life of about 5,730 years. That means that, after 5,730 years, only half of the original amount of ^{14}C remains; after 2 x 5,730 = 11,460 years, only a quarter remains; and so on. Wait long enough and nearly none remains. Coal, formed from living plants several hundred million years ago, contains virtually no ^{14}C. By these simple calculations, we can determine the age of an artifact from two numbers: the amount of ^{14}C in the artifact at its formation and the amount of ^{14}C in the artifact now.

The second of these numbers can be determined by laboratory analysis. The first, however, presents a greater challenge. The amount of ^{14}C in the artifact at the time of its formation is fixed by the level of ^{14}C in the atmosphere at

1 An early mention of the method appears in the journal literature in brief closing remarks in Anderson et al. (1947).

that time. The isotope ^{14}C occurs in atmospheric carbon in roughly the ratio of 1 atom of ^{14}C to 10^{12} atoms of ^{12}C.[2] Although atmospheric ^{14}C is decaying with the half-life of 5,730 years, the atmospheric levels are maintained at roughly constant levels through a process that creates new ^{14}C atoms. Cosmic rays strike nitrogen atoms in the atmosphere and convert them to ^{14}C atoms. Since the rate of replenishment rises and falls with the intensity of the cosmic rays impinging on the atmosphere, there is a corresponding movement in the levels of ^{14}C. The ratio of 1 to 10^{12} is a rough estimate of a ratio that varies over time. Many other processes affect this ratio. Some have a large effect. The ratio dropped significantly after 1880 because of the large amounts of carbon-based fossil fuels burned in the industrial revolution. The ^{14}C in the atmosphere was diluted by essentially ^{14}C free carbon from the fossil fuels. This and other factors have sufficiently disrupted the rate of replenishment that radiocarbon dating of artifacts is practicable only to artifacts older than 300 years.[3]

3. The Need for Calibration

For artifacts older than 300 years, the variability in the atmospheric ^{14}C levels and other factors lead to incorrect dating, commonly an underestimate of the age of the artifact. In the early years of radiocarbon dating, when there were fewer means available to check it, a thorough analysis of the errors was not possible. Arnold and Libby (1951, 111) collected eighteen months of radiocarbon dating in a report presented as "an overall-check of the method which was the main purpose of the research." As a part of these efforts, they presented the historically known and radiocarbon ages of samples from ancient Egypt (wooden beams from tombs, wood from a funerary ship, wood from a mummiform coffin, ancient wheat and barley grains). They reported the radiocarbon ages of samples from many other locations but generally without historically determined ages.

By the 1960s, discrepancies between the radiocarbon and true dates of historical artifacts were becoming apparent. Stuiver and Suess (1966) reported on the accumulation of evidence of the discrepancies. The relationship

2 As cited by Key (2001, 2338).

3 These other effects include seventeenth-century rapid changes in solar magnetic intensity and the artificial production of ^{14}C as a result of atmospheric testing in the twentieth century. For more details and more general background, see Taylor (1997, 69).

between the two ages, they stressed, depends on so many potentially variable factors that it requires an approach other than the theoretical analysis that then gave radiocarbon ages:

> This relationship cannot be determined theoretically, but can be derived empirically by determination of the radiocarbon contents of samples of known age. (534)

They reported the existence of samples of known age from old wood whose age could be determined by the counting of tree rings. They expressed high hopes for samples that would soon be available of bristlecone pine wood more that 6,000 years old. These samples did meet their expectations and now play a central role in determining the relationship that they sought.

The corrections needed came to be summarized in calibration curves that map the radiocarbon age of a sample against that sample's true calendar age. The term "radiocarbon age" is precisely defined in the radiocarbon dating literature. It designates the age indicated by depletion of ^{14}C in the artifact if we make a series of convenient but false stipulations. They include the assumption of the constancy of reservoir ^{14}C levels, an incorrect but formerly used half-life of 5,568 years, the counting of time from 1950 AD as the zero point, and more.[4] Recent calibration data and curves have been provided by Reimer et al. (2013). Figure 10.1 is a calibration curve plotted from their data for samples created in the northern hemisphere.

4 For more details, see Taylor (1997, 67–68).

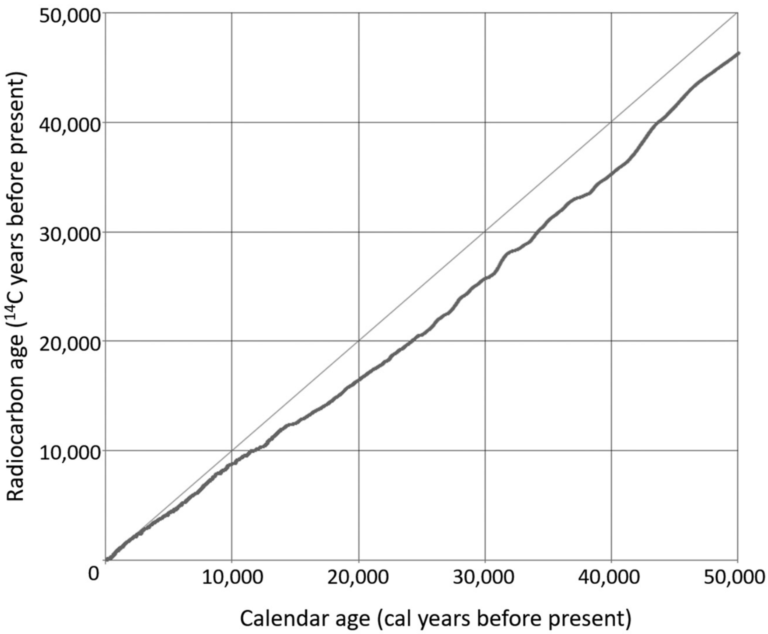

Figure 10.1. Northern hemisphere calibration curve, IntCal13; from data in Reimer et al. (2013) and reproduced in conformity with a Creative Commons CC BY-SA 3.0 license granted by the copyright holder at https://en.wikipedia.org/wiki/File:Intcal_13_calibration_curve.png

The curve shows that radiocarbon age might underestimate the true calendar age by as much as 20%. Once the curve has been used to correct the radiocarbon age, I call the new age the "recalibrated radiocarbon age."

4. Relations of Evidential Support

The relations of evidential support to be considered here are between two types of propositions:

H: The historically determined age of a designated sample is the true age.

R: The recalibrated radiocarbon age of a designated sample is the true age.

Here "historically determined" indicates that dating was carried out by the traditional methods of history, archaeology, and dendrochronology (tree ring dating), excluding radiocarbon methods.

So far, we have seen that propositions of type *H* are used to give evidential support to propositions of type *R*. Indeed, propositions of type *H* are used to construct the calibration curves that recalibrate the propositions of type *R*. Thus, they provide the evidential support for the correctness of the recalibrated ages.

However, the relations of evidential support can be reversed. Propositions of type *R* can support those of type *H*. We might become uncertain about the dating ascribed to some sample in a proposition of type *H*. Perhaps we might become unsure of the archaeological dating of 4,650 +/– 75 years of the acacia wood beam from the tomb of Zoser at Sakkara, listed in Arnold and Libby (1951, 111). We can use the recalibrated radiocarbon dating of samples from it to reaffirm its archaeological dating.

An interesting, concrete example of the crossing over of relations of support between the two types of propositions is provided by the radiocarbon dating of the shroud of Turin. As most people know, the shroud bears front and rear impressions of someone with injuries compatible with crucifixion. It is purported to be the burial shroud of Jesus. However, it did not appear on public display until the 1350s. In a careful series of tests reported in Damon et al. (1989), samples of the shroud were sent to three laboratories. In a failed effort to blind the tests, three control samples were also sent to each laboratory. The results showed agreement among the three laboratories for dating of all the samples. They concluded with 95% confidence that the linen of the shroud was created from flax grown sometime between 1260 and 1390 AD.

The crossing over of relations of inductive support arose in the context of the three control samples:

> *Sample 2*. Linen from a tomb excavated at Qasr Ibrîm. Dated by embroidery pattern and Christian ink inscription to the eleventh and twelfth centuries.

Sample 3. Linen from an early-second-century AD mummy of Cleopatra from Thebes. Radiocarbon dated to 110 BC–75 AD at 68% confidence.[5]

Sample 4. Threads from the cope of St. Louis d'Anjou. Dated by stylistic and historical evidence to 1290–1310 AD.

These three samples are dated by *H*-type propositions and then by *R*-type propositions from the three independent laboratories. Since the dating of all of the samples agrees in both types of propositions, we can read the relations of support in each case as passing in both directions.

The intended direction of the calibration of the laboratories is that the *H*-proposition dating of the samples provides evidential support for the laboratories' *R*-proposition dating. However, we can choose equally to read the evidential support as proceeding in the opposite direction: if there was any doubt about the dating of the three control samples, then their radiocarbon dating by the three independent laboratories affirms their correctness. That is, the *R* propositions provide evidential support for the *H* propositions.

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5 Damon et al. (1989) indicate only a radiocarbon dating for the sample. However, the description of the artifact at the British Museum also indicates a historical dating. The mummified body is of "Cleopatra, daughter of Candace, a member of the family of Cornelius Pollius, Archon of Thebes" (https://www.britishmuseum.org/collection/object/Y_EA6707) and is elsewhere identified as "…daughter of Candace, a member of the Cornelius Pollius family, the Archon of Thebes, under the rule of Emperor Trajan" (https://egypt-museum.com/mummy-of-cleopatra/). Trajan's reign from 53 to 98 AD overlaps with the interval provided by radiocarbon dating.

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