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The Diffusion of the Codex

The adoption of the codex for literature in the Roman world was one of the most significant developments in the history of the book, yet remains poorly understood. Physical evidence seems to contradict literary evidence from Martial's epigrams. Near-total adoption of the codex for early Christian works, even as the book roll dominated non-Christian book forms in the first centuries of our era, has led to endless speculation about possible ideological motives for adoption. What has been unquestioned is the importance of Christian scribes in the surge of adoption from 300 C.E. onward. This article reexamines the foundation of many theories, the timeline for non-Christian adoption sketched by Roberts and Skeat in their study, *The Birth of the Codex*, and reevaluates it through the lens of "diffusion of innovations theory" in order to reconcile the evidence and elevate practical considerations once and for all over ideological motives.

The adoption of the codex form for literature in antiquity has been called the greatest development in the history of the book after the invention of the printing press.[1] Yet it remains imperfectly understood. When, in 386 C.E., Augustine heard the voices of children in the garden chanting *"tolle, lege, tolle, lege,"*[2] and returned to where he had been sitting, the book he took up was a codex. Flipping it open at

William Harris suggested the problem of the literary codex to me, and offered boundless encouragement and assistance as I struggled with it. The usual caveat: any errors herein are decidedly my own. Thanks to Dagmar Riedel for inviting me to present an earlier version of the first two sections of this article to the Columbia University "Seminar on Religion and Writing." Joseph Howley was kind enough to have me talk with his students in his graduate seminar on "The Book in Roman Literature" and later invite me to present an earlier version of this paper as a work-in-progress at a conference organized by Stephanie Frampton and himself, "MATERIA: New approaches to material text in the Roman world." I was honored to attend, and this text is much improved thanks to interactions with my fellow presenters, the organizers, and attendees.

1. Roberts and Skeat 1983: 1.
2. "Take up and read, take up and read."

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random, he found in a passage the impetus for his conversion to Christianity and, having closed it, marked his place.[3]

This small but important episode at the end of the fourth century illustrates most of the features of the codex,[4] the form of book we use today, comprising sheets folded into pages and bound on the left: its compactness and portability, its ease of reference, and of marking one's place. That it was a Christian book is a feature historians have identified as of crucial importance. For, in contrast to Romans of other sociological backgrounds, Christians seem to have taken to the codex book early in our era, in preference to the universally accepted roll form, and communicated that enthusiasm to their non-Christian counterparts in the third and fourth centuries C.E., as the size and respectability of the Christian population was exploding.[5]

If the so-called Christian codex was, however, the parent of the codex book adopted by the wider Roman world, where did the Christians get the codex?[6] What is to be made of the literary codices described in the first century C.E. epigrams of Martial,[7] which then seem to vanish?[8] If strictly practical concerns, such as portability and compactness, were the prime drivers of adoption,[9] how to explain the near total and immediate adoption by Christian scribes while the long, slow adoption by others?[10] If, on the other hand, there were some religious or

3. August. *Conf.* Liber viii. 29–30. Gospel cleromancy had a secular version that was popular at that time, too, the *sortes Virgilianae*: finding of oracles in the words of Virgil (Harris 1989: 303), a hint, then, of the rising prevalence of the codex.

4. The codex is so obviously the book in the modern era that we call it simply a book. The book roll, the codex's predecessor, is retained in our linguistic memory when we refer to volumes of a book, the Latin word for book roll being *volumen*, in reference to being something rolled (*OLD*, s.v. "volumen").

5. Harris 1991: 74. On the population growth of Christians, Keith Hopkins, against a "heavily inductive" method (Hopkins 1998: 186), posits a mathematical model for Christian population growth anchored around two additional assumptions: about a thousand Christians in 40 C.E., and six million by 300 C.E. (Hopkins 1998: 191–94). With a constant rate of growth, this implies 210,000 Christians ca. 200 C.E., rapidly increasing to a million by 246 C.E. (Hopkins 1998: 192 Fig.1).

6. We find varying and sometimes contradictory answers suggested in Roberts and Skeat 1983, Skeat 1994, Stanton 2004, Meyer 2007, and Kraft 2008a. While I touch on the merits and demerits of these proposed explanations later on, I will suggest a more straightforward theory that encompasses the totality of codex adoption.

7. The codex, though not denoted by the Latin word *codex*, is plainly indicated in Mart. *Ep*. I ii, and in *Ep*. XIV clxxxiv, clxxxvi, cxc, and cxcii. His own poems seem to be available in codex form, as well as editions of Homer, Virgil, Cicero, Livy, and Ovid.

8. Pliny Elder and Younger, Suetonius, Aulus Gellius, Lucian, Aelius Aristides, and Galen seem to be silent on the literary codex (Roberts and Skeat 1983: 28). And Martial does not mention the codex again after 86 C.E. (Howell 1980: 3, 105) in over 1,500 poems (Blake 2014: 77).

9. As suggested in Harris 1991: 80–81.

10. By the third century C.E. only 18.5% of non-Christian Greek literature in Egypt is in codex form, while virtually all Christian literature is (Roberts and Skeat 1983: 37, 40–41). To see why Skeat proposes an ideological reason, consider that the practical advantages are more or less matters of degree: the codex is more portable, more capacious, easier to reference, and less expensive, than the book-roll. Given that Christian adoption of the codex appears to happen almost at once and to be more or less total, as opposed to happening simply to a higher degree than the slow adoption by

otherwise ideological impetus, how to explain that?[11] The consensus view of the transition from book roll to codex introduces rather more problems than it solves.

The problem of the codex has special significance in our time, when the "e" in e-book is beginning to drop out, and one often cannot tell in what form a book is being read. One need only inspect one's own library, where a growing number of volumes can be read digitally on a tablet or phone.[12]

Except for scant literary mentions (unsurprising, since how often do we ourselves comment on the commonplace when writing about something else), and representations in paintings and sculpture that tend to tell us more about the iconographic status of codex and roll than their actual use,[13] the most (only?) fruitful path toward an understanding of the adoption of the codex appears to be the physical evidence: codices, rolls, and their fragments that have survived, primarily in Egypt, dated by the uncertain science of paleography.[14] This was the data that allowed Roberts and Skeat, in their 1983 monograph, *The Birth of the Codex*, to sketch what remains the unchallenged timeline for the adoption of the codex at the root of our current, shaky understanding.[15]

Solving this problem requires reassessment of the data as collated by Roberts and Skeat, with an eye toward re-interpretation through a novel framework that can resolve the tension between the apparently slow adoption of the codex for literature by non-Christians and the corresponding rapid Christian one. This framework should, one hopes, add depth of understanding to our view of individuals and populations in antiquity which may have utility beyond the immediate issue.

It is possible in attempting to elucidate a more accurate picture of the birth of the codex and its adoption that too much might be made of the opposition of Christians and non-Christians in Roman society. This is, in some ways, unavoidable

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other Romans, a sudden and whole transition seems inexplicable to him from these reasons alone (Skeat 1994: 263).

11. Skeat (1994: 263) suggests that the early church adopted the codex form because it fit the canonical gospels. But the early church had no hierarchy with which to impose such an adoption (Harris 1991: 76). The reigning suggested ideological reason for adoption is an effort by early Christians to differentiate themselves from Jews (see Meyer 2007: 297, 303, and Reudenbach 2014); however, Jews seem to have used the codex as well. At least one early Jewish codex survives (P. Oxy. 656, from the late second or early third century, Kraft 2008b), and the view of early Egyptian Christianity, as expressed in Meyer and others, has "weaknesses" (Kraft 2008a). In fact, Christians continued to use rolls in their iconography as symbols of wisdom and learning (e.g., Jesus depicted with a book roll), further undermining the notion of an ideological motivation (Harris 1991: 77).

12. More than one third of American adults who read a book in 2014 read it on an electronic device, and half of Americans own a dedicated e-reader (Zickuhr and Rainie 2014). Benjamin Dreyer, copy chief at Random House, recently remarked, "After brief flirtations with e-book and eBook we've settled on ebook. . . . We do, by the way, frequently refer now to 'print books.' Because we must" (Dreyer 2016a, b).

13. Stanton 2004: 170.

14. Roberts and Skeat 1983: 28. See, especially, Turner 1977: 2–3 on the uncertainties of paleographic dating. Stanton 2004 disputes paleographers' various characterizations of Christian "hands" in manuscripts.

15. "The starting point for serious discussion of the question" (Stanton 2004: 167).

because of the framing of the scholarly consensus on the codex from Roberts and Skeat onward; but our method allows us to reach some important conclusions without making assumptions about the nature of early Christianity. It is also a method of investigation that relies on an aggregation of data about texts: this is in contrast to approaches that measure texts and tablets[16] and knowingly reflect on the quality of hands in manuscripts,[17] their margins, the quality of materials, the method of construction and binding, whether they are constructed from one or multiple gatherings,[18] and all other physical characteristics and materiality of the text. In doing so this article does not reject such codicological knowledge, but offers a missing, and illuminating, complement to it.

The reassessment is rounded out by a review of data from the LDAB, containing more recent discoveries and more current editorial decisions on dates, which leads to a reconsideration not only of the adoption but of the birth of the codex itself.

I. SOURCES

Most of the books that survived the Middle Ages, to be recovered from dusty shelves in secluded places by the enthusiasm of a Petrarch or Boccaccio, survived between the protective covers of codices.[19] The codex form had become so entwined with the idea of literature that in the 18th century C.E., when a well dug in the garden of the Augustinian fathers northwest of Pompeii struck marble and excavators discovered a room in a rich villa containing blackened papyrus rolls (which were first mistaken for sticks of charcoal),[20] it was asserted they could only contain the kind of bureaucratic records that rolls had been consigned to in the intervening centuries.[21] But the painstaking, and sometimes disastrous, opening of the rolls revealed that they held literature, if not exactly first-rate stuff.[22]

16. As in Meyer 2007.

17. As in Stanton 2004 (also serving as an example of an investigation of the codex within the detailed socio-cultural context of early Christianity).

18. As in Turner 1977.

19. "No book that was not transcribed from roll to codex was likely to survive the Dark Ages" (Cameron 2010: 455). For an account of the Renaissance hunt for classical literature see Duel 1965.

20. Paderni 1754: 821, and Winckelmann 1771: 80.

21. "M. Martorelli . . . maintains the manuscripts of Herculaneum . . . are not learned dissertations or books, but simple documents, deeds of gift, contracts, judgments, and the like; for it would, says he, be absurd to think, that, sagacious as the ancients were, they should chuse for their books so inconvenient a form, as he affects to think that of rolls, whereas a square book is much easier to use" (Winckelmann 1771: 90). See Kenyon 1899: 3 on the survival of a small quantity of papyrus letters and municipal archives from "mediaeval times."

22. The works that have been read are from minor Epicurean poet-philosopher Philodemus, or copies of known works of Epicurus or other philosophical treatises (Kenyon 1899: 71–72). See Davy 1821 for a description of some of the destructive experiments the rolls were put through. The latest effort has centered on a non-invasive measure, uniting X-rays and computer imaging to read text on the interior of rolls (Mocella et al. 2015).

Because both primary materials used for book rolls and codices, papyrus and parchment,[23] are highly susceptible to moisture damage, other than the rare find at Herculaneum, the largest share of physical evidence for the early book comes from Egypt, which in the 19th century saw a flowering of discoveries in provincial areas clustered around the Fayum,[24] an area spared moisture from rain, from the sea, and from the flooding of the Nile.[25] These Egyptian finds flowed slowly and at times mysteriously into the hands of collectors and scholars; the first inkling that the birth of the codex, once thought a deliberate affair of Late Antiquity, could be more complex and even precipitous was the bombshell publication of the Chester Beatty Biblical papyri, released over a series of years in the 1930s: all twelve Christian manuscripts were in codex form and dated to as early as the second century C.E.[26]

Additional finds suggested that Christians had taken to the codex right away, an "addiction," which C. H. Roberts addressed in two important lectures published as "The Codex" in 1954, suggesting a (later rejected) theory for the origin of the "Christian" codex in parchment notebooks carried by Mark from Rome to Alexandria.[27] The work of cataloging and dating texts proceeded through the 1960s and culminated in the mid-1970s, when the publication of the Christian bibliographies of K. Aland and J. van Haelst (in 1976) joined the extensive categorization of Greek and Latin literary texts by R. A. Pack (1965) and put a significant amount of data about the dates and forms of Christian and non-Christian books in the hands of researchers. Informed by this and by the work of E. G. Turner on the typology of the codex, T. C. Skeat, former Keeper of Manuscripts in the British Museum, and Roberts expanded and reissued "The Codex" in 1983 as *The Birth of the Codex*.[28]

Their monograph touches on all aspects of the codex, reviewing the extant literary and physical evidence, and although its hypothesis about the adoption of the codex[29] has not found acceptance,[30] their timeline for non-Christian adoption has, in the decades since, been thoroughly accepted, ratified in the light of new

23. Parchment and papyrus were both "perfectly adequate and acceptable" materials for books, codex and roll, during antiquity; papyrus was neither brittle, fragile, nor difficult to fold. It seems choice of material was guided by circumstance, of which the most important was that parchment could be produced outside of Egypt, while papyrus could not (Roberts and Skeat 1983: 5, 7, 8).

24. See Kenyon 1899: 1–3 for a first-hand view of the excitement of these discoveries.

25. Roberts and Skeat 1983: 3.

26. Stanton 2004: 166. For a colorful telling of the provenance of 19th century Egyptian papyrus finds, see Duel 1965.

27. See both Stanton 2004: 167 and Meyer 2007: 299, 299n.20 on the development of the subject.

28. Roberts and Skeat 1983: 3, 36, 38.

29. That codices might have developed from the notebooks Jewish children in Antioch used which Christians then used to record the Oral Law as spoken by Jesus. Connected with accounts of the Passion, these became proto-Gospels, and, thereafter, the real thing (Roberts and Skeat 1983: 55–56, 59–60).

30. As Skeat 1994 acknowledged while putting forth an alternative hypothesis that was also not accepted. See above, n.10.

evidence by scholars such as van Haelst, Harris, Cavallo, Stanton, Meyer, and Kraft.[31] This timeline introduces the codex to its first literary use at the end of the first century C.E., reaching parity with the book roll around 300 C.E. and only supplanting it in the sixth century. Christian books, even the oldest, are found almost exclusively in codex form; a handful of exceptions, mostly on re-used rolls, seem to prove this rule.[32] While later scholars propose a range of different and sometimes competing theories for the Christian preference, all have agreed it likely that Christian scribes gifted the codex to the Western world.[33]

A principal difficulty of this supposition is that, according to some epigrams of Martial, a fairly broad selection of Latin literature could be obtained in codex form in Rome as early as the first century C.E.[34] One interpretation suggested by the absence of the codex from literary mentions and strongly reinforced by the timeline of physical evidence is that Martial's codices were an innovation that failed to catch on.[35] Our only scrap of an early Latin codex is a fragment of an obscure historical work from about 100 C.E.[36] Galen, in the second century, mentions a parchment codex in which a baldness remedy was found:[37] Roberts and Skeat do not take this to be proof of literary use but rather view it as the kind of parchment notebook that doctors and lawyers employed.[38] They also remark upon a papyrus fragment from the same period mentioning a mobile bookseller who sold codices (P. Petaus 30), but this is not significant enough to shake the confidence that something special occurred for non-Christian literary use of the codex as the third century turned into the fourth.[39]

According to most interpretations and especially due to their shared name, the early papyrus codices of the Christians are considered to be based on the Roman

31. Cf. Roberts and Skeat 1983, Harris 1991, Cavallo 1992, Skeat 1994, Stanton 2004, Meyer 2007, and Kraft 2008. Bagnall 2009, however, suggests that statements about "the distinctive association between Christianity and the codex" are "partly misleading and need significant qualification" (71). He arrives at this conclusion by finding later dates for Christian codices than commonly accepted and comparing the number and type of codices of Christian works to non-Christian ones (11–21; 72–79). Ultimately, Bagnall undercuts his argument and joins the rest when he acknowledges the domination of the codex form for Christian "scripture" (79–80). This paper reaches its conclusion without wading into the debate about the age of Christian codices (see below, n.59).

32. Of 172 Christian religious texts from about 400 C.E. and earlier, 158 are found on codices and 14 from rolls, and of the 14 rolls, only two rolls can be characterized as "normal" (Roberts and Skeat 1983: 38–39). Even if we quibble about Roberts and Skeat's definition of normal, this is striking.

33. Meyer 2007: 331 characterizes the literary codex poetically as a gift; similar sentiments are in, for example, Stanton 2004: 171, and Harris 1991: 74.

34. See above n.7.

35. Characterized as a "still-born" "experiment" at Roberts and Skeat 1983: 29; affirmed by Meyer 2007: 302, and Harris 1991: 71. This judgment was rejected by van Haelst 1989: 21 as "excessif" (and again by Stanton 2004: 179) but without offering a serious challenge, ultimately admitting that the history of the codex could not have much to do with Rome.

36. P. Oxy. 30, called *De bellis Macedonicis* (Roberts and Skeat 1983: 28).

37. Galen, *Opera*, ed. Kuhn, xii. 423.

38. Roberts and Skeat 1983: 22. A later discovery shows the true nature of Galen's notebook. (See below n.94.)

39. van Haelst 1989: 21–23. Also remarked on in Harris 1991 and Stanton 2004.

wooden tablet codices, either directly or through the medium of the parchment notebook.[40] These codices were comparatively bulky, wooden tablets strung together in pairs or as multiple leaves, whose centers were spread with wax into which writing was impressed and could be erased, for use as a notebook or ledger for business transaction, or sealed and used as legal documents. Or, possibly, Christian codices could have arisen from the parchment literary codices which Martial described.[41] Mostly, these interpretations carry the model for the Christian codex from Rome to Egypt, to be re-invented for literary use there even as it failed to catch on where it originally arose. Why did non-Christian Romans not adopt the codex for literature at the same time? Why did the codex book only achieve popularity as Christianity did?

The host of competing and unsatisfactory hypotheses for the adoption of the codex that continue to be posited are universally based on the timeline forming the centerpiece of *The Birth of the Codex*. This suggests a strong starting point for any effort at unraveling these difficulties: we should reassess the data that is the foundation for these hypotheses. It is unlikely that we will soon have unequivocal description of the adoption of the codex from a new literary source; and analyses of existing sources, either through traditional close-reading or complicated statistical methods, continue to founder against this physical picture.[42]

II. THE DATA

Roberts and Skeat collated the published Egyptian finds to create a table of Greek literary papyri over the first five centuries C.E. The two opted to include only Greek, not Latin, material, and to exclude anything considered non-literary such as school exercises, single sheets, and mathematical references, and they ignored the distinction between papyrus and parchment, concentrating on only form: codex or roll. For purposes of dating, they relied on opinion of initial editors of the texts in almost all cases, then grouped by century.[43]

40. See Roberts and Skeat 1983: 11–16 on writing tablets and their presumed evolution into the parchment notebook. According to Cavallo 1992: 101, "nel I secolo a. C., dunque, il libro di papiro in forma di codice (e la stessa cosa si deve pensare per il libro di pergamena), ispirato dal libro di tavolette, era sostanzialmenta già nato." Meyer 2007: 303 identifies the Roman wooden tablet ("itself the parent of the parchment literary codex"), especially for legal documents, as the prototype for the Christian codex.

41. But why should the parchment codex inspire Christians, and then disappear for non-Christian works? (Asked in Meyer 2007: 302.)

42. An analysis of uses of the word *codex* in Augustine has found support for the idea that Augustine use the term only where the foregrounding of its practical characteristics made it the logical choice for employed over a form-agnostic term like *liber* or *volumen* (Holtz 1989: 111). Petitmengin 1994: 1027 makes a strong point when he addresses the "banalité du codex" in Augustine, its everyday aspect. The physical form of a book is unlikely to be stressed in a literary work except where pertinent to the larger literary subject. Earlier mentions are scarce to nonexistent (see above n.8) while later mentions take us into the Middle Ages. A close reading of Martial on his own terms (see later Section VII) is preemptively discounted in the face of physical evidence. (See above n.35.)

43. Roberts and Skeat 1983: 36.

Their data are as follows in Table 1. Some dates straddle centuries: Roberts and Skeat were unwilling to divide counts for documents whose editors suggested dates straddling centuries evenly, as had been suggested by William Willis, "on the grounds that [for a document dated second-third century] there's a statistical probability that in fact 50% will have been written in the second century and 50% in the third."[44]

A quick look at the table shows a sea-change from row III, with 81.5% in rolls, to row III–IV with only 52% rolls. Although other scholars have already done so, it makes sense to reconsider and ratify the decisions made in creating this table to see if it can really provide a reasonable basis for assessing the non-Christian adoption of the codex for the whole empire. We remove some noise and geographical uncertainty by concentrating on Egypt, where the bulk of our finds originate and the sheer number of documents suggests a representative sample. These data do come from relatively provincial backwaters,[45] but wealthy Alexandrians, who would have been the primary source of found books, had villas in these provincial regions, and Alexandria was a principal city in the empire; Roman officials, merchants, and nobles would have traveled and communicated habitually to and from Egypt.[46] We can be satisfied that the form of book in use would have spread.

Selecting only Greek material seems justified in a province where Greek was the dominant language among the literate.[47] Turner, in his consideration of the codex, supports us when he expresses a concern about mixing languages from the jumbled source material for unitary consideration.[48] Where literate individuals

Table 1: Data from Roberts and Skeat 1983: 37.

Century	*Rolls*	*Codices*	*Total*	*% Rolls**	*% Codices**
I	252	1	253	100	0
I–II	203	4	207	98	2
II	857	14	871	98 ½	1 ½
II–III	349	17	366	95 ½	4 ½
III	406	93	499	81 ½	18 ½
III–IV	54	50	104	52	48
IV	36	99	135	26 ½	73 ½
IV–V	7	68	75	9 ½	90 ½
V	11	88	99	11	89

* To nearest ½ %.

44. Roberts and Skeat 1983: 36.
45. Roberts and Skeat 1983: 3.
46. Roberts and Skeat 1983: 35.
47. At least the dominant language of the government and immigrant population, if not the language "of the fields" (Harris 1989: 190).
48. Turner 1977: xxii. But our findings may free us of some of that concern.

were bilingual, we easily imagine their book forms to be similarly chosen across the languages. Excluding non-literary material involves a considerable judgment, but as long as those judgments are consistently applied any attendant error would be distributed over time and leave our picture of the transition (that is, the shape of the curve made by the percentage share of codices in each time period) the same. By excluding Latin material, we make another immediate gain. At least one Latin codex fragment (the previously mentioned P. Oxy 30)[49] was revised to an earlier date in light of Martial's first-century mention.[50] Looking at Greek only, we avoid this potential source of contamination.

Parchment was introduced as a regular substitute for papyrus around the second century B.C.E., presumably as coming from a more readily available source for most of the Roman world.[51] It probably took some time for its manufacture, a more complex process, to become efficient and to produce the highest quality material, but codices seem to have been parchment at Rome in the first century C.E., and many rolls too; while in Egypt, with papyrus easily available, both roll and codex continued for centuries to be made of papyrus.[52] Given the flexibility of material for both roll and codex across the empire and over time, it is highly unlikely that this had any bearing on the transition to codex and therefore there is no reason not to ignore material and concentrate on form.[53]

Excluding what are judged Christian works from consideration may presuppose that the Christian adoption was a separate entity from the non-Christian one, but we can quickly see that it makes no difference to our consideration. If the Christian adoption was part and parcel of the wider adoption, the small percentage of Christian documents rejected during the time of our consideration will have no impact on the overall shape of our curve. If the adoption was separate, we need not consider them. The danger of considering Christian documents is that early Christian documents were sacred texts and likely subject to a more zealous preservation. If Christians, a small percentage of the population,[54] really were early adopters of the codex, any differing rate of preservation of Christian materials against the non-Christian background would skew our curve.

Finally, with respect to dates: Roberts and Skeat were careful to accept the dates of the original editors for each manuscript.[55] Dating manuscripts is a tricky

49. See above, p. 188.

50. Blake 2014: 68n.9.

51. Plin. *NH* xiii. 21 says parchment was invented in the second century B.C.E. at Pergamum after the Ptolemies banned export of papyrus. But this is unlikely anything but a fantasy. (Put more diplomatically in Roberts and Skeat 1983: 6.)

52. Roberts and Skeat 1983: 8.

53. For a more detailed argument, see Roberts and Skeat 1983: 5–10.

54. Using Hopkins's model (see above n.5) and a rough estimate of 60 million Romans (Hopkins 1998: 195n.19), at the start of the Decian persecution Christians constituted less than 2% of the population.

55. "Except in a few cases the figures are based on the estimates of date given by the original editors." The sources of their data were Pack^2(1965), F. Uebel, *Literarische Texte unter Ausschluss*

business, based in part on internal clues and in part on paleography.[56] Turner added a typology of the early codex in the late 1970s, comparing shapes and sizes, organizations of quires, and reconsidered dates for a number of codices from those assigned by editors.[57] His main point of contention was over early dates for some Christian codices,[58] but because our data touch only on non-Christian ones, we can set aside that issue. Since our dataset comprises 2,609 texts and a number of different editors, we can be fairly sure the broad outline is correct and that individual errors are more or less randomly distributed so as to cancel each other out.[59]

Following the suggestion of William Willis (see above), we can transform the data as provided by Roberts and Skeat into a form that will lend itself to a more clear view. Suppose we assign the codices and rolls for century-straddling codices evenly to their surrounding centuries. We reckon that it is likely that something dated between two centuries would have been created in the latter half of the first or the prior half of the second century. Following this same logic, we also assign the texts that fall into the bucket for one century evenly between the first and second half of that century. In cases where there is no clean break, following the general trend of the data, we assign the extra codex to the following half-century, and the extra book roll to the preceding half-century. This produces a time series with 10 data points with a resolution of 50 years, and we can calculate the proportion of codices to book rolls for each. (See Table 2.)

When we plot the percent of codices per time from Table 2, we get a graph showing an S-shaped curve (see Fig. 1). This immediately brings to mind another graph, from a 1943 paper on a very different subject (see Fig. 2).

III. DIFFUSION OF INNOVATIONS THEORY

The second graph (Fig. 2) comes from a 1943 study of the adoption of hybrid seed-corn by Bryce Ryan and Neal Gross. This study spawned what became known as diffusion of innovations theory, a successful framework for understanding the spread of technological innovations through social systems.[60] Diffusion of

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der Christlichen in *Archiv fur Papyrusforschung*, 21, 1971: 170–82, and *Testi recentemente pubblicati: Testi letterari greci* in *Aegytpus* 1971–80 vols. 51–58, 60 (Roberts and Skeat 1983: 36).

56. This involves comparing spelling and letter forms (Roberts and Skeat 1983: 28). Paleographers can also consider such subjective evidence as "uprightness," "roundness," and "scale" (Turner 1977: 100).

57. Of which work Roberts and Skeat made "much use" (Roberts and Skeat 1983: 36).

58. Turner 1977: 99–100. In fact, Turner (answering the earlier 1954 monograph), affirms C. H. Roberts's "general theory," while believing no existing Christian codex except for P. Ryl iii 457, a fragment of St. John, as early as the first half of the second century (Turner 1977: 100).

59. In considering editors' dates for manuscripts, Turner felt himself led into some irreconcilable contradictions (Turner 1977: xxi). But we let the differences reconcile themselves (see later n.199).

60. Rogers 2003: 46

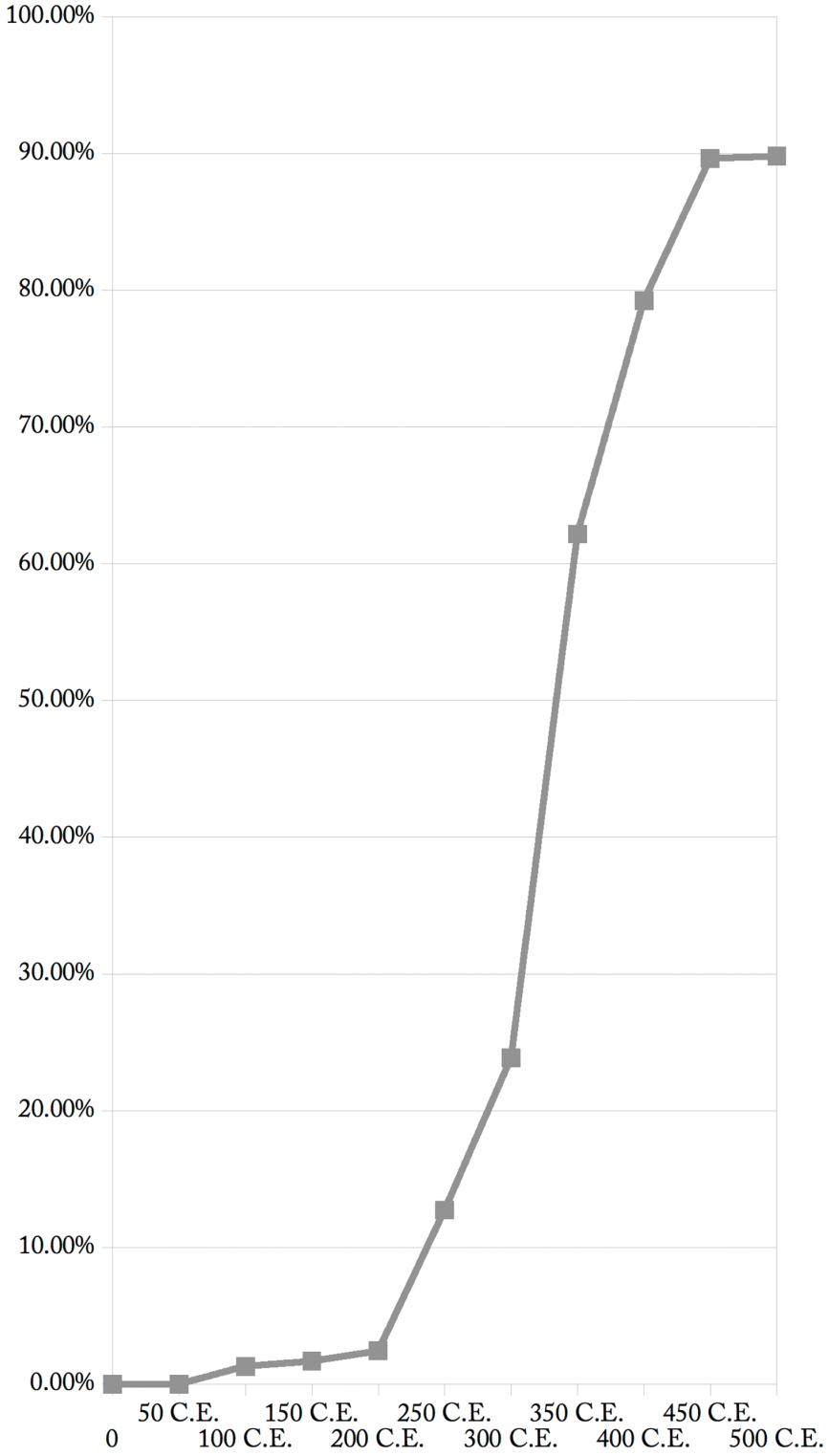

Fig. 1: Proportion of Codices to Book Rolls

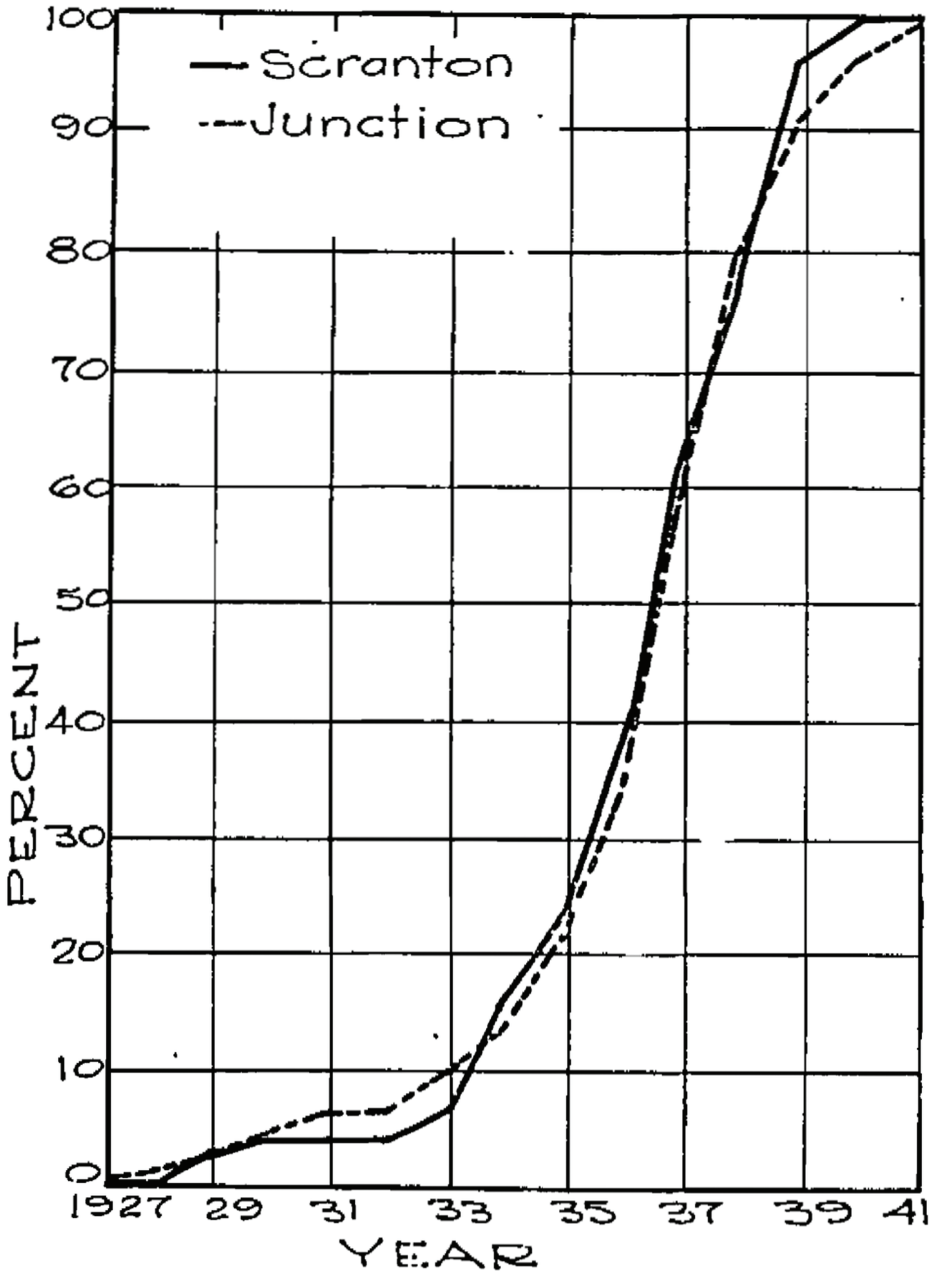

Fig. 2: Source-Ryan and Gross, 1943

Table 2: Data from Roberts and Skeat 1983. (See Table 1.)

Time	*Rolls*	*Codices*	*Total*	*Codices/Rolls*
0–50 C.E.	126	0	126	0.00%
50–100 C.E.	228	3	231	1.30%
100–150 C.E.	530	9	539	1.67%
150–200 C.E.	603	15	618	2.43%
200–250 C.E.	377	55	432	12.73%
250–300 C.E.	230	72	302	23.84%
300–350 C.E.	45	74	119	62.18%
350–400 C.E.	22	84	106	79.25%
400–450 C.E.	9	78	87	89.66%
450–500 C.E.	5	44	49	89.80%

innovations theory has expanded from its original application (understanding the spread of modern farming technologies in the United States) to healthcare technologies and commercial products, even to intangibles, such as education methodologies.[61]

Ryan and Gross analyzed survey responses from individual adopters of technological innovations for the benefit of agricultural extension services which were tasked with studying and improving farming practices and encouraging the use of new processes, tools, and hybrid seeds.[62] Understanding the diffusion process would help change agents (those hoping to spread a technology) to better tailor efforts. Farmers were asked a series of questions about an adopted technological innovation, elucidating factors that led to the adoption, its timing, and the socioeconomic standing of the adopters.[63]

Diffusion of innovations theory is now usually applied to recent or ongoing technological adoptions. This is due in part to the nature of diffusion research, focusing on survey data taken near or during adoption,[64] and in part to the reasons for diffusion research, which is often directly funded by change agents, ranging from international aid and government institutions to corporations looking to gain actionable insight into the diffusion process for the purpose of marketing and product development.[65]

The S-shaped curve of codex adoption in Fig. 1 strongly suggests we should be able to apply the diffusion of innovations framework to our problem. While diffusion research is based on asking adopters when they adopted an

61. This summary of diffusion of innovations research comes from *Diffusion of Innovations* by Everett M. Rogers, a prominent diffusion researcher, representing a synthesis of nearly 4,000 publications and a revision of the theoretical framework (Rogers 2003: xviii).

62. Rogers 2003: 55.

63. Rogers 2003: 32–33.

64. Rogers 2003: 105.

65. Rogers 2003: 83.

innovation, scribal choice of book form as represented by physical finds is a reasonable proxy.

"The heart of the diffusion process consists of interpersonal network exchanges and social modeling between those individuals who have already adopted an innovation and those who are then influenced to do so. Diffusion is fundamentally a social process."[66] This means that the generalizations of the theory are not dependent on technological differences but on certain attributes of human nature that can transcend narrow circumstances of time and place. Insights gleaned from diffusion of innovations theory have already been successfully applied to historical problems, such as the slow adoption in the 18th and 19th century of a scurvy prevention diet by the Royal Navy.[67] It has also been used to analyze the spread (and failure to spread) of technologies in the developing world and among indigenous people, like the boiling of water, use of wells, adoption of new crop varieties, and utilization of family planning.[68]

That our curve covers five centuries may seem an impediment to comparison, but consider that the pace of technological change was slower in antiquity. Punctuation marks, for example, introduced separately, each took a minimum of a hundred years to come into popular use.[69] Furthermore, since diffusion is a communication process, consider also that communication in the modern era has been almost instantaneous as compared to a past when communities were separated by weeks or months.[70] In discussing the spread of Christianity in the ancient world, A. Grafton and M. Williams emphasize that modern religions spread along existing social ties on a "one-to-one" basis; they make the same appeal to the slow dispersion of news and point out that tradition held back change even more then than now.[71] Some modern technologies have been very slow to catch on: the fax machine was invented in 1843 and only reached a general adoption in 1987,[72] change close to our centuries-long timescale. In Fig. 1 each point of data represents an adoption decision, either to create a new book in codex form, or to copy an old book from roll to codex. Unlike fields, which are planted every year, ancient books were expensive, durable, and could last centuries before replacement.[73]

66. Rogers 2003: 35.
67. Rogers 2003: 7–8.
68. Rogers 2003: xviii.
69. Small 1997: 18.
70. Richard Duncan-Jones examined documentary evidence from Egypt to assess how quickly news traveled to the provinces. He found that while some urgent news could be transmitted quickly, the best times were on the order of a few weeks while during the "slow season" for maritime travel news could be delayed 80, 100, or more days (Duncan-Jones 1990: 26–27).
71. Grafton and Williams 2008: 73.
72. Rogers 2003: 345.
73. The fourth century C.E. saw efforts across the empire to restore libraries whose contents were "crumbling through long neglect." From subscriptions on texts restored by Euzoïus, bishop of Caesarea ca. 367–379 C.E., we see that he copied deteriorating papyrus book rolls onto parchment codices. The same was said of texts in the library of Constantius at Constantinople, in 357 and 372 C.E. (Cameron 2010: 425–26).

The analysis of individual manuscript finds and readings of primary sources in this paper are subject to criticism on the same grounds as have already been levied, here and elsewhere, against preexisting scholarship on the codex. Though I believe these readings and analyses offer a more coherent view of the accurate history of the codex form, and are more consistent with recent scholarship on the nature and spread both of Christianity and technology in the Roman world, and thus to have a higher claim on accuracy, the keystone of this paper is the statistical investigation of an aggregate of physical evidence and a resort to the generalizations of diffusion of innovations theory.

The reader has seen by a reassessment of the data in Roberts and Skeat that the adoption of the codex by Romans for literary, non-Christian works in antiquity follows an S-curve, a shape characteristic of technological adoptions studied by diffusion of innovations theory. Later in this paper we will investigate to what degree is this a valid picture and employ a different method on another dataset to check our conclusion.

In spite of the considerations above, it might still be strongly objected that the findings of diffusion of innovations theory cannot be applied because the timescales of the changes are too different. (Many of the studies involved in originating the generalizations and overall theory occurred in modern times, and over years or decades, not centuries, as in the case of the codex.) It might also be objected that something in the nature of the past makes comparing modern and ancient processes impossible or entirely ineffective. Finally, the argument might be made that even if the exercise were applicable, it could only be judged against a precise understanding of the exact socio-political circumstances of each population and time period involved. This last objection is an extreme take, but any shading of it confuses the nature of this article's main thrust, namely that a statistical view of the larger picture moves the focus of the adoption of the codex from one small segment and region to the population of Romans and scope of Rome as a whole, and offers a guide for evaluating competing ideas about individual data points which might otherwise be equally supportable.

The skeptical reader who has not been moved by the successful application of diffusion of innovations theory to slow and historical technological adoptions, like to that of the fax machine or the scurvy prevention diet, nor by the application of the theory to societies at very different levels of development should consider a further defense, one requiring some minimization of diffusion of innovations theory, which by no means denigrates its accomplishments.

The S-curve is merely a description of an adoption process that begins slowly, then picks up speed, and shows evidence of a critical mass, at which point adoption will continue apace before leveling off at a point somewhat below, but close to, universal acceptance. A host of the generalizations come from simple mathematics, namely the correspondence of the adoption curve to a picture of the adopters themselves, distributed into a normal curve which has some members at either end and a bulge in the middle. More generalizations follow from understanding

adoption as a communicative process and accepting that adopters are connected by networks. Naturally the speed of adoption arises as a factor, then, of the strength, quality, and rate of communication between the individuals.

At no point have we introduced or been required to introduce specific details about the individuals, the range of time involved, or the means of communication, or the nature of the society that connects them, which might span cities or generations. This greatly limits the range of what can be said, but also demonstrates the great power of the approach and represents the best claim for our application.

Visually, the results are compelling, but how close is our curve to a pure mathematical S-curve? The formula for an S-curve is $f(x)=\frac{1}{1+e^{-x}}$. We can adapt it to fit the broad outlines of our knowledge about the codex book, which are not disputed: introduction around 50 C.E., parity in 300 C.E., and 90% adoption by 500 C.E.[74] The formula for a transformed S-curve is $f(t)=\frac{1}{1+e^{-\alpha(t-T_0)}}$.[75] We choose values of $T_0 = 285.42527$ and $\alpha = 0.02790$ to deform the curve to meet the final two requirements. To see how well this curve fits our data, we calculate *R2* (the coefficient of determination). A result of one indicates a perfect fit, while zero indicates no fit. If this is a good fit, very close to one, we have high confidence that an S-curve is an appropriate model for our data.[76]

As a second verification, we can compare the fit of our model (Model A) to another plausible model, which we will call Model B. We could imagine that the adoption of the codex was linear with a very slow growth until something, say the expansion of Christianity and the influence of Christian scribes, caused the rate to increase greatly, which fits the hypothesis that Christian scribes influenced the adoption of the codex by non-Christian Romans. This model consists of a line with two different slopes. The first line segment starts at 50 C.E. (per our assumption) and grows 2.1875% every period until 250 C.E., when it then begins to grow at 16.25% every period until it reaches 90% adoption in the period from 450–500 C.E.

In Table 3 we chart our observed percentage of codices against two possible models, the S-curve (Model A), and the straight-lines model (Model B), followed by *R2* as calculated for each.

The S-curve is virtually a perfect fit, with an *R2* of 0.99560. The alternate model is still very good for our entire dataset, with an *R2* of 0.95193, but when we consider only the period 250–500 C.E., the S-curve has an *R2* of 0.98517, while Model B has a coefficient of determination of only 0.83293, a much less confident number. For a better view, consider that the S-curve (Model A) with *R2* of 0.99560 explains 93% of the standard deviation of our data, while Model B, at 0.95193 explains only 78%, and over the latter period explains only 59%, against 88% for the S-curve.[77]

74. See above, p. 188.

75. For more about generating and transforming S-curves, see Brandwinder 2008.

76. "What's a good value for R-squared?" Nau 2016.

77. For more background on how how *R*2 can be used for analysis and its relation to standard deviation, see Nau 2016.

Table 3:

Time	*Percent Codices*	*Model A (S-curve)*	*Model B*
0–50 C.E.	0.00%	0.00%	0.00%
50–100 C.E.	1.30%	0.10%	0.00%
100–150 C.E.	1.67%	0.50%	2.19%
150–200 C.E.	2.43%	2.00%	4.38%
200–250 C.E.	12.73%	7.60%	6.56%
250-300 C.E.	23.84%	24.40%	25.00%
300–350 C.E.	62.18%	54.00%	41.25%
350–400 C.E.	79.25%	77.30%	57.50%
400–450 C.E.	89.66%	86.50%	73.75%
450–500 C.E.	89.80%	89.10%	90.00%
*R*2	N/A	**0.99560**	**0.95193**

The situation for our Model B is even worse when we consider that, for Christianity to be the deciding factor in the adoption of the codex, the slope of adoption requires an increase starting in 250 C.E., which is much too early given the state of Christianity in Rome at the time.[78] A better fit for the hypothesis would have something more like an exponential growth, starting very slowly, then speeding up. But it is obvious that this would make the model fit the data even less.

The most compelling reason for adopting the S-curve model is that diffusion of innovations theory, through the concept of critical mass, shows that non-Christian adoption of the codex was inevitable before there could have been any meaningful influence of Christian books or Christian scribes.

IV. CRITICAL MASS

In diffusion theory, all successful innovations share an S-shaped adoption curve, in which adoption starts to build slowly until it reaches a point of critical mass, at which point the speed of adoption takes off, slowing again only when it reaches near-total diffusion.[79] Critical mass is the percentage adoption of an innovation that must be reached for adoption to become self-sustaining. But considered from the point of an individual, there is an adoption threshold: how many other people in their social network need to have already adopted the innovation in order for them to adopt.[80]

78. With the Decian persecution beginning ca. 250 C.E. and the state of Christianity such that David Potter can say that even after the ascension of Constantine, if "he had not twelve years of sole rule before his death, and if he had not been succeeded by sons who, to the best of their limited abilities, shared his vision for the next thirty-one years, we cannot be certain that Christianity would have become the force that it did" (Potter 2014: 66).

79. Rogers 2003: 23.

80. Rogers 2003: 355–58.

The area of the curve in which the initial slow adoption changes slope to speed up dramatically is called the take-off:[81] this is when critical mass has been reached. For our curve, this takes place in the hundred years between 150 and 250 C.E.[82] Since we have chosen Greek, non-Christian texts, this means that during this period enough people in the social group who created and consumed these texts adopted the codex form to make wide adoption of the codex by this entire group inevitable. This places the non-Christian adoption of the codex squarely out of the likely influence of Christian scribes.

The S-shaped adoption curve for various technologies has different slopes, based on the characteristics of the invention and of the social group adopting it. For example, in cases where innovations are used for interactive communication, the rate of adoption begins much more slowly and is much faster after the critical mass of adopters is reached, due to the increasing utility of the invention as more people take it up, like the telephone and the fax. A telephone in the possession of just one person is useless but becomes useful as other people adopt.[83] The S-curve for the codex is like these curves, in that the early adoption was extraordinarily slow.

It makes sense to think of a codex in these terms of interactive communication. Augustine sent a particularly long letter as a codex, although his apology for it makes clear that this was not common practice.[84] It was common for authors to share their work in public recitations,[85] but even absent a public performance, before the invention of printing, the relationship of author-publisher-reader was a far more interactive one.

Books were obtained primarily through copying the books of acquaintances,[86] and it is impossible to over-stress how important social networks were for the transmission of ancient texts.[87] As adoption progressed it would become increasingly easy to "try out" a book in codex form, and since note-taking was already being done in parchment notebooks, users would have had some experience and comfort with referring to text in the codex form.[88] This trialability is just one characteristic of the codex that impacted its adoption.

V. RELATIVE ADVANTAGE

In diffusion of innovations theory, five additional factors arising from the nature of the innovation and its relation to potential adopters can speed or slow

81. Rogers 2003: 11.

82. By 250 C.E., when, from a constant growth model, Christians were not quite 2% of the population (see above, n.55), codices already make up nearly 13% of books and are on their way to doubling their proportion (Table 2).

83. Rogers 2003: 343.

84. August. *Ep*. 171 (Discussed in Roberts and Skeat 1983: 24).

85. Harris 1989: 226.

86. Harris 1989: 224–25, 298.

87. Haines-Eitzen 2000: 104.

88. Roberts and Skeat 1983: 15–23.

adoption. These are its relative advantage, compatibility, complexity, trialability, and observability. Observability is the degree to which the benefits of using the innovation can be seen by others. Trialability reflects how able a potential adopter is to experiment with an innovation before adopting it. Complexity is the perception of how difficult to understand and use an innovation is. Compatibility is the degree to which an innovation fits with adopter values, past experience, and needs. Last, but most important, is relative advantage: how advantageous adoption of the innovation is perceived to be.[89]

The benefits of the codex would have been fairly observable. Of the practical benefits of the codex, the most visible would have been ease of reference — seeing someone find a passage by flipping pages or opening to a bookmark, or put down the volume with a finger or marker holding the place, as Augustine did in the garden. Portability would have been a close second. Martial notes that a codex of his works would make an excellent traveling companion in *Ep*. I.ii. The capacity of a codex is also plainly visible: in *Ep*. XIV.cxc, part of his catalog of Saturnalia gifts, Martial marvels that all of Livy, which his library could scarcely hold, is compressed "into little parchment."[90]

We have already remarked on its trialability. Ready familiarity with the notebook, and with writing on parchment and papyrus, speaks to its compatibility with existing practices and though larger codices with many quires are relatively complex, the simplest codex is just several sheets folded together, and even the most complicated codex is relatively simple to use. We would expect, if practical characteristics were important to adoption, that uses in which these practical considerations were most important would find a greater rate of adoption. This is true: in the period between 100 and 200 C.E. for materials designed as almanacs or otherwise calendrical, there are fragments of 6 codices compared with 88 rolls, a rate of 6.82%, which is nearly three times the 2.43% rate we find for 150–200 C.E. (see Table 2).[91]

Galen's "notebook"[92] has been revealed by the recent discovery of a lost text, Περὶ Ἀλυπίας ("On Consolation From Grief"), to have been one of a number of "purpose-made collections" assembled with "the greatest care," meant to last (they

89. Rogers 2003: 15–16. "Diffusion scholars have found relative advantage to be one of the best predictors of an innovation's rate of adoption" (Rogers 2003: 233).

90. How could all of Livy fit into one codex? (As in XIV.190.) But nothing implies there was only one codex involved; just that as a codex what would have filled a library (*quam mea non totum bibliotheca capit*) is contained in the parchment (*pellibus exiguis artatur Livius ingens*). Blake points out that Martial offers many fanciful or exaggerated objects in his *Apophoreta* (Blake 2014: 89) but is led into error by the dominant narrative of the Latin codex as improbable in the first century C.E. in imagining that the parchment represents some kind of case (Blake 2014: 90) and not parchment codices, a supposition which has already been amply refuted by the arguments in Roberts and Skeat 1983: 26.

91. Figures for calendrical materials derived by Kraft "from a search of M-P^3" (Kraft 2008a).

92. See above, p. 188.

were "stoutly bound" and "bequeathed as valuable objects").[93] Whatever we can try to say about the "status" of the codex, and about how these collections were assembled from this testimony,[94] what is more salient and obvious is that the codex form more readily suits this purpose. The codex, with its "easy to leaf through pages, and regular, formulaic, clearly laid-out recipes, would have made a handy source of reference for a doctor and medical writer."[95]

What I have been describing are all factors that would have spread the adoption of the codex and that make it easy to see how adoption could be self-sustaining. That knowledge of the innovation was spread through communication and that adoption required the replacement or creation of a new book meant that literacy, the rate of new production and expense and rate of replacement, and slow communication were all limiting factors that would tend to retard the pace. But why should the codex spread at different rates through different social groups? The rate of Christian adoption seems instantaneous but is more likely simply too fast for the granularity of our "microscope," which can only see in hundred and fifty year increments. The Christian adoption will follow a similar curve, just over a shorter time-scale: slow at first, then quite rapid.

Compare first the size of the populations as represented by the finds. In the first two centuries C.E., we find 1,514 Greek literary documents[96] and only 11 Christian ones.[97] Even if our data are flawed, this result shows a vastly different number of individuals involved. From the perspective of critical mass, each single adoption in a smaller population is much more likely to trigger a critical mass than in the larger one. At the same time, each of the innovation characteristics is to be viewed relative to the social group and the individual adopter. For example, the benefits of the codex would be even more obvious to the Christian congregation since their liturgy was based on public readings; in fact the frequent appearance of reading aids in early Christian texts indicates that they were intended for public use.[98]

Considering that early Christianity was a religion of itinerant missionaries[99] and that they faced early persecution, the portability and capacity of the codex would have been relatively more advantageous to them than other populations. Contrary to the assertion that matters of degree could not propel Christian adoption,[100] matters

93. Nicholls 2010. In this work, Galen describes his stoicism in response to the loss of some of his most valuable possessions in the fire of 192 C.E., describing lost works, and, most interestingly for our purposes, two parchment codices of remedies.

94. And the idea of the status of the codex in Martial over which much is made of little, inconsistent, and probably irrelevant details by Roberts and Skeat and others (see below, p. 210).

95. Nicholls 2010: 385.

96. Roberts and Skeat 1983: 37.

97. Roberts and Skeat 1983: 40.

98. Harris 1991: 80–81. Also Haines-Eitzen 2000: 14.

99. Meyer 2007: 297.

100. The assertion by Skeat: see above, n.10.

of degree are sufficient, when combined with a much smaller population,[101] to achieve critical mass much earlier. Since early Christians copied their own works, were in fact writing new works of their own, and were not beholden to other scribes or to the conservatism of trade (looking to preserve the efficiency of established production methods),[102] they would not have been held back by the accumulated bulk of the past.

VI. ADOPTER CATEGORIES

Though Roberts and Skeat and succeeding scholarship have generally posited a completely separate adoption of the codex for Christians than for other Romans, it is highly unlikely that the Christian adoption and the wider adoption were entirely separate processes. It makes sense, then, for us to consider all Roman adopters of the codex together in the light of the adopter categories from diffusion of innovations theory. In the Ryan and Gross study, farmers who adopted the hybrid seed-corn were divided into five adopter categories based on when they adopted the technology and forming a bell-curve around the mean-time for adoption. In successive diffusion studies these categories were found to have stable characteristics. Adopters were divided into: innovators, early adopters, early majority, late majority, and laggards.[103]

Christians were certainly, if not innovators, early adopters of the codex. We can compare the generalizations derived from diffusion of innovations theory in a cursory way to offer additional support for our result. According to diffusion of innovations theory, innovators and early adopters tend to be less dogmatic, better able to deal with abstractions, are less fatalistic than average, more cosmopolite, more interconnected in their social network, and are often considered to be deviant from the established social system.[104] Kim Haines-Eitzen emphasizes that Christian scribes "worked from within private networks of friendships and acquaintances," and this is reflected in the spread of Christianity as a whole.[105]

While any blanket statements about the nature of Christianity and Christians tout court run the risk of oversimplification and caricature, early Christianity could

101. Hopkins estimates (relying on his model of Christian population and Harris's 1989 study on ancient literacy) only about 42 adult male Christians were "fluent and skilled literates" in 100 C.E., with 420 possessing some ability to read and write. This shows, he says, that "the part of Christianity which is preserved and transmitted in the sacred texts, was composed, explained and developed, by a tiny group of specialists, very thinly spread across the eastern and central Mediterranean basin" (Hopkins 1998: 212). Compare this to Hopkins's estimate of 400,000 literary sophisticates in the wider Roman world (Hopkins 1998: 209). See Appendix 2 for a look at Christian population through diffusion theory and a conclusion that these numbers could be even lower.

102. See Haines-Eitzen 2000.

103. Rogers 2003: 280.

104. Rogers 2003: 298.

105. Haines-Eitzen 2000: 16, 18, and 104.

be considered more abstract than the other current religions.[106] Early Christians may have felt they had a chance, in choosing to be Christian, to better their future prospects in this life and in the life to come, and hence may have been less fatalistic than the average. Like diffusion of innovations' innovators and early adopters, Christians were decidedly considered deviant from the established social order.[107]

Christianity in its early stages was a religion of missionaries and small churches communicating across continents via letters, often from bishops in cities: in this way the Christian community was more cosmopolite. Church gatherings also brought people together, often in secret:[108] overall, Christianity was a "grassroots" movement,[109] with social gatherings in churches acting as the seeds of growth.[110]

It is likely, then, that the average early Christian had a greater social participation with and was more highly interconnected in his or her social network, just as Christian scribes seem to have been. It is true that religious innovators seem likely be innovative in other respects. It is also true that various combinations of these characteristics would have adhered to other, non-Christian individuals in the community, who would have been drawn to the codex as well.

VII. MARTIAL AND PLINY

The examples of Martial and Pliny the Younger in the first century have challenged scholars grappling with the history of the Roman adoption of the codex. Martial seems to be quite familiar with literary codices,[111] while Pliny the Younger, who knew Martial and his epigrams,[112] does not mention the literary use of the codex once. This silence and the silence of other authors during the first and second century[113] contributes to, and is, in turn, supported by a reading of Martial's epigrams that paint "Martial's codex" as an experiment, an evolutionary dead-end.[114] This jibes well with the prevailing interpretation of the physical remains of ancient texts, an interpretation already challenged here.[115]

106. Christianity stood in contradiction to a world where the gods were "vibrant beings, who hovered rank after rank above and around the human race" (Brown 2013: 59).

107. "A religion that took as its founder a man who had been crucified by a Roman magistrate, a man who was quoted as saying that salvation was dependent upon faith in the will of God no matter what one's social status, was plainly at variance with cults that were integrated with existing social groups" (Potter 2014: 38).

108. Brown 2013: 73.

109. Brown 2013: 79.

110. Brown 2013: 63.

111. See above, n.7.

112. See Plin. *Ep.* III.21, quoting Martial X.20.12–21. Pliny recommends the recipient of his letter consult the book roll (*remitterem te ad ipsum volumen*) of Martial's work himself, which Pliny does not have.

113. See above, n.8.

114. See above, n.35.

115. See Section IV above, particularly.

Roberts and Skeat devote a chapter in *The Birth of the Codex* to Martial, with a careful reading of each of Martial's epigrams that could be interpreted as referring to a codex, and engage with a long bibliography going as far back as Birt.[116] Their primary conclusions are that Martial indeed mentions the literary codex in these epigrams, that Martial's works were available at some time in codex form, and that the codex represented for Martial a kind of failed experiment which he may even have been in on in partnership with a bookseller. These conclusions have been either emphatically accepted or not entirely rejected by historians of the codex.[117] Scholars of Martial, meanwhile, seem to have integrated Roberts and Skeat's ideas into their readings to one degree or another in so far as they address themes in Martial's work, or questions of chronology and modes of publication of Martial's texts.[118]

Did Martial reissue Book 1 in codex form, after he had achieved some fame? To what extent does Martial's engagement with the codex represent a meta-literary intent? In an effort to break out of the mold, Sarah Blake points out the danger of relying on Martial's mentions of the codex as evidence, since they are "deeply compromised" by their literary surroundings and Martial's aims.[119] It is true that by focusing on the individual mentions Roberts and Skeat's treatment lacks a broader context within Martial's work. They do, however, a sound job of evaluating the texts within the historical context they have established for the codex. While Blake sets aside the idea of the codex as an invention of Martial, she replaces it with the idea of the codex as a literary invention, a channeling of the parchment notebook into a literary context.[120] This in fact amounts to much the same thing: in one view Martial is an entrepreneur peddling an invention for financial gain; in the other, he is peddling an imaginary invention for literary gain.

The simplest explanation, which Blake offers first then sets aside, is that Martial was an early adopter of the codex for some reason or other, and that it did not catch on at that time. She finds it "not very interesting" and complains it does not "fully take account of the literary sophistication of Martial's epigrams."[121] I too find, with Blake, that Roberts and Skeat's treatment (as well as others'

116. Roberts and Skeat 1983: 24–29. In this chapter Roberts and Skeat cite, among others, Birt (1907), J.W. Duff, R. P. Oliver, L. Ascher, F. Bilabel, F. G. Kenyon, and R. R. Johnson. I have added Howell 1980, Fowler 1995, Fitzgerald 2007, and Blake 2014 of those primarily treating Martial as opposed to the problem of the codex.

117. See, for example, Meyer 2007: 302 and Harris 1991: 71.

118. Fowler 1995 is interested in the idea of a reissue of Martial's work in codex form because of the literary possibilities Martial seems to exploit in the interplay between readings of the roll and rereadings of the codex, while Fitzgerald 2007: 74 flirts with the idea of dueling introductions, one to the codex and one to the roll. Neither of these literary possibilities is at all negated by simultaneous codex and roll editions, just nuanced.

119. Blake 2014: 91.

120. Blake 2014: 90.

121. Blake 2014: 90.

addressing the codex evidence in these epigrams) is lacking in an appreciation for Martial's literary sophistication.

Even without taking into account our revised historical context, however, showing the successful adoption of "Martial's codex,"[122] a careful reading of Martial's first book implies that the codex could not have been Martial's literary or physical invention but must have been, at that time, a perfectly acceptable, if niche, alternative form for literary works.

Instead of beginning with the *Apophoreta*, an early book where Martial offers up what are most likely codices as potential Saturnalia gifts in individual epigrams that are undeniably part of the collection, but which have offered a problematic interpretation as codices,[123] we attend to the introductory poems of Book 1. Here he emphatically mentions the codex, but in poems that some have identified as having been added later, in a reissue or new collection of Martial's work, where several book rolls that were circulating have been put together into a codex edition.[124] The idea that the codex has been introduced as a form of advertisement is linked both to the content of the epigrams and to the possibility they were added later, which itself is suggested by a reading of the text and the contents of some surviving manuscripts.

In the first epigram of the pair, I.i, Martial trumpets his worldwide fame, after having only published several prior books.[125] Crucial for our problem, in I.ii he says, "you who are keen to have my books with you everywhere, and want to have them as companions for a long journey, buy these ones, which parchment confines within small leaves."[126] And, "so that you may not fail to know where I am for sale . . . look for Secundus, the freedman of learned Lucensis, behind the threshold of the Temple of Peace and the Forum of Minerva."[127]

One of our known texts omits these first two epigrams, which includes the above reference to the bookseller Secundus, so it is conceivable that Martial released his first few books of epigrams in multiple editions, with this introduction added in codex form this time, perhaps.[128] By this indeterminate later time, also, he could have gained more of the fame he claims for himself in I.i.[129] Without

122. See above, p. 200. The codex that has achieved critical mass between 150 and 250 C.E. is manifestly the codex of Martial.

123. Were they mentions of complete books or just little anthologies or abridgments? Would the gifts, such as a complete Livy, be too costly and out of scale to other gifts? Roberts and Skeat 1983: 25–27 address these objections fairly convincingly. Blake 2014: 90 also raises the possibility that Martial's reference to *membrana* in the *Apophoreta* refers to a covering for a book roll or tablet, not their actual material. This is a wide stretch that runs counter to her own article, and to the rest of the scholarship. It makes no sense for the epigram opening Book 1 anyway.

124. As in Fowler 1995: 201–202.

125. Howell 1980: 103. Probably three: *De Spectaculis*, *Xenia*, and *Apophoreta* (Fowler 1995: 200).

126. Martial *Ep*. I.ii, translation from Howell 1980: 31.

127. Martial *Ep*. I.ii, translation from Howell 1980: 31.

128. Howell 1980: 102.

129. Fowler 1995: 201 points out it just does not "look like" the introduction to his "first mixed collection" and insists it must have more significance.

copyright laws ancient authors had no source of royalty income from booksellers, who could simply copy whichever books they pleased.[130] Booksellers might commission a book, however, paying an author to be first to copy it.[131] Martial's earliest book may then have been commissioned,[132] and by explicitly pointing out the bookseller Secundus, may have acknowledged his rights.[133] Was it, then, an "innovation, marketed jointly by a struggling author and an enterprising publisher"?[134]

It is also true that Martial never uses the term *codex*[135] but only describes the features of the object, as if the codex were a recent invention; with the words bordering on each mention, he seems to go out of his way to stress the convenience and capacity of the form.[136] After Book 1, mentions of the codex cease, and Roberts and Skeat suggest this joint innovation failed.[137]

But, the contention that Martial could not have claimed fame without actually having it belies a long tradition of premature poetic pronouncements of renown, which seems prophetic only after the fact and should not be taken literally.[138] It is even possible that some of Martial's epigrams circulated separately as *libelli*, in small sheets, beforehand.[139] The other basis for thinking these poems part of a later edition is that while one manuscript does leave them out, another surviving text has epigrams I.i and ii placed in the Preface, which could have meant they stood, at one time, before the incipit of the book—something that regularly confused scribes into dropping material.[140]

But Fitzgerald notes a neat feature about the organization of Book 1 that argues firmly for the integrity of the book including I.i and II.ii. When we consider Martial's organization of the poems in his books for variety of length, meter, subject-matter, as well as the interdependence of epigrams on earlier ones for full meaning,[141] it shows that great care was taken assembling each book as a unified work. Fowler points out this is especially true in regards to their closure.[142] What

130. Howell 1980: 2.
131. Howell 1980: 2.
132. Howell 1980: 3.
133. Howell 1980: 2.
134. Roberts and Skeat 1983: 27.
135. Roberts and Skeat 1983: 24n.3, Howell 1980: 106, and Blake 2014: 77 all make a point of this.
136. "Martial is at pains to commend the form of the parchment codex to a public unaccustomed to it, pointing out, for instance how much space it saves in the library when compared with the roll" (Roberts and Skeat 1983: 25).
137. Roberts and Skeat 1983: 27.
138. See Harris 1989: 227; Howell 1980: 103 lists Alcman, and, among Latin antecedents, Horace and Ovid.
139. An idea strongly rejected by Fowler 1995: 205–206. In his mind, these *libelli* refer not to single sheets but to smaller complete books. This gains some credence later, as we look to Julius Caesar's "idiosyncratic way of writing his dispatches" (Roberts and Skeat 1983: 24). (In Section IX.)
140. Howell 1980: 102–103. Also Fitzgerald 2007: 70n.4.
141. Howell 1980: 12.
142. "Martial's books may be seen as possessing particularly ingenious effects of closure" (Fowler 1995: 199).

Fitzgerald points out is that in "th[e] *penultimate* poem of the book, Martial echoes the directions to the bookstore of Secundus (freedman of Lecensis) in the *second* poem of the book. Secundus is selling the codex, Atrectus the book roll."[143]

The shopkeeper will take it down, "shaved with pumice and dressed up in purple" from "the top pigeon-hole,"[144] implying an expensive book roll, in direct opposition to the small, portable codex at the start. In the penultimate poem we see a subtly changed reflection of the second poem, metaphoric (and literal) book-ends. Both poems reference the self-same book of Martial's being read, one in codex form, a portable companion for travel, the other an expensive, refined volume, clad in purple. The last to be purchased opposite Forum Caesaris,[145] the first is to be found off Forum Minerva.

The poet has, as Fitzgerald says of I.ii, "merged with his book."[146] This transformation and translocation from at-hand to deluxe, from a place by name associated with wisdom to a place by name obviously associated with power, reflects both a wish for work and life, and a portrait of a man and a literature which is flexible. This is but a sketch of what Martial has achieved, literarily, by engaging with the physicality of his books.[147]

Conceptual integrity, scribal error, and poetic tradition all speak to one, original edition of Book 1. More early codices were single quires, or even single sheets, folded, making sixteen and four pages respectively, than were multiple-quire codices.[148] Considering this relieves some of the tension of having to imagine that the codex edition of Martial comprised more than a single book, which can lead to tortured readings of the epigrams.[149]

Given Martial's assertion in his Preface that his epigrams "have their fun without . . . attacking real people by name," although his works are filled with proper names,[150] it is to be wondered whether the bookseller "Secundus," a name which can also bear the significance of "favorable" or "lucky,"[151] existed at all, or only

143. Fitzgerald 2007: 101n.65 (emphasis his).

144. Martial *Ep.* I.cxvii, translation from Howell 1980: 91.

145. Howell 1980: 106.

146. Fitzgerald 2007: 99. Cf. Martial *Ep.* I.ii, "where I am for sale" and the discussion in Howell 1980: 107.

147. This connects nicely to Holtz's (1989) and Petitmengin's (1994) treatments of the uses of *codex* in Augustine. See above, n.43.

148. Turner doubts the multiple-quire codices arose as a development from single quires, but H. Ibscher has suggested it (Turner 1977: 98–99). Though they are rare, he does find single-sheet codices contending with single-quire ones for the earliest form of the codex "in view of their early dates" (Turner 1977: 60).

149. While Fowler's points about the inherent textuality of the epigrams are well taken, the idea that Martial is numbering his books in connection with their organization into a codex, or that an epigram ending Book 2, which depicts a reader who has purchased it but not the first, gains in significance when imagined they are in the same codex (as described in Fowler 1995: 202–203), is rather convoluted and improbable stuff.

150. Martial *Ep.* Praefatio lines 3–4 in Howell 1980: 29.

151. *OLD* s.v. "secundus."

added significance to Martial's metaphor.[152] Blake finds in the secondary meaning of the name a hope for a kindly, benevolent reader.[153]

But metaphor, for an author, is a power that arises when the object in question has some general familiarity for the audience. Far from being an alien innovation to his readers, for the composition to work the codex book in the introduction must have been at least as known an object as the book roll at the end: it could not have been his invention as Roberts and Skeat have suggested, or a literary invention invoking notebooks in an unfamiliar or groundbreaking form as Blake suggested. But this does not steal anything from Martial's literary achievements. It also, alongside a revised picture of the physical data, belies a common assertion that the codex form was "an unusual expedient."[154]

We can learn something from Martial's portrayal about the general perception of the codex at the time. In I.ii, comparing the container for a book roll to his codex, he says, "provide cylinders for great authors: one hand can hold me."[155] Martial wants to contrast the imposing size and weight of epics with the more human dimensions of his epigrams. In combination with his earlier assertion that the codex makes a book your companion for a journey, we can see that Martial exploits that the codex was known for convenience and portability.

We wonder, then, along with Robert and Skeat, if codices could have been the paperbacks of their time?[156] This comparison fails in at least one aspect: when introduced in the 1930s, paperbacks were an order of magnitude less expensive than hardcovers,[157] while the savings for a codex would have been only on the order of 25%,[158] if, indeed, there were any savings at all, given that there must have been a learning curve for their more complex manufacture.[159]

If we look to diffusion theory, we can get a better answer to whether this roughly 25%[160] cost reduction could have been the deciding factor. From 1980, when the cost for each unit was about $1,200 to 1993, when it was $200, the purchases of VCRs skyrocketed to nearly total adoption. But the cost was only one factor spurring on adoption, and this was a reduction of nearly 84%, more than three times the cost-reduction imagined for the codex.[161] In fact, as we can see

152. In line with the construction of the poems of Martial (Fowler 1995: 219), this nod to "Secundus" more likely serves figurative than economic ends, a finding Blake agrees with (Blake 2014: 76).

153. Blake 2014: 74.

154. As claimed, for example, in Grafton and Williams 2008: 10.

155. Howell 1980: 31.

156. They claim a low status for the codex editions mentioned in Martial; the codex is "[not for] the bibliophile" (Roberts and Skeat 1983: 27).

157. When introduced in the 1930s, paperbacks were 1/10th the cost of their hardcover cousins (Shaffer 2014).

158. Roberts and Skeat 1983: 46.

159. As there was likely in the development of parchment (Roberts and Skeat 1983: 5–8).

160. According to Skeat 1982: 175, 26%, to be exact.

161. Rogers 2003: 230.

from Martial's metaphorical usage, the codex was not perceived as comparatively cheap—the concluding book roll bears not the gilding of wealth but the symbolic trappings of aristocratic favor—but rather as useful.

In the epigrammatic tradition, every practical detail is employed for maximum impact from of a minimum of expression:[162] Martial does not mention the codex after this not out its failure as an innovation, but because the object has already served his metaphorical purposes, and, while the object remains in use, he himself has no more poetic use for it.

If Martial had a literary reason for referring to the codex separate from the various reasons the format would be appealing to him, Pliny the Younger may have had a literary reason for not mentioning the codex in his letters, even as he probably had adequate reasons for not employing codices for his personal books as well. Pliny's letters were literary performances not unlike those of Martial.[163] While Martial was actively seeking a higher level of social status, Pliny was a member of the gentry, a senator, with estates and slaves, but more importantly Pliny came from and exemplified a social background that was, in contrast to the "sophisticated vices" of Rome, stolid, respectable, and cautious.[164] Diffusion of innovations theory tells us that, while the wealthy tend to be early adopters, individuals looking to maintain their position as opinion leaders will often hold back in adopting uncertain innovations.[165] In contradistinction, the less well-off who are on the move in the direction of higher levels of social status tend to be earlier adopters of an innovation.[166] Here in a nutshell is a distinction between Pliny and Martial, where the latter would be likely to latch on to a recent innovation in his literary efforts, while the former would maintain a conservative attitude.

Whether Pliny actually read or kept books in codex form is more difficult to know. There are reasons to believe he would have found continuing to use book rolls to be more advantageous; the notions of compatibility and relative advantage can be hard to distinguish,[167] since what is not compatible lowers the relative advantage of an innovation for a potential adopter. Pliny would have had access to large preexisting libraries on his estates, and potentially through his uncle, most of which would have already been in roll form. Libraries for codices and rolls would plainly be set up differently, hence more inconvenience of storing codex and roll together. Traveling from stocked villa to stocked villa with a retinue of slaves, Pliny would have had no use for the capaciousness or portability of the codex, either. Finally, in his social role, in his need to signal his literary credentials, either before of a group of people at a recitation,[168] or on his way to the law court,

162. Born, as it was, out of carving into stone (Blake 2014: 67).
163. Sherwin-White 1969: xv–xvi.
164. Sherwin-White 1969: xiii.
165. Becker 1970: 276.
166. Rogers 2003: 288. This allows us to nuance strongly the idea that the codex format was perceived one way or the other in socio-economic terms, discussed in Cavallo 1989 and Meyer 2007.
167. Rogers 2003: 249.
168. Harris 1989: 226.

the book roll would have been symbol and signifier of his erudition and literate nature in a way the codex would not.

Martial, with a small establishment, would have felt the needs for portability and capacity and would not have had an inheritance of ancestral book rolls and roll paraphernalia. Conceivably his epigrams were jotted into small notebooks, and the nature of this poetry over and against longer works may have made the idea of flipping back and forth more natural. Overall, the codex is more compatible with the needs and values of the likely adopting Martial against non-adopting Pliny, hence more obviously advantageous. Pliny, while giving us less (an absence of) material to work with, is, in some ways, the more interesting figure than Martial in showing how a new technology, which we find so obviously superior, can be rejected.

VIII. MORE RECENT DATA

The Leuven Database of Ancient Books (LDAB) includes 15,703 items identified as ancient books dating from the fourth century B.C.E. to 800 C.E.[169] Entries in the database contain a variety of information about provenance, dates, subject matter, and language. (See example in Table 4.)

Table 4: Musurillo, Acta Alexandrinorum 15 (Musurillo, Herbert A.) = P. Aberdeen 136 (Turner, Eric Gardner) = CPJ 3 456 (Fuks, Alexander / Stern, Menahem)

TM nr:	58922
LDAB id:	17
Catalogues:	Mertens-Pack 2236A. Harker Loyalty and dissidence 2008 p. 194
Nestle-Aland:	
Publication:	Musurillo, Acta Alexandrinorum 15 (Musurillo, Herbert A.; 1961; transcription)
Other publications:	CPJ 3 456 (Fuks, Alexander / Stern, Menahem; 1964; transcription, translation)
	P. Aberdeen 136 (Turner, Eric Gardner; 1939; transcription)
Authorname:	Acta Alexandrinorum?
Book:	Acta Alexandrinorum
Quotations:	
Attested Authors:	Acta Alexandrinorum (1. Direct attestation)
Provenance:	Egypt, 00a - Soknopaiou Nesos (Dimeh) (?) [found] cf. P. Aberdeen, 1939, p. v Egypt [written]

(*continued*)

169. "About" (Clarysse et al. 2016). Bagnall 2009: 72 chooses this dataset, as we did, as the basis for his consideration of the spread of the codex as being "more or less up-to-date" and "not embodying any single idiosyncratic viewpoint about dating manuscripts," though he uses it only to create tables similar to Roberts and Skeat, for comparison's sake.

Table 4. (Continued)

Inventory:	Aberdeen, King's College 7 r
Century:	AD02
Date:	AD 150 – 199
Material:	papyrus
Bookform:	roll?
Recto-verso:	Ro
Back:	
Reuse:	
:	
:	
Columns:	1
Pagination:	0
Language/script:	Greek
Script_type:	
Culture:	literature
Genre:	prose: history, acta
Religion:	classical
Bibliography:	
Stud Paleo Gr:	
Stud Literature:	A. Harker, Loyalty and dissidence, 2008, p. 222: uncertain
Photo:	P.Aberdeen pl.III
URL:	
Related resources:	
HGV:	
Library:	
Number of lines:	

Source: *Leuven Database of Ancient Books*.[170]

This is a more comprehensive, more recent, and more detailed source of information with which we can compare what we found in the data from Roberts and Skeat. In order to make as close a comparison to their data as possible, we restrict ourselves to books found in Egypt, in Greek, in roll or codex form, and which are identified as "literature."

Until now, we have blithely accepted this designation, the differentiation between literature and non-literature. There is no doubt that parchment notebooks in codex form were employed by students for note-taking and exercises and by professionals like lawyers and doctors. There seems to be an idea that literary productions, for use in a different context, were substantially different. Based on careful study of textual remains, people have been able to differentiate between exercises and jottings on the one hand, and a literary text on the other. Of course even easier is the differentiation between documentary and literary papyri. No one would look at a sheet of

170. Texts in LDAB are referenced for permalinks via their Trismegistos number. TM nr: 58922 = http://www.trismegistos.org/text/48922 (Clarysse et al. 2016).

measurements, or math problems, and class it in the same category as an edition of Homer. An examination of the descriptions and details of a sample of texts marked in LDAB as "literary" vs. those marked as "non-literary" offers some satisfaction that the majority of these "non-literary" papyri can be safely ignored. For example, marked "culture: science," but not also "literature," we find TM nr: 27520 which is a "Greek - Latin glossary: names of fishes,"[171] and TM nr: 62360, a law text "De formula Fabiana; Ad Plautium viii (fragments)."[172] Both of these texts would be expected to be found in codex form early and are securely planted in the realm of the notebook.

We should, however, be wary of making too firm distinctions. The "notebooks" of Galen were thought by Roberts and Skeat to be notebooks of the rough and ready type,[173] whereas the rediscovery of Galen's account of some that were lost in a fire shows that they were deluxe and sturdy affairs, worthy of any literary production.[174] Blake, as we saw earlier, suggested that Martial used the codex to emphasize the instability of text, its rewritings and erasure, and the meta-literary idea of the interactivity of author and reader.[175] Scribes who prepared non-literary documents would also prepare literary ones, and vice versa.[176] At some point, the non-literary blends into the literary, and the form of the book is both crucial to its writing and reading and, paradoxically, at the same time completely immaterial. Before now, scholars have considered the idea reasonably well-defined. For the sake of engaging the debate on its own terms, I have elected to maintain this distinction and to rely on scholarly consensus. Afterwards, I hope, we can allow for a more nuanced understanding by letting the hard boundaries fade.

Of Greek books, in roll or codex form, from Egypt, we find 5,422 records (excluding 56 wooden tablet codices[177]). We include bilingual books as long as one language is Greek. In the case where a single bookform has been registered but with a mark indicating uncertainty, we include that record under the bookform (so, for example, we accept the book from Table 4 as a roll). In the case where forms are indicated, as in "roll? or codex?"[178] we take the first mentioned form and consider the book a roll. (So "codex? or roll?" would be counted a codex.) Finally, we restrict our dataset to literary works, and so including only where "culture" contains "literature." This leaves 4,757 remaining records, nearly twice as many books as Roberts and Skeat considered.[179]

171. TM nr: 27520 = http://www.trismegistos.org/text/27520 (Clarysse et al. 2016).
172. TM nr: 62360 = http://www.trismegistos.org/text/62360 (Clarysse et al. 2016).
173. Roberts and Skeat 1983: 22.
174. See above, pp. 201–202.
175. Blake 2014.
176. See discussion in Haines-Eitzen 2000: 32–33.
177. Like Roberts and Skeat, we ignore the material composition of the book, except in this particular case, where wooden tablet codices represent a wholly different object.
178. LDAB ID 1263, TM nr: 60149 = http://www.trismegistos.org/text/60149 (Clarysse et al. 2016).
179. As against 2,609. See above p. 192. We can be sure we are considering similar objects, since Roberts and Skeat also took much of their data from Pack (see above n.56), and since, for the LDAB

We saw before that Roberts and Skeat created a series of buckets, by century and straddling centuries, from the first through the fifth century C.E.[180] A quick inspection of the dates available in the LDAB shows a wide range of possibilities. The example from Table 4 has "AD 150 – 199" while other examples include: "AD 150 – 250,"[181] "AD 100 – 199,"[182] "AD 100 – 299,"[183] and "AD 325 – 375."[184] Dates can also be singular and not ranges, and/or tagged with "?"[185] "about,"[186] "before,"[187] and "after."[188] If we simply identified a century and put the books in buckets, we would lose a lot of our data. Instead we consider, as suggested by the use of "?" and "about" in places where these dates indicate educated guesses, that ranges represent the realistic bounds of these guesses. For each individual book, the actual date of creation is some actual year within or around that range with some probability distribution: if we take the upper and lower dates as intervals of 95% confidence,[189] which seems like a reasonable claim to make, we can represent the probability of the book's actual date as a bell-curve, a Gaussian (or normal) distribution with the start and end years two standard deviations from the center of the curve, or mean.

Again, we create buckets of 50-year intervals and instead of splitting larger buckets up, as we had done before, we can go through our records and put individual texts in these buckets. But how? For each text, we pick a random year from the range, but in a way which is guaranteed, over time, to match the probability distribution we identified for each text. This is called the "Monte Carlo method" and was developed in the 1940s in conjunction with the rise of computers and the atomic arms race. Stanislaw Ulam, a Los Alamos physicist, convalescing from a cold, had thought about calculating the probability of a successful outcome in a certain game of solitaire simply by playing out a hundred games and counting the results. Mathematician John von Neumann conceived of using random numbers and a finite number of simulations to simplify the incredibly complex problem of neutron diffusion and employed this method on ENIAC,

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"the term 'books' is used in the same wide sense as in the catalogues of Mertens-Pack and Van Haelst" (Clarysse et al. 2016).

180. See Table 1.

181. TM nr: 58943 = http://www.trismegistos.org/text/58943 (Clarysse et al. 2016).

182. TM nr: 58931 = http://www.trismegistos.org/text/58931 (Clarysse et al. 2016).

183. TM nr: 218328 = http://www.trismegistos.org/text/218328 (Clarysse et al. 2016).

184. TM nr: 58998 = http://www.trismegistos.org/text/58998 (Clarysse et al. 2016).

185. "AD 663?" TM nr: 59359 = http://www.trismegistos.org/text/59359 (Clarysse et al. 2016).

186. "AD 485 about" TM nr: 62075 = http://www.trismegistos.org/text/62075 (Clarysse et al. 2016).

187. "AD 131 Oct 10 before" TM nr: 20607 = http://www.trismegistos.org/text/20607 (Clarysse et al. 2016).

188. "AD 573 Dec 16 after" TM nr: 59706 = http://www.trismegistos.org/text/59706 (Clarysse et al. 2016).

189. 95% confidence levels are generally used, for example, in reporting information about health data (Washington State Department of Health 2012). I think it is fair to say that the confidence ratings of scholars' estimates for book dates should fall in line with this usage.

Table 5: Simulation results (first trial)

*Year**	*Codices*	*Rolls*	*Pct Codices*
0 C.E.	0	141	0.00%
50 C.E.	0	179	0.00%
100 C.E.	3	258	1.15%
150 C.E.	10	633	1.56%
200 C.E.	37	746	4.73%
250 C.E.	116	538	17.74%
300 C.E.	137	313	30.44%
350 C.E.	177	74	70.52%
400 C.E.	174	34	83.65%
450 C.E.	170	12	93.41%
500 C.E.	180	6	96.77%

* Each year represents 50-year bucket ending that year.

the earliest general-purpose electronic computer. Since then, the Monte Carlo method has successfully applied to a range of scientific problems, most recently the election forecasting of Nate Silver and Sam Wang.[190] There is no reason why we cannot run our predictions against the past, as well as the future.

For texts without date ranges but which have been identified with single dates, we set the suggested date as the mean with a distribution of 25 years on either side to address any potential sources of errors in the date. If the date has been marked with a "?" we instead add 50 years to each side as our range. If the date is a "before" date, we place the date at the high end of the distribution instead of the center, and for an "after" date, we put it at the low end. (These "individual" dates represent only 21 records, and so this procedure, while I think quite correct, will have little bearing on our results.)

Take the first record: LDAB id 333 (Mertens-Pack 0130). It is a papyrus roll, dated "BC 263 – 229? (P02 or P03)."[191] We take 263 B.C.E. for the start of our 95% confidence interval, 229 B.C.E. for the end interval, and 246 B.C.E. for the mean. We pick a date, randomly according to the distribution, and arrive at 247 B.C.E.

The first codex record is LDAB ID 6 (Pack 0001), a papyrus codex, dated "AD 200 – 250."[192] The randomly selected date is C.E. 226. One more example, from the end of our dataset, LDAB id 653675 (not in the catalogs[193]), is a papyrus roll, dated "AD 200 – 399." Our date? 272 C.E. When we have completed

190. For the birth of the "Monte Carlo method," see Eckhardt 1987: 131–33. For background on polling-based simulations used to predict election results, see Jones 2012.

191. TM nr: 1845 = http://www.trismegistos.org/text/1845 (Clarysse et al. 2016).

192. TM nr: 58911 = http://www.trismegistos.org/text/58911 (Clarysse et al. 2016).

193. TM nr: 653675 = http://www.trismegistos.org/text/653675 (Clarysse et al. 2016). This is one of many book fragments that would not have been available for Roberts and Skeat to consider.

this task for all 4,757 texts, we have run a simulation against our data.[194] When we enter these texts according to the result of our simulation into half-century buckets, we get the breakdown of codex and roll counts (for 0–500 C.E.) printed in Table 5.

We can plot these percentages as before and get a familiar result (see Fig. 3), which is extremely heartening, considering that we are working with a much larger dataset and have picked a different method for generating our table. Every time we run the simulation, we should get varying results for the individual dates of each of the books, but within the ranges set down by the texts' editors and according to a Gaussian distribution.

It is conceivable, however, that the shape of the curve on our first simulation is due to chance selection. Therefore we re-run the simulation some number of times to validate the result. See Figs. 4 and 5 for results of the 10th and 100th run of our simulation. The curve in Fig. 4 is not as clearly an S-curve, while Fig. 5 shows much closer result. Our final graph from the effort (Fig. 6) clarifies our view, representing the average result of 10,000 simulations.[195]

The average result of our myriad trials is manifestly an S-curve. In fact, we can identify an S-curve generated by substituting T_0 = 327.09735942 and α = 0.02341740 into the equation $f(t)=\frac{1}{1+e^{-\alpha(t-T_0)}}$,[196] which has an *R2* value of 0.99511, nearly identical to our earlier finding (using the data from Roberts and Skeat) of 0.99560.[197] There can be no doubt that an S-curve is the best representation of the adoption of the codex in antiquity, in reviewing the results of this simulation on the more recent and comprehensive data from LDAB (see Fig. 7).

We have, though, neglected to exclude books identified as Christian from our sample. When we remove literary works identified in the LDAB with religion tagged as "Christian," we reduce our count of books to 3,930 and get a result in our first trial that is somewhat far from an S-shaped curve (See Fig. 8); but when we average the result of 10,000 simulations (Fig. 9), it also resolves into a fairly good S-shaped curve.[198]

194. This is the method that underpins the election forecasts of Nate Silver's *FiveThirtyEight*, in which his team takes the results of polls (like our book fragments), generates a probability average for the projected results, and runs 10,000 simulations to predict the outcome (Silver 2016).

195. See Appendix 1 for more detailed results and a link to the data.

196. An initial S-curve was generated using the method outlined in Brandwinder 2008. Then α and T_0 were varied from $\alpha-1/\alpha$ to $\alpha+1/\alpha$ by intervals of $\alpha/1000$, and from $T_0-1/$ to $T_0+1/$ by intervals of $T_0/1000$, and the combination was taken that produced an S-curve with the smallest mean-square-error against our datapoints.

197. See above, p. 198.

198. Because of the way we have grouped the results into buckets, and because we are running many simulations to pinpoint the date of each individual book with a distribution that extends somewhat past editors' start and end dates, our possibilities for error are greatly reduced by the law of large numbers. We also include small contributions from unlikely or unanticipated scenarios. Random errors cancel each other out, while systematic errors, such as any trend toward dating codices or rolls differently, would only shift our curve, not reshape it.

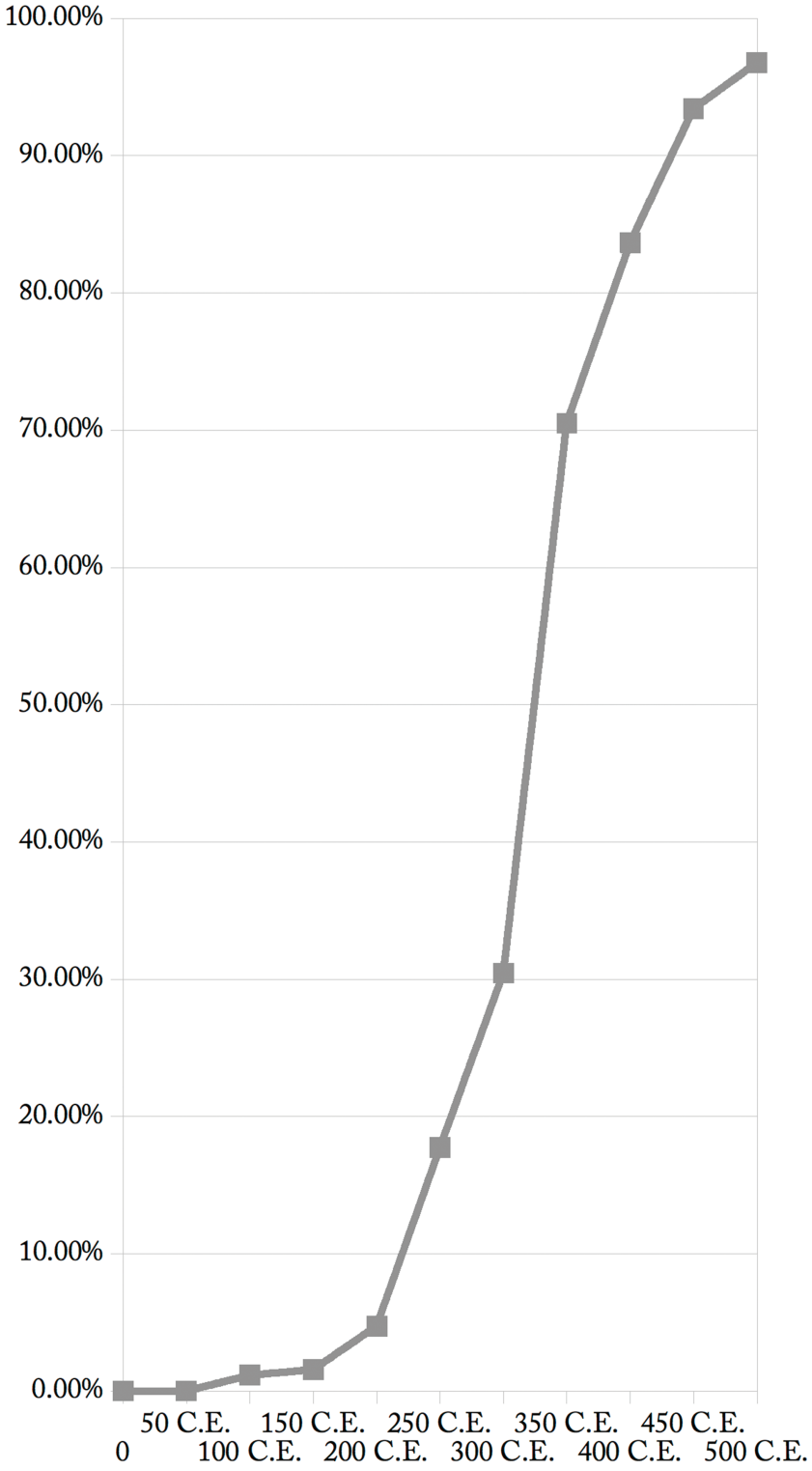

Fig. 3: Proportion of Codices to Book Rolls (LDAB Simulation, Pass 1)

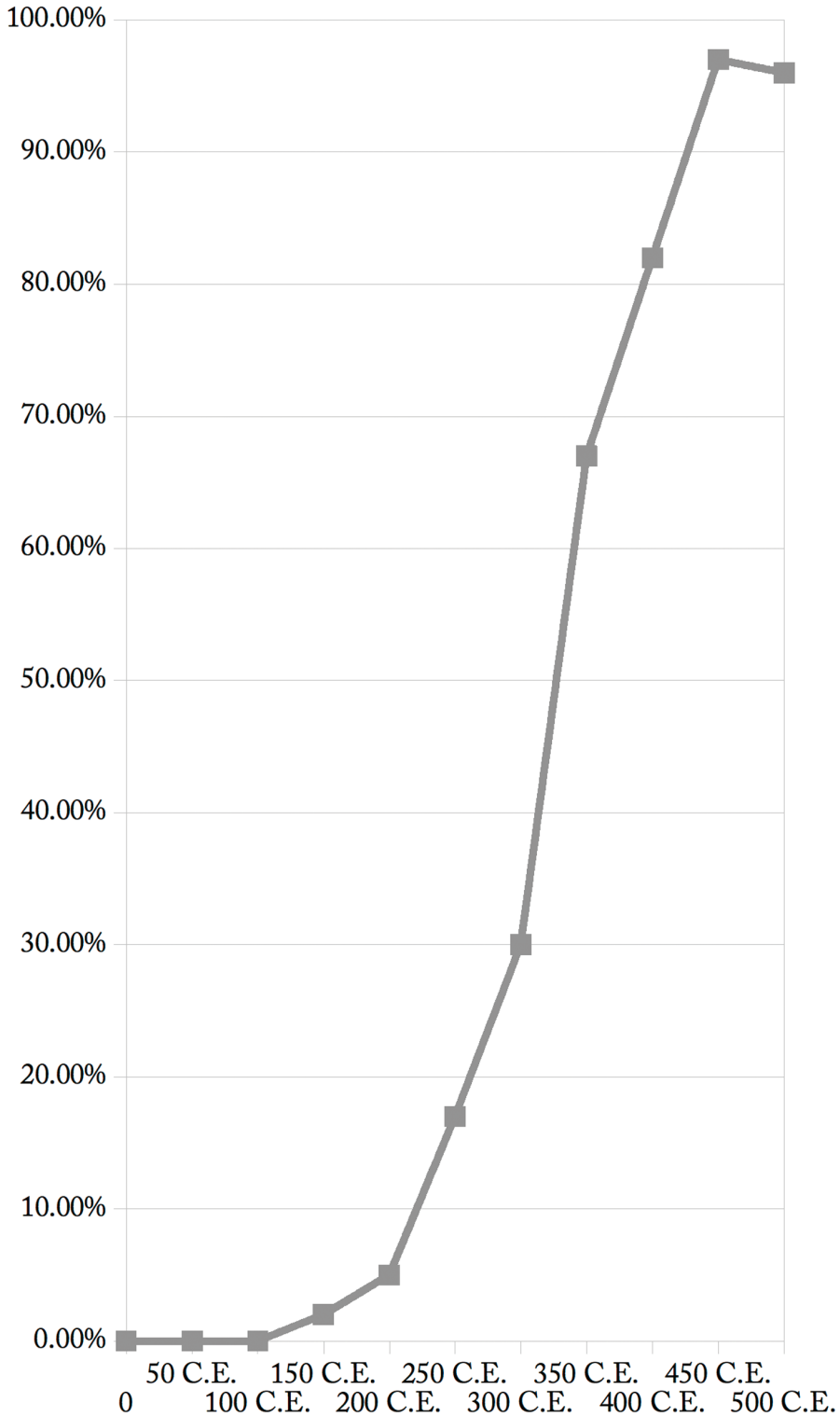

Fig. 4: Proportion of Codices to Book Rolls (LDAB Simulation, Pass 10)

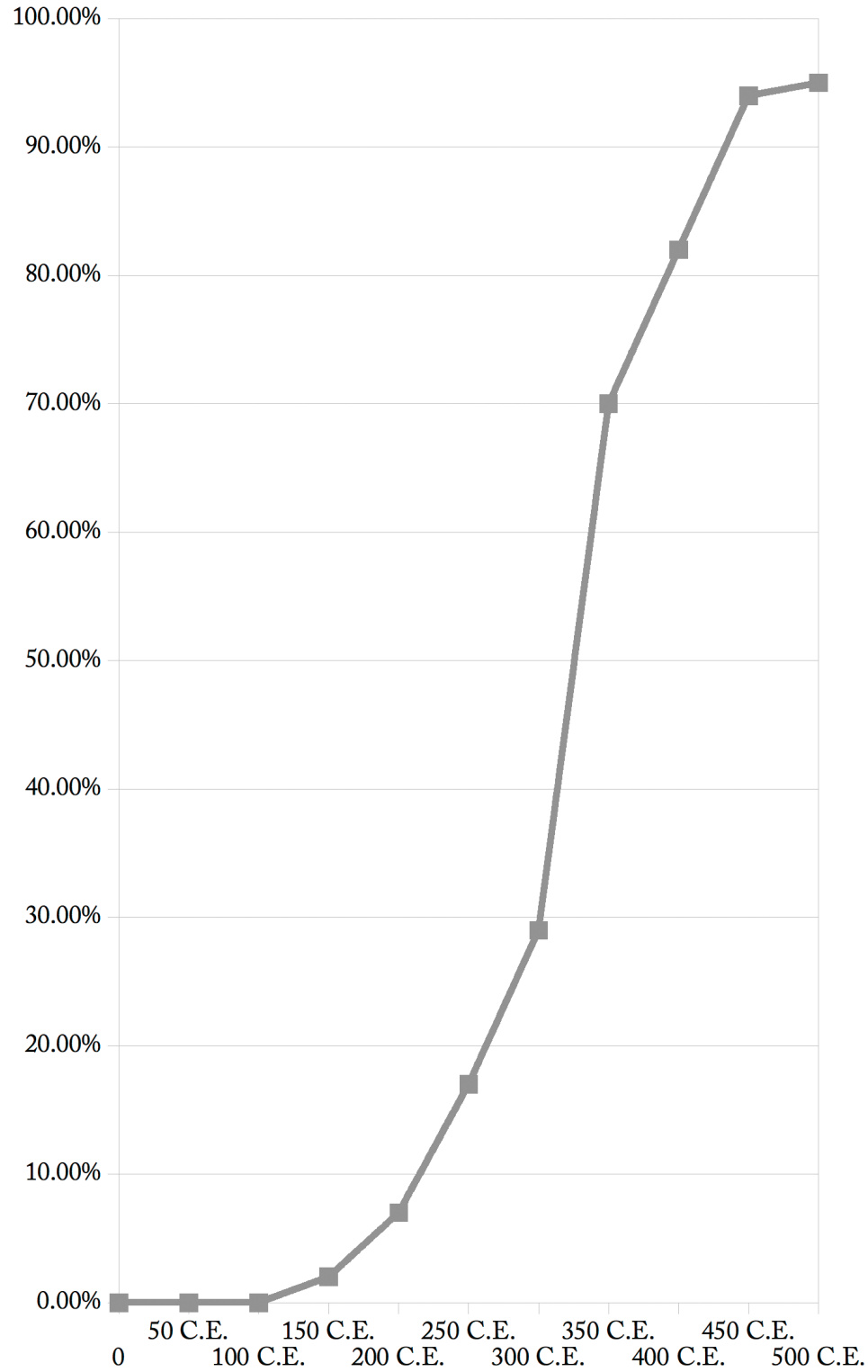

Fig. 5: Proportion of Codices to Book Rolls (LDAB Simulation, Pass 100)

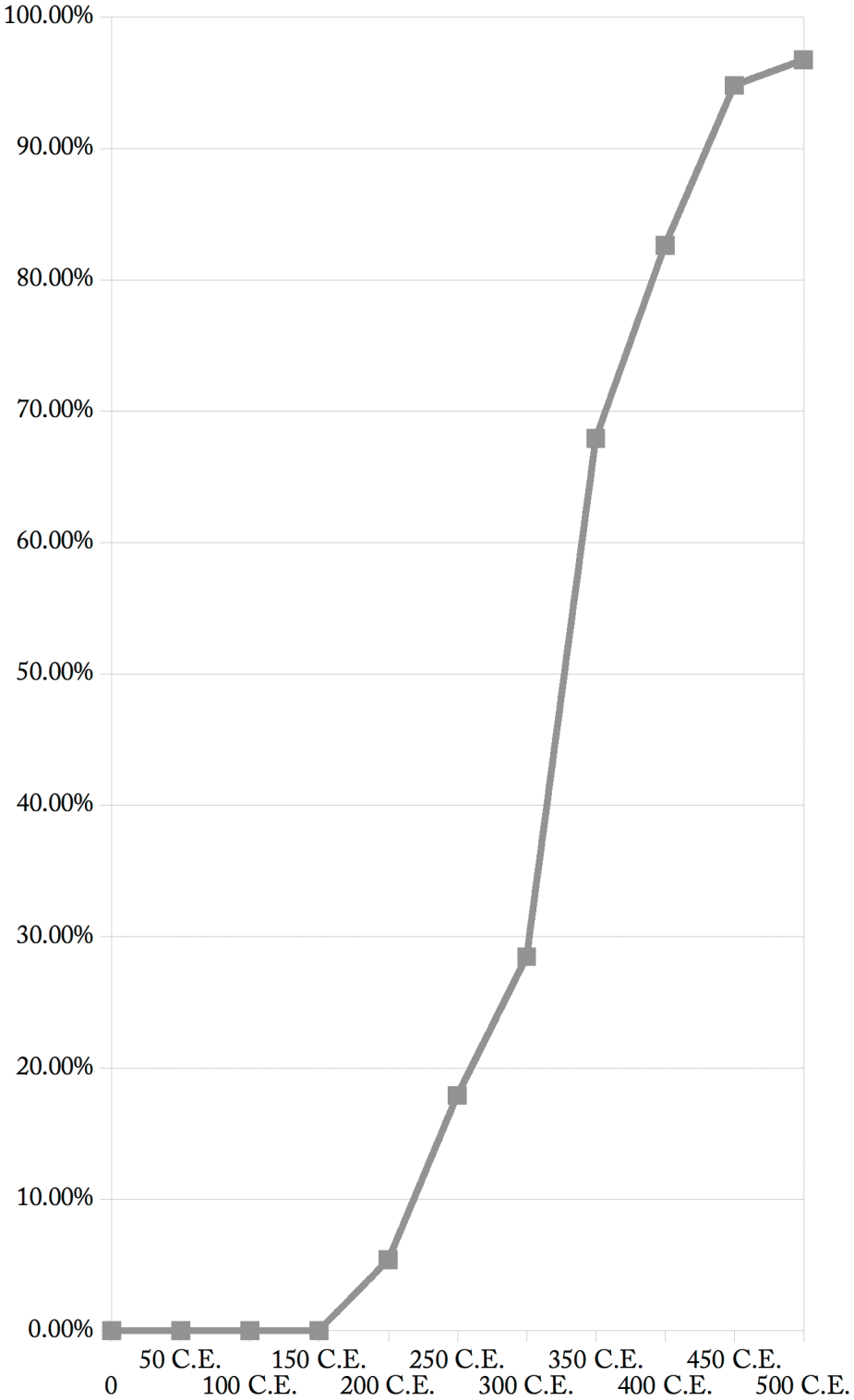

Fig. 6: Proportion of Codices to Book Rolls (LDAB Simulation, Average Result)

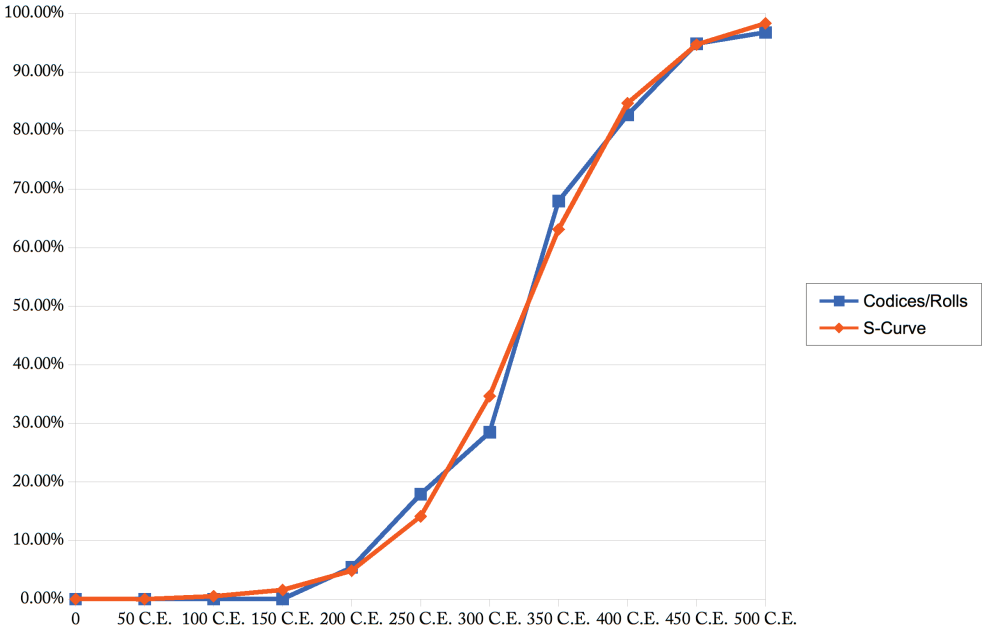

Fig. 7: Proportion of Codices to Book Rolls vs. "Best-Fit" S-Curve

In fact, the curve is so good that we are able to find values for T_0 and α such that the S-curve generated has an *R2* value of 0.99713, which is slightly better than before.

It is tempting to try to read something into the slightly better figure, but the difference between the *R2* values is only .02%. The safest conclusion remains that the diffusion of the codex was a population-wide phenomenon in which various social groups played a role, but that critical mass would have been achieved with or without the adoption by the Christian population.

IX. BIRTH OF THE CODEX, REVISITED

One interesting feature of our simulations from the LDAB data is that, focused on only non-Christian works, we find in the first century C.E., and even in some cases in the first century B.C.E., some small justification for an earlier debut of the codex than previously thought. We relied on a Gaussian distribution for our confidence intervals, which have somewhat short tails, restricting the chances of a long-shot prediction. If we used something like Fleishman's transformation[199] we would have even more increased the chances of seeing early codices. We consider non-Christian codices both because the Christian codices are already regarded as early by prevailing scholarly opinion, and because very early Christian codices cannot reasonably be thought to occur before the existence of Christianity, while non-Christian codices can.

199. As Nate Silver's team did in predicting the 2014 U.S. Senate outcome (Silver 2014).

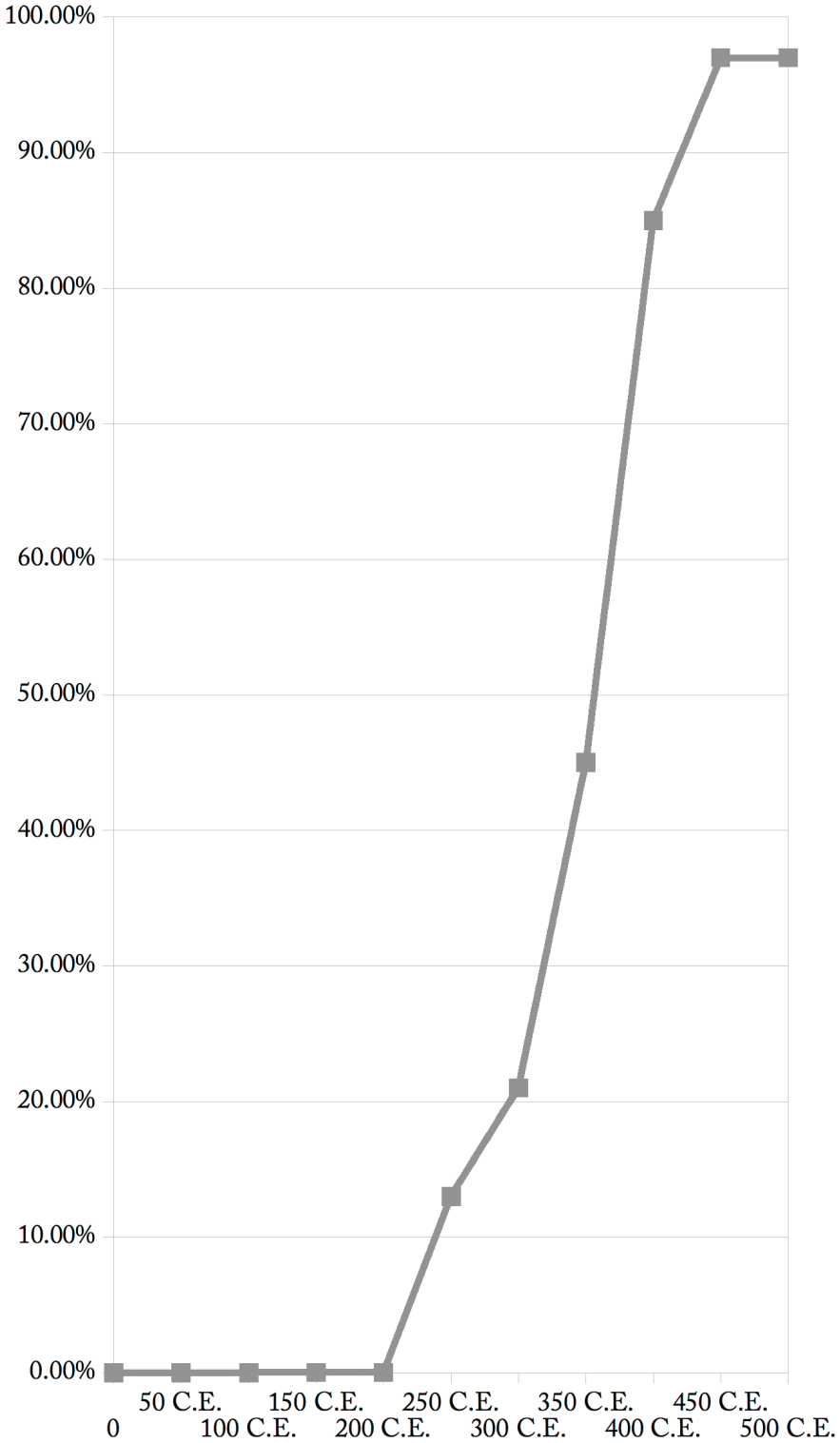

Fig. 8: Proportion of Codices to Book Rolls (LDAB Simulation 2, Pass 1)

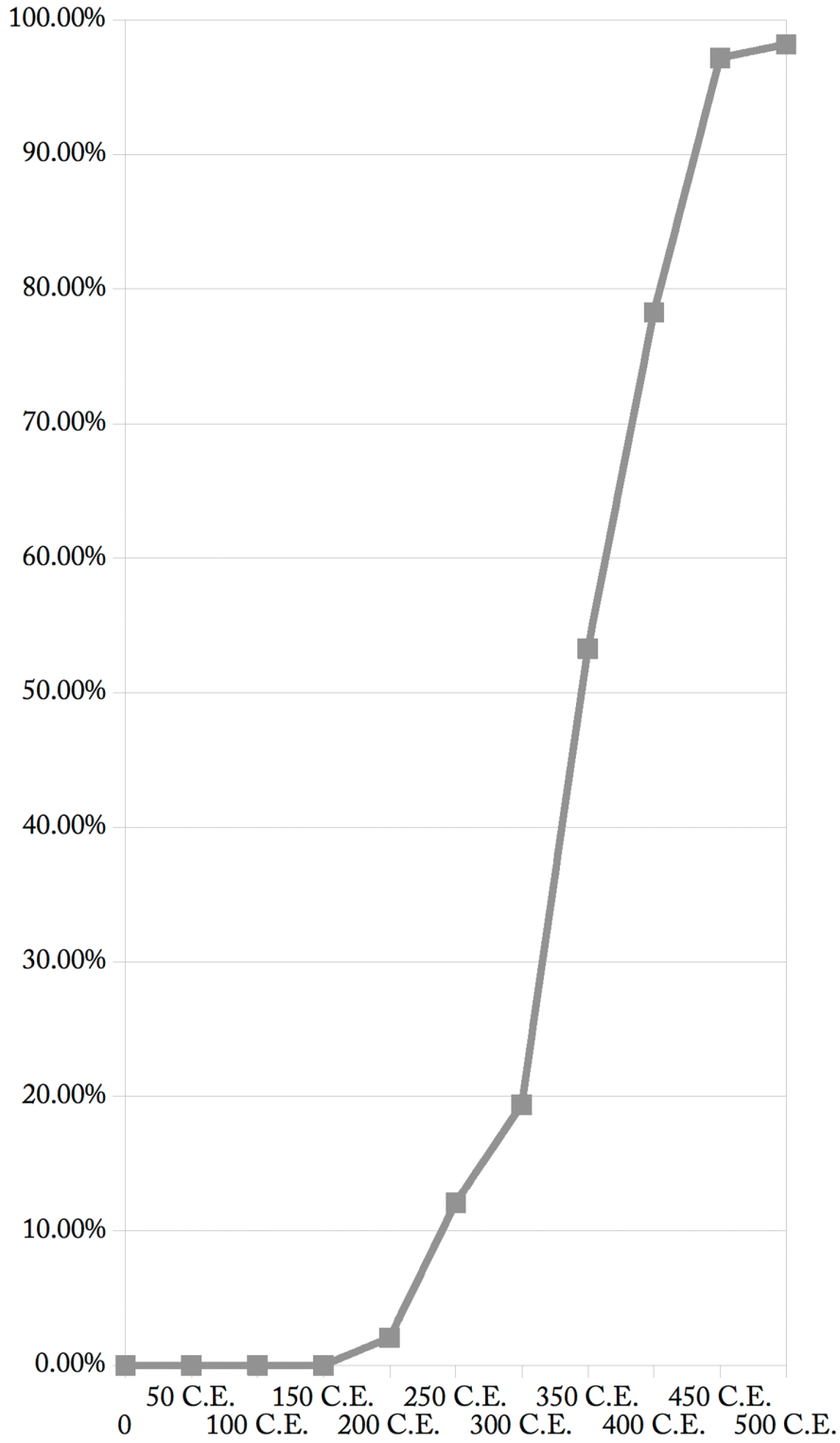

Fig. 9: Proportion of Codices to Book Rolls (LDAB Simulation 2, Average)

In Table 6, we see the frequency of the earliest non-Christian Greek codex by half-century, out of 10,000 simulations.

This chance of an early date for the non-Christian codex lets us consider the context for its invention: it places the outside bound for that invention roughly during the life of Julius Caesar and lends some credence to a theory introduced by C. H. Roberts from 1933, that a passage of Suetonius in the life of Caesar has something to say about the birth of the codex,[200] namely that Caesar may have employed sheets of papyrus folded into pages to send his dispatches from Gaul, a proto-codex. Roberts and Skeat, revisiting the issue fifty years later, find the passage in question tempting but ultimately judge the interpretation too uncertain for any conclusions (one suspects the outline of the data was not too encouraging either).[201]

Bolstered by our simulation and adding more recent scholarship I will briefly outline the argument. Suetonius writes: *epistulae quoque eius ad Senatum extant, quas primum videtur ad paginas et formam memorialis libelli convertisse, cum antea consules et duces non nisi transversa charta scriptas mitterent*.[202] That is, there are dispatches to the Senate which Caesar was the first to send in a particular form, of a memorandum book composed in *paginas* instead of as earlier *duces* and *consules* had sent them, written *transversa charta*, that is, across the papyrus parallel to the short side of the roll, with the sheet rotated 90 degrees from its normal direction.[203] This style of writing was common on Roman *diplomatas*, "double-documents" serving as postal passes and authorizations, requisitions, warrants, and certificates.[204]

It was customary for Roman governor-generals to send dispatches to the Senate; the contents of some of Cicero's from Cilicia are extant. These were usually sent as papyrus rolls, but victories were reported in the form of waxed wooden-tablets.[205] These dispatches were a highly stylized performance,[206] and, for Caesar, absent from Rome, challenging the aristocratic party,[207] and serving at the Senate's whim,

Table 6: Occurrences of earliest non-Christian Greek codex, by frequency out of 10,000 trials.

50 B.C.E. - 0	*0 – 50 C.E.*	*50 – 100 C.E.*	*100 – 150 C.E.*	*150+ C.E.*
3	127	1,917	4,638	3,315

200. Roberts 1933: 142.
201. Roberts and Skeat 1983: 19.
202. Suet. *DJ* 56.6.
203. Roberts and Skeat 1983: 19.
204. Meyer 2004: 190–91.
205. Osgood 2009: 338.
206. Osgood 2009: 339.
207. As a soldier, Julius Caesar wielded a sword; but in his contest for political power he wielded the pen, fighting civic battles with the written word. In 59 B.C.E. Caesar instituted the unprecedented practice of recording confidential proceedings of the Senate and made them public, an attack on aristocratic elite (Harris 1989: 206). While political writing existed in the second century B.C.E., Caesar's

were both a danger and an opportunity. Caesar's dispatches do not survive, but they were undoubtedly a success.[208] In 56 B.C.E., Cicero cited Caesar's dispatches in debate; despite opposition, Caesar's command in Gaul was ratified, and he received financing for additional officers and his four new legions.[209]

Caesar would have sought to set his dispatches apart, to break from traditional aristocratic forms. If he had written the dispatches traditionally, Caesar may have appeared more concerned with appeasing the Senate than serving the people.[210] Suetonius's discussion of Caesar's dispatches comes after a long section on his literary output, and some have thought that *libellus* means literally little book, to imply that Caesar rendered his reports more as a literary work than the standard dispatch.[211] But the adjective *memorialis* clearly points toward the conclusion that the dispatch was written in the form of a notebook. Still, Cicero could refer to taking notes *in libellum* without any adjective;[212] hence *memorialis* seems at the same time superfluous.

Suetonius, who had access to the Imperial archives and who could comment on the quirks of Augustus's handwriting,[213] must have seen these dispatches with his own eyes. Question of form and content is tangled into Suetonius's labored syntax, which must be communicating a complex thought, for he would not use so "cumbrous [a] phrase for a simple idea."[214] I contend that Suetonius is addressing both form and content here: *memorialis* ties the content to a more personal perspective, drawing on one's memory and subjective experience. These dispatches may have been the sourcebooks for his commentaries, would have conveyed a more active and personal role for Caesar, and certainly fulfilled the same propagandistic purpose of showing his actions in the best possible light.[215] The Caesar of the *veni, vidi, vici* letter[216] is not likely to have written with the pompous obsequiousness of Cicero dispatching to the Senate from Cilicia.[217]

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commentaries on the Gallic and Civil wars took propaganda to a new level (Harris 1989: 211). Even in battle Caesar employed words, scattering written pamphlets into the armies of Scipio Nasica, an attempt to convert the soldiers to his cause (Harris 1989: 253n.413). In fact, the pen itself was Caesar's last weapon, if Suetonius is to be believed: as he was being stabbed in the Senate house, Caesar drove his stylus into Casca's arm before receiving his final wound (Suet. *DJ* 82). He was a consummate master of communication when the use of the written word was gaining wider currency in economic and social spheres with expanding Roman rule (Harris 1989: 175).

208. Osgood 2009: 339.

209. Osgood 2009: 340.

210. Osgood 2009: 350.

211. Roberts 1933: 139, an opinion shared by Kenyon and Turner (Roberts and Skeat 1983: 19n.4).

212. Roberts 1933: 141.

213. Small 1997: 23.

214. Roberts 1933: 139.

215. Osgood 2009: 339.

216. Suet. *DJ* 37.

217. *Fam*. 15.1 = SB 104, 15.2 = SB 105.

Pliny the Elder marvels at the mental powers of Caesar to dictate four or even seven letters at once, or to write or read and dictate simultaneously.[218] Dictation was common for all kinds of writing in antiquity, and every notable writer had access to scribes.[219] Quintilian, however, enumerated problems with scribes: that they wrote slowly, or lacked intelligence, but most of all complained of the absence of privacy when dictating.[220] It was not uncommon for more personal letters to be written in the author's own hand: Cicero apologizes in one of his letters to Atticus for employing a scribe.[221] Were Caesar to have written his dispatches himself, it would have had the added benefit of transmitting his autograph hand to be seen at Rome. Among the elite, autograph writing was valued as a sign of familiarity, though due to a dependence upon literate slaves it would not always be done well or legibly.[222] Lucian, in the second century C.E., suggests that personal handwriting was sufficiently valued that autograph copies of literary manuscripts were appreciated as collectibles.[223]

The codex form, then, would have been ideally suited to writing in columns, would have fit more content, and would have echoed the tablet format of victorious reports while setting Caesar's dispatches apart from the aristocratic form of rolls. This codex notebook would have been papyrus, since Suetonius pointedly mentions papyrus in the dispatches of former governors and generals, and since papyrus was the stubborn mainstay of army life.[224] Caesar, with an eye toward writing his commentaries, would have found the codex format attractive both for its capacity and for its ease of reference. The explicit mention of writing *in paginas,* that is, columns, has been singled out as an indication that Caesar highly valued this latter feature.[225]

In Suetonius, *libellus* is used elsewhere to refer to petitions.[226] The petition was common in Roman life, a way for ordinary people to submit their desires to the powers that be.[227] These *libelli* were short messages,[228] likely to be on single sheets. Caesar went to his death in the Senate house with his left hand full of *libelli*.[229] If Caesar had some such sheets of papyrus, and rotated them 90 degrees, and wrote in columns across them, the sheets could be stacked together, folded, and consulted like a codex book. The stack of papyrus sheets held in the hand

218. Plin. *NH* 7.25.91.
219. Small 1997: 151.
220. Quint. *Inst*. 10.3.20–21.
221. Small 1997: 151.
222. Harris 1989: 249.
223. Small 1997: 24–25.
224. Roberts and Skeat 1983: 19n.5.
225. Osgood 2009: 339.
226. Roberts 1933: 140.
227. Harris 1989: 214.
228. Harris 1989: 215n.207.
229. Harris 1989: 215 (discussing Suet. *DJ* 81.8).

and folded seems a more rational archetype than the wooden tablet,[230] with the name *codex* applied later by analogy.

There is no question that Caesar was an innovator. Whether he was responsible for the codex form is unlikely; what is likely is that Caesar was highly invested in the written word and in taking advantage of the latest in communication. More importantly, Caesar lived at a time when literacy was spreading along with the use of written material for administration of an expanding Rome. In the army alone, writing was an essential part of communication and record-keeping, where extensive use was made of it, among other things, for financial records, inventories, requisition orders, daybooks, and duty rosters.[231] Similarly the fax machine in modern times was invented long before it became a useful tool. It was made useful by our communication patterns altering around it, and then spurred to adoption as a critical mass of innovative and early adopter individuals took advantage of it.[232] If not Caesar, others would or did latch on to this invention and innovate. So with the codex, its latent existence in sheets of papyrus,[233] waiting for the needs of society to catch up with it.

One final note: the sheer variety of materials, sizes, and styles of the early codices show that knowledge of the codex form, transmitted by the codex itself, was re-invented by the scribes who employed it.[234] As time passed, codices grew, and the texts they contained gained tables of contents, page numbers, columns, punctuation, and illustrations.[235] This degree of reinvention is consonant with a model of diffusion as a decentralized system where innovations arise at the operational level and then spread over peer networks horizontally, as opposed to a centralized system where the innovation is introduced by a change agent after a research and development process, with adopters serving as their own change agents.[236]

X. CONCLUSION

The other day, I found myself running my index finger along the surface of a print book, suddenly (and surprisingly to myself) frustrated that the motion had not highlighted the passage, as it does when I perform the same action on my tablet. The codex book is not so superior after all! The adoption of a new technology is

230. Which most claim as its origin, as van Haelst (1989: 14) does: "L'origine matérielle, physique du codex est la tablette à écrire."

231. Osgood 2009: 334.

232. See above, p. 200.

233. Although these sheets were probably cut from rolls of papyrus (Turner 1977: 44–45), just as paper today is cut from the rolls in which it is manufactured (see it in process: https://www.youtube.com/watch?v=oeZ_NVYuMmw).

234. See an example of the variety by looking at the list of codices and their sizes, number of columns per page, material, etc., in Turner 1977: 102–85.

235. Harris 1991: 80 and discussion in Small 1997.

236. Rogers 2003: 395–98.

spurred by uncountable moments like this, followed by countless choices which over time lead an individual to more and more reach for a particular object over a competing form; not an isolated process, but a social one, in which the sum of decisions of other members of that person's social group, and the past decisions also rate. Though I had heard of their advantages, I had resisted the idea of getting a tablet for reading until I saw a woman doing just that, highlighting passages while she read near me on the subway.

A historian, looking back, wonders why the codex was not adopted much more swiftly: "It has taken over 2500 years to develop this object [the book] we take so much for granted . . . It would not seem to take a very great leap of the imagination to use sheets of papyri instead of bulky tablets . . . Yet the first major attempt to produce a codex was not made until the first century [C.E.]"[237] Diffusion of innovations theory tells us that people championing a change, and diffusion researchers themselves, have a strong bias towards innovation.[238] Historians, too, are very different from the people we study,[239] and this difference can be difficult to overcome, especially where the difference is subtle.

Skeat was on the right path when he famously experimented with wallpaper rolls to show that with some practice the use of a book roll could be very convenient,[240] and thinking about the advantage of being able to unroll a decent amount of book onto a table and look at different pages shows that our conception of what is advantageous is intensely relative to what we read, how we read, and where we read. But Skeat's exercise remains unconvincing for us because we are too conditioned by our own experience of books. When we consider the advantages of portability, capacity, and ease of reference to an individual in the ancient world, we must consider them relative to that person's needs. The codex was not adopted rapidly for general literary use because it was not perceived, for most people, for a long time, as having sufficient relative advantage over the book roll and may have been incompatible with their needs. At the same time, the codex was adopted quickly for some uses and by some populations, in places where its relative advantage was quickly perceived.

A solid framework, like diffusion of innovations theory, can help to rationalize the understanding of this process and to shed our innate biases as we try to understand the past from the fragmentary picture the data afford, and from the vantage point of the future, where some technologies have caught on and others have long faded away. Most importantly, in the case of the codex, the two differing approaches (namely the reorganizing of Roberts and Skeat's data and running simulations against the dates from the LDAB, which gave us the S-shaped curve of diffusion of innovations theory), remind us that our data are not inscrutable

237. Small 1997: 9.

238. Rogers 2003: 106–10.

239. Change agents often badly misunderstand the needs of their individual targets (Rogers 2003: 375).

240. Skeat 1990.

and that the inevitable adoption of a technology can be secured once a fraction of users and use-cases have been won over.

This article may seem to be heavy on data manipulation, formulas, and simulation. But we started from the primary sources, and discovered that their interpretation and understanding is dependent on an understanding and interpretation of the physical finds. It was necessary to reevaluate that understanding in order to provide a better framework for interpreting the evidence in the few primary sources, both what was said in them, and what was left out.

A reader will note that Roberts and Skeat, as well as the investigations of a host of other worthy scholars on the problem of the codex, continue to be cited throughout this work, despite having to set aside from time to time the conclusions tentatively reached. My aim is not to replace but to complement earlier work and to act as a guide for future more detailed and more learned study of the subject. Nor is this article intended to be exhaustively comprehensive, but attempts to address the major primary and secondary literature where they are required to motivate or execute our statistical approach, or are illuminated by it.

We are no longer compelled to find a reason for the triumph of the codex for literate Roman society in the ideological influence of a subgroup of individuals, but to the society at large; and at last we can reconcile the debate over the codex by a realization that practical considerations were evaluated by diverse individuals in a cultural and social context. We have also been able to cast off the prejudices of our own social and cultural context.

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APPENDIX 1: SIMULATIONS

The full results of the two sets of simulations I ran on the LDAB data are available on GitHub for download.[241] These include two tab-separated files. One contains the results of 10,000 simulations on texts from the LDAB matching these characteristics: Greek for the language (or as one of the languages), origin or discovery in Egypt, in codex or roll form, in material parchment or papyrus, and identified as culture: "literature." Each row has the TM nr for the text, the type (roll or codex), followed by the start and end dates of the date range as determined according to the method on p. 215, followed by the midpoint of those dates and the resultant standard deviation if the start and end points had represented 2 standard deviations from the midpoint. These columns are followed

241. https://github.com/benjaminharnett/ldab_simulation_results

by the results of each simulation, first the individual date determined, then the "bucket" that date is placed in. E.g.:

1845 roll −263 −229 −246 8.5 −242 −3 . . .

This file is called simulation_1.tsv.

A second file, simulation_2.tsv, is in the same format but with fewer rows, as it excludes any text which has been tagged with religion: Christian.

There are six additional files, three for each simulation run. A first file has been generated which shows only the frequencies of codices against roll for each of the numbered buckets, which are converted to dates, taking the final year (in fact, the bucket ends on the last day of the previous year) of each bucket for graphing. This is called simulation_n_freq.tsv, where n is the number of the simulation (1 or 2). A second file called simulation_n_avg.tsv (n=1 or 2) contains only the average for the 10,000 simulations. The final file, simulation_n_sc.tsv contains the best-fit S-curve for the respective simulation.

The frequency files were used to make the graphs in the article, and also produced these two graphs using d3.js (with basis interpolation), showing all the simulations plotted together.

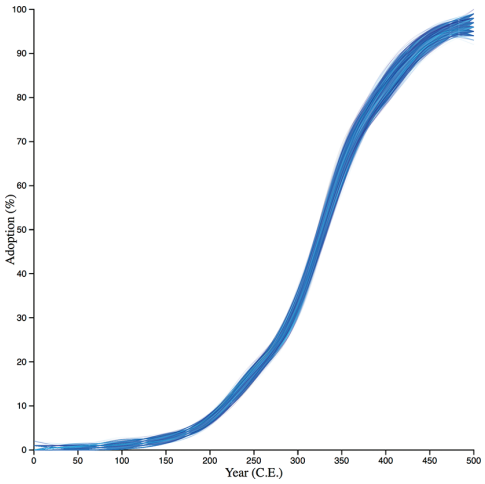

Fig. 10: Simulation 1–10,000 trials

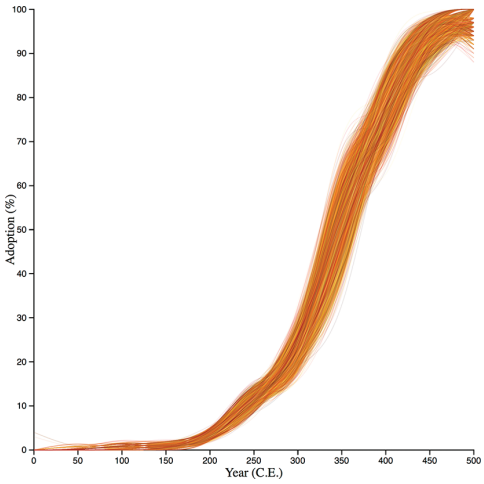

Fig. 11: Simulation 2–10,000 trials

APPENDIX 2: CHRISTIAN POPULATION

In 1998, Keith Hopkins proposed a "parametric" method for estimating the Christian population in the first four centuries C.E., a mathematical model based on a few assumptions pulled from historical sources and general scholarly consensus: an initial population of 1,000 Christians in 40 C.E. and Christians making up 10% of the Roman population around 300 C.E. He opposed it to the inductive method and tagged it as "speculative" and probabilistic, an estimate and a "boundary against

which to test other conclusions."[242] Like his article, this one strives to demonstrate how "the same 'facts,' differently perceived, generate competing, but complementary understandings."[243]

Since religion, like technology, spreads through a network of personal connections,[244] we can apply diffusion of innovations theory to add some nuance to Hopkins's model of the fraction of Christians in the Roman population. While, alongside Hopkins,[245] we grant that "Christianity" had a fluid, changeable definition through the early centuries, so that the Christian of the second century is of a decidedly different character than the Christian of the fourth or fifth, for the purposes of a general picture of the growing population we collapse these distinctions.

Instead of straight exponential growth, we program Hopkins's same assumptions into an S-curve model.[246] We start with 1000 Christians in 40 C.E. out of a population of 60 million Romans (a shade more than $1/1000^{th}$ of a percent or effectively 0), and a 10% share in 300 C.E. Per Hopkins's model, with constant growth, total adoption of Christianity is achieved somewhere between 369 and 370 C.E. We set our target, somewhat arbitrarily, at 95% by 400 C.E. With these numbers, following our earlier method,[247] we find values for T_0 and α which generates an S-curve which is the closest match to these points. We find the best match at $T_0 = 345.364576699999$ and $\alpha = 0.0418499999999969$, and we tabulate the results by 50-year intervals as follows:

Table 7: S-curve vs. exponential growth models for Christian population growth.

Year	*S-Curve Model %**	*Number of Christians**	*Hopkins's Model*
50 C.E.	0.00043%	257	1,400
100 C.E.	0.00347%	2,082	7,400
150 C.E.	0.0281%	16,875	40,000
200 C.E.	0.2275%	136,499	210,000
250 C.E.	1.81%	1,088,744	1,100,000
300 C.E.	13.03%	7,816,649	6,000,000
350 C.E.	54.83%	32,900,796	32,000,000
400 C.E.	90.78%	54,465,129	§60,000,000

* In the first few buckets we include only a few digits in the percentage as the numbers are very small. Our estimated number of Christians is rounded to nearest whole number. Based on a total population of 60 million. §Hopkins's estimates stop at 350 C.E., but extrapolate to total adoption before 400 C.E.

242. Hopkins 1998: 192.
243. Hopkins 1998: 186.
244. See above, p. 203.
245. Hopkins 1998: 187.
246. This exercise for the Christian population is suggested in Bagnall 2009: 19, though he does not follow through on it, since the low numbers of the early Christians suggested by a constant growth rate are sufficient for his argument about the dating of Christian books.
247. See above n.197.

Our model tracks Hopkins's fairly well in the last century and a half but is skeptical of the size and growth rate of the Christian population in the first two. It projects significantly smaller Christian populations between 100 and 200 C.E., but a larger burst of growth to 250 C.E. This nicely points to an even stronger case for the pressures triggering the Decian persecution, with the number of Christians surging from fewer than 150,000 to over a million in just fifty years.

Finally, we graph the adoption curve of Christianity against the best-fit S-curve for the average result of our simulations of the LDAB books[248] to show the contrast between the two adoptions (see Fig. 12). What the graph shows is two similar but separate adoptions, with the adoption of the literary codex taking off about a century before Christianity, while Christianity, starting later, shows significantly faster growth.

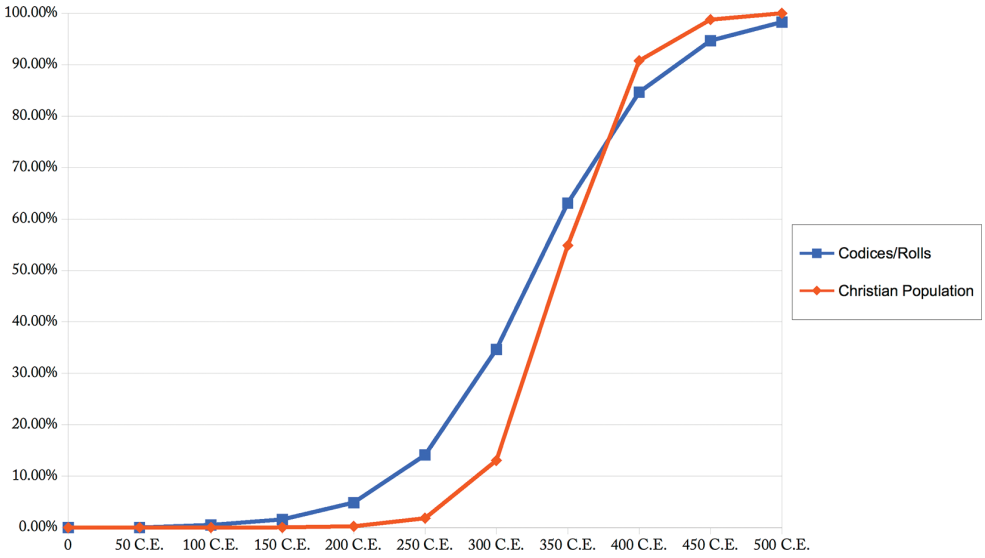

Fig. 12: Proportion of Codices to Book Rolls vs. Adoption Curve of Christianity

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248. From Fig. 7 above.

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