Analysis of the Talpiot Tomb
Using Bayes' Theorem and Random Variables

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Abstract

We analyze the Talpiot tomb, which has been alleged to be the family tomb of Jesus of Nazareth. Using Bayes' Theorem, we derive a simple function that estimates the probability that the tomb houses the remains of Jesus and his family. Unfortunately, this function cannot be evaluated exactly, because several of the key parameters are unknown. By using random variables with reasonable probability distributions, we examine the mean behavior and range of the function under a variety of conditions. We conclude that the probability is low (on the order of 2% or less) that the Talpiot tomb is the family tomb of Jesus of Nazareth.

Introduction

In March of 2007, Emmy award-winning producer Simcha Jacobovici and his collaborators released a documentary [7] and book [8] alleging that a tomb excavated in 1980 contains the ossuaries of Jesus of Nazareth and several members of his family. Jacobovici enlisted the help of statistician Andrey Feuerverger and claimed that the odds were roughly 600 to 1 that the Talpiot tomb is in fact the family tomb of Jesus.

In this article, we will sketch an alternative estimate of the probability that the Talpiot tomb is the family tomb of Jesus of Nazareth. Any such calculation is obviously going to be an

approximation. A number of complex issues muddy the water. We will be content to make a simple calculation using Bayes' Theorem and evaluate the result in a random simulation.

This paper is organized as follows. We will first briefly review the relevant aspects of the tomb as they apply to our statistical calculations. We'll then lay out the equation for the probability that the tomb belongs to Jesus of Nazareth; the equation follows from Bayes' Theorem. Next we'll describe some of the complications and will explain how we propose to deal with them. Then we'll derive an analytic formula for the probability function. Because the data is fuzzy, it is impossible to evaluate this formula exactly, although it can be simulated numerically by making some reasonable approximations. We'll describe our calculational methods using Java classes that simulate random variables of arbitrary distributions. Finally, we'll describe the results of a baseline calculation, and several variations on it.

The Talpiot Tomb

The facts of the Talpiot tomb are described at some length in Feuerverger's article [4]. We believe that his method of statistical analysis is a very useful approach for difficult problems like the Talpiot tomb. Our main argument with his article lies in certain of his "a priori hypotheses" (APH 1 through APH 8) and assumptions (A.1 through A.9). For simplicity, our calculations here will use a Bayesian analysis that allows us to do most of the computation analytically, leaving only a few random variables that require numerical simulation.

In writing this article, we are drawing on discussions with several scholars and casting those discussions into a form suitable for statistical analysis.

The tomb contained ten ossuaries, holding the remains of an unknown number of persons. It has been estimated [10] that as many as 35 skeletons may have been interred in the tomb, but this is speculation.

Four of the ossuaries were uninscribed. The other six ossuaries bore inscriptions which we will transliterate [with translation in brackets] as follows:

1) "Yeshua bar Yehosef" [Jesus son of Joseph]
2) "Yehudah bar Yeshua" [Judah son of Jesus]
3) "Marya" [Mary]
4) "Yoseh" [Joses]
5) "Matya" [Matthew]
6) "Mariamenou Mara" [diminutive form of Mary, followed by "Mara" which may be a short form of "Martha" or may mean "Master". The precise reading of this inscription has been much debated.]

Simcha Jacobovici [7], [8] identified ossuary #1 with Jesus of Nazareth; ossuary #2 with a previously unknown son of Jesus; ossuary #3 with Mary the mother of Jesus; ossuary #4 with Joses, one of the four brothers of Jesus; ossuary #5 with a previously unknown relative of Jesus; and ossuary #6 with Mary Magdalene.

These identifications raise some "interesting" theological questions. We can make no comment on those issues here. The statistical problems are difficult enough. We'll sketch the statistical issues below for each ossuary in turn.

Ossuary #1: "Jesus son of Joseph"

Both "Jesus" and "Joseph" were common names in first-century Jerusalem. The standard reference work on the frequency of Jewish names was compiled by Tal Ilan [6]. "Jesus" was borne by about 4% of men, while "Joseph" was the name of about 8.8% of men.

The number of adult men who died in Jerusalem during the period when ossuaries were in use is not known. The best estimate seems to be by Camil Fuchs [5], summarized in section 8

of Feuerverger's article [4]. Fuchs estimated the number of adult male deaths to be 36420. This is of course overly precise, but the magnitude is quite reasonable. The true number is probably in the interval [25000, 50000].

For definiteness, we'll accept Fuchs' number and estimate the number of men named "Jesus son of Joseph" to be (.04)(.08)(36420) = 128. One of these men was Jesus of Nazareth. The other 127 are unknown to history.

Define N_J = the number of men named "Jesus son of Joseph" who died in the relevant time period. We have estimated:

$N_J \approx 128$

The question to be decided is whether the Talpiot tomb belongs to Jesus of Nazareth or to one of the approximately 127 unknown men named "Jesus son of Joseph". As a very rough first estimate, we compute a probability of 1/128 that the tomb belonged to Jesus of Nazareth. In the rest of this article, we'll refine this estimate using Bayes' Theorem.

Ossuary #2: "Judah son of Jesus"

The ossuary inscribed "Judah son of Jesus" creates a serious problem for Jacobovici's "Jesus family tomb hypothesis." The reason is that no son of Jesus is known in the historical record. It is *possible* that Jesus had a son. In his culture, this would also imply that he was married. It is *possible* that Jesus was married. Most historians would consider both possibilities quite unlikely.

In first-century Jerusalem, most Jewish men were married and did their best to fulfill the Biblical commandment to be fruitful and multiply. While it is impossible to estimate precisely the probability that Jesus might have had a son, we can say with high confidence that Jesus of Nazareth was less likely to have had a son than were other Jewish men of his time. Recall that

Jesus had four brothers who assumed positions of influence in the early Jesus movement. If a son also existed, he would likely have joined his uncles in a position of influence and we would have heard of him. Since we have not heard of him, he likely did not exist.

Mathematically, we can form a ratio: the probability that Jesus had a son, divided by the probability that other Jewish men of his time had a son. We'll use the symbol ρ_{son} to represent this ratio. We can assign it both an upper and lower bound:

$$\rho_{son} \in [0,1]$$

Most historians would say that ρ_{son} lies near the lower end of this interval, but for our baseline calculation, we'll make no such assumption.

Ossuary #3: "Mary"

The Aramaic name "Marya" is the short form of "Mariam."

Ilan's data says that about 23.3% of women in first-century Jerusalem bore some variant of this name [6]. About 29.5% of such women who were buried in inscribed ossuaries had the short form "Marya." Feuerverger's assumption A.3 asserts that "Marya" is the most appropriate form for the mother of Jesus of Nazareth [4].

There are two reasons for rejecting this assumption.

First, Stephen Pfann compiled a list of all occurrences of "Mary" in the New Testament and found that the mother of Jesus was called by the long form "Mariam" 13 times and the short form "Marya" only 6 times [12].

Second, we have discussed the issue of short forms versus long forms via email with various scholars, including Richard Bauckham, Mark Goodacre, and Stephen Pfann. The consensus as we understand it is that most Marys could be called by either form, depending on social context, and one can't predict which form would be inscribed on the woman's ossuary.

We conclude that the "Marya" inscription in the Talpiot tomb could refer to 23.3% of the Jewish women in first-century Jerusalem, and that Mary the mother of Jesus was one of these.

The data does not support the assumption that the mother of Jesus would most likely have had the inscription "Marya" on her tomb, nor that only 6.9% of Jewish women were likely to have had their ossuaries inscribed in this way.

Ossuary #4: "Joses"

The Aramaic name "Yoseh" is the short form of the formal name "Yehosef." In English, the short form is often translated as "Joses," while the long form is translated "Joseph."

Ilan's data shows that about 8.8% of all men were named with some variant of this name. Of such men whose names were inscribed on ossuaries, about 15.2% had the short form "Yoseh." [6]

Feuerverger's assumption A.3 asserts that "Yoseh" is the most appropriate form for the second brother of Jesus of Nazareth [4].

As with "Marya," this assumption cannot be proven, although it is more plausible in this case, for reasons to be explained shortly.

The first issue is that the data for the second brother of Jesus is very sparse in our only early source, the New Testament. This brother is mentioned just twice. Mark calls the brother "Yoseh," while Matthew calls him "Yehosef." With only two data points, the variance on the data is too large to make any firm conclusion.

There is simply no reason to believe that the brother of Jesus could *only* have been known by the short form "Yoseh" on his ossuary. We have consulted with scholars and the consensus is that either form could plausibly have been used.

This leads to the second issue, which muddles the matter even more.

The scholars we consulted noted that in the family of Jesus, since the father's name is Yehosef, it is more likely that any son in the family named after the father would go by the short form "Yoseh" so as to distinguish between the two.

But this is equally true of *all such families*.

We are given a tomb with an inscription "Jesus son of Joseph." The patriarch of this family is Joseph (in Aramaic, "Yehosef"). We must conclude that if there is an ossuary for a Joseph in this tomb, it is somewhat more likely to be inscribed "Yoseh" than it would under ordinary circumstances.

We can't say how much more likely, but it is *more likely*. If we did not know that the patriarch of the family is "Yehosef," then Tal Ilan's data would tell us that any Joseph has a probability of about 15.2% of having his ossuary inscribed as "Yoseh." But since we know that the patriarch of the family is "Yehosef," then this probability lies on the interval [.152, 1.0].

We have no way to estimate the actual value, so we simply note that this is the range of possible values.

Ossuary #5: "Matthew"

Just about everybody assumes that the ossuary inscribed "Matthew" is a neutral piece of data. There is no particular reason to believe that the family of Jesus was either more likely or less likely to have a person named "Matthew" than was any other family in first-century Jerusalem. Feuerverger assigns no weight to this data and we agree with him on this point.

Ossuary #6: "Mariamenou Mara"

This ossuary has provoked massive controversy, most of it on linguistic issues that don't concern us here. In the documentary and book by Jacobovici, he made much of this name,

claiming that it was unique to Mary Magdalene, in much the same way that "Ringo" was unique to Richard Starkey of the Beatles [7], [8].

This assumption is simply wrong. Jacobovici misunderstood the work of Francois Bovon, who had done a study of a fourth century document, the Acts of Philip, which tells a tale of Mary Magdalene. Bovon has repudiated Jacobovici's interpretation on the web site of the Society of Biblical Literature: "I do not believe that Mariamne is the real name of Mary Magdalene." [2]

Richard Bauckham analyzed the inscription in detail and concluded that we have no evidence that Mary Magdalene ever went by this name. [1]

Stephen Pfann has argued that the inscription itself has been misread, and that it should be read as "Mariame and Mara" (i.e., "Mary and Martha.") [12] He points out that the first half of the inscription "Mariame" is in a different hand than the second half "and Mara."

Pfann's argument is not universally accepted, but he also tabulated the various mentions of Mary Magdalene in the New Testament. He found that she is called by the longer form "Mariam" four times and by the short form "Maria" 10 times. No first-century document refers to Mary Magdalene by "Mariamne" or any variant of it.

We have belabored this point because it gave Feuerverger's calculation enormous illicit "leverage."

Feuerverger's assumption A.7 asserts that this inscription is "the most appropriate specific appellation for Mary Magdalene from among those known." Based on this, he assigns it an extra probability factor of (1/44) which is completely illegitimate.

We have consulted various scholars and the consensus is that if one finds the inscription "Mariamenou Mara," it is neither more likely nor less likely to refer to Mary Magdalene than to any other "Mary" of Jerusalem.

We can estimate that about 8500 women in first-century Jerusalem bore the name Mary. Given the data we have, the ossuary bearing the inscription "Mariamenou Mara" is equally likely to refer to *any* of them. One simply can't claim that the inscription is a solid indicator for Mary Magdalene.

The Rock-Cut Tomb

The final statistical issue to deal with is the fact that the Talpiot tomb is a rock-cut tomb. Archaeologist Jodi Magness has discussed this problem at some length [11]. In first-century Jerusalem, most people were wrapped in a shroud and buried in a simple trench grave (dug into the earth) within 24 hours of death. Wealthier Jews were laid in rock-cut tombs like the Talpiot tomb and left to decompose. After about a year, their bones were interred in ossuaries such as those found at Talpiot.

Jesus of Nazareth was laid to rest immediately after his crucifixion in a rock-cut tomb, but not at Talpiot. The New Testament asserts that Joseph of Arimathea laid the body of Jesus in a tomb near the crucifixion site, some three miles from Talpiot. Within about 36 hours, the New Testament asserts that the body went missing.

The earliest Jesus movement explained this by claiming that Jesus was resurrected and that he ascended to heaven, a claim outside the bounds of scientific investigation. If one looks for a naturalistic explanation, Magness says that the likeliest one is that Jesus was reburied in a simple trench grave like other poor men. She argues on several grounds that it is implausible that Jesus was reburied in a rock-cut tomb like the one at Talpiot [11].

If Jesus *had* been buried in a rock-cut tomb used by other members of his family, it is certain that the earliest Jesus movement in Jerusalem would have known about it. One then has to explain a number of knotty questions: why no mention of such a tomb is ever made in any

historical sources; why the tomb did not become an object of pilgrimage; and why the apostle Paul knew nothing of the tomb. These are not statistical questions, so we'll not pursue them here. But it is obvious that the difficulty of answering these questions has a direct bearing on the statistical question at hand, for the following reason.

We don't know the probability that any given man of Jerusalem would have been buried in a rock-cut tomb. However, we can say with high confidence that Jesus of Nazareth was *less likely* to have been reburied in a rock-cut tomb than other Jewish men of his era.

Just as we did with the issue of "Judah son of Jesus," we can form a ratio: the probability that Jesus was buried in a rock-cut tomb, divided by the probability that other men of his time were buried in such a tomb. We'll use the symbol ρ_{tomb} to represent this ratio. Again we have both an upper and lower bound:

$$\rho_{tomb} \in [0,1]$$

We note that most scholars would estimate a value closer to 0 than to 1, but our baseline computation will make no such estimate.

Bayes' Theorem

Given the data of the tomb, we would like to estimate the probability that the tomb belongs to Jesus of Nazareth, as opposed to some other randomly chosen man of first-century Jerusalem. This is a conditional probability, and it is natural to apply Bayes' Theorem.

Jay Cost was the first to suggest using Bayes' Theorem (within about a week of the *Lost Tomb of Jesus* documentary). He and this author wrote an article at the end of March, 2007, detailing our preliminary conclusions [3].

In September, 2007, Kevin Kilty and Mark Elliott wrote an article that also applied Bayes' Theorem [9]. Kilty and Elliott eliminated Jacobovici's assumption that the

"Mariamenou" inscription implies the presence of Mary Magdalene in the tomb. However, their baseline calculation assumed that "Yoseh" was a rare name that applied to few men in Jerusalem, and that it certainly applied to the brother of Jesus.

Their analysis estimated roughly even odds (49%) that the tomb belonged to Jesus of Nazareth. This was far lower than that of Feuerverger (who computed odds greater than 99.8%). Kilty and Elliott acknowledged that their estimate relied heavily on the assumption that "Yoseh" was a rare name. They showed that without this assumption, their odds dropped to only 6%.

Kilty and Elliott did not account for two counter-indicators: the "Judah son of Jesus" inscription, and the implausibility of the burial of Jesus in a rock-cut tomb. As we'll see, these tend to lower the odds even further.

First, however, we'll present the basic computational apparatus for applying Bayes' Theorem. Define the two events J and T as follows:

J = the "Jesus son of Joseph" in the Talpiot tomb refers to Jesus of Nazareth

T = the observation of the rest of the Talpiot tomb data

We'll denote the negation of the event J by the symbol ~J.

We want to compute the conditional probability P(J|T) using Bayes' Theorem:

$$P(J \mid T) = \frac{P(T \mid J)P(J)}{P(T \mid J)P(J) + P(T \mid \sim J)P(\sim J)}$$

Define the two ratios:

$$\alpha \equiv \frac{P(\sim J)}{P(J)}$$

$$\beta \equiv \frac{P(T \mid \sim J)}{P(T \mid J)}$$

Then our formula simplifies to:

$$P(J \mid T) = \frac{1}{1+\alpha\beta}$$

The behavior of this function is very clear. The larger the product of α and β, the smaller P(J|T) is. As we'll see, α tends to be large, while β is near 1. We can easily compute α now.

We estimated earlier that about 128 men named "Jesus son of Joseph" lived in Jerusalem at the right time and are candidates to be the Jesus of the tomb. So the odds of any randomly chosen "Jesus son of Joseph" being Jesus of Nazareth are about (1/128), while the odds of being somebody else are about (127/128). So $\alpha \approx 127$, given this estimate.

In general, if there are N_J men of Jerusalem named "Jesus son of Joseph," then we have:

$$\alpha = N_J - 1$$

In order to compute β, we need to define our formulation more precisely. We do not think this is controversial, and we'll proceed in much the same spirit as Feuerverger did.

We are comparing two hypotheses, J and ~J, using the data T to distinguish between the two. Bayes' Theorem tells us to compare how well J and ~J predict the data T, using the probability of J and ~J as weighting factors.

For each of these two hypotheses, we imagine a statistical ensemble of tombs "similar" to the Talpiot tomb. We'll make random draws from each ensemble and tabulate the frequency of "hits" (random draws that agree with the data T).

We'll stipulate that each member of these two ensembles should contain an ossuary inscribed with "Jesus son of Joseph" and a second ossuary inscribed with "Judah son of Jesus." It should also contain two ossuaries bearing female names, two ossuaries bearing male names, and four uninscribed ossuaries. The distribution of names on the inscribed ossuaries must match the

distribution of the names of persons living in Jerusalem in the first-century, subject to the constraints of the two hypotheses.

In the case of the ~J hypothesis, there are no constraints.

In the case of the J hypothesis, the only constraint is that the tomb must contain at least the names of certain members of the family of Jesus, with any remaining slots in the tomb filled with names chosen using the distribution of names in Jerusalem.

Given these two statistical ensembles of tombs, we will compute P(T|J) and P(T|~J). From these, we can then compute β.

Before we can do so, we need to face some complications.

Complications

We now consider three issues that must be resolved:

1) Who do we expect to be in a "Jesus family tomb?"
2) What is the "equivalence class" of the Talpiot tomb?
3) What is the gender distribution of the uninscribed ossuaries?

We'll look at each of these in turn and explain why it's a problem and describe how we plan to solve it.

Who Should Be in a "Jesus Family Tomb?"

In order to calculate P(T|J), we need to specify which family members we expect to see in the family tomb of Jesus of Nazareth. According to Richard Bauckham [1], a family tomb normally contained only members of the extended family: grandparents, parents, sons, and any of their wives. Women who married out of a family would be buried in the tomb of the family they married into.

During the adulthood of Jesus, we hear nothing of his father Joseph, who is generally presumed to have died in Nazareth. Jesus' mother Mary and his four brothers James, Joses, Judah, and Simon are all mentioned in our sources, as well as some unnamed sisters (at least two). Later church traditions give these sisters the names Mary and Salome, but no first-century documents mention these names, so they must be considered speculation. Since the sisters are likely to have married out of the family of Jesus, we won't include them in our baseline calculation.

What about Mary Magdalene? Feuerverger's "a priori hypothesis" APH 5 asserts that Mary Magdalene should be expected to be in the tomb of Jesus [4]. This simply isn't so. There are no first-century documents that include Mary Magdalene in the family of Jesus. Even the later Gnostic gospels (that play a large role in sensationalist books like *The DaVinci Code*) don't actually say that Jesus was married to Mary Magdalene. There is no particular reason to include Mary Magdalene in a family tomb of Jesus, and so we leave her out of our baseline calculations.

As noted earlier, it is *possible* that Jesus was married, and therefore it is *possible* that Mary Magdalene was his wife. But neither of these slim possibilities belongs in a baseline calculation.

So we have five known candidates for the immediate family of Jesus, (Mary, James, Joses, Judah, and Simon). However, we cannot know for certain that all five would be buried in a family tomb of Jesus, if it existed. For example, James Tabor has posited that the brother Simon is actually the "Simon son of Clopas" whom most historians consider the cousin of Jesus. Simon son of Clopas took over administration of the Jesus movement in Jerusalem about the year 62 C.E., after the death of James the brother of Jesus [13]. Tabor believes that Simon (and his brother Judah) lived on for a number of years after the Roman destruction of the city in 70 C.E.,

and so neither was buried in the family tomb of Jesus. (Feuerverger's article assumes Tabor's hypothesis on this point.)

Tabor may be right, or he may not. The practical problem for us is that the calculations for P(T|J) depend on which family members are hypothesized to be in the tomb.

Our solution is simply to consider all possible cases for the five core members of Jesus family (Mary, James, Joses, Judah, and Simon). Since each of these can be either in or out of the hypothesized family tomb, there are 32 different hypotheses to consider. We'll compute the average over these 32 hypotheses, as well as the minimum and maximum.

Equivalence Classes

The Talpiot tomb contains ossuaries bearing the names of two known members of the family of Jesus: Mary and Joses. It also contains a second Mary, a Matthew, and a "Judah son of Jesus," none of which are known to be the names of members of the extended family of Jesus, although each of them might be.

There are also four uninscribed ossuaries. If this were the real family tomb of Jesus, it is anyone's guess who might be in these. The brothers James, Judah, and Simon are candidates, along with wives of any of the brothers, and probably cousins.

The important thing to note here is that finding "Mary and Joses" was interesting, but we would be equally interested in finding "Mary and James" or "James and Judah" or a number of other combinations.

In computing P(T|J), we are interested in counting these other combinations when making random draws from our statistical ensemble of Talpiot-like tombs. But which combinations should count as "hits?"

Feuerverger solved this problem by defining an "RR" value (relevance plus rarity) which measured the "surprisingness" of a particular find. He counted as "hits" any configuration of possible names that had an "RR" value as good or better than the actual Talpiot tomb.

This is a valid approach, but in this article we are looking for a procedure that is less fine-grained. We have identified six possible ways to define a "hit:"

- Finding at least one Mary and at least one Yoseh
- Finding at least one Mary and at least one Joseph
- Finding at least one Mary and at least one name chosen from the set {James, Yoseh, Judah, Simon}
- Finding at least one Mary and at least one name chosen from the set {James, Joseph, Judah, Simon}
- Finding two different members from the set {Mary, James, Yoseh, Judah, Simon}
- Find two different members from the set {Mary, James, Joseph, Judah, Simon}

In the above, "Mary" means any variant of Mariam, including Marya. "Joseph" means any variant of Yehosef, including Yoseh. "Yoseh" means finding the specific short form Yoseh.

Note that the different definitions of "hits" will change the computations for *both* P(T|J) *and* P(T|~J), so it may be that the ratio of the two probabilities will not change radically. That is something to be tested.

Our solution is to compute our results using all six of the above definitions of "hits." We'll report each result separately.

Gender Distribution

At first glance, it might appear that the uninscribed ossuaries are irrelevant to our calculations. This is true for computing P(T|~J), because in the ~J case, our statistical ensemble

of tombs is populated with persons bearing names in a distribution identical to the general population of Jerusalem.

However, in computing P(T|J), we are enforcing constraints on the names of *some* of the persons in the tomb. For example, if we are testing the hypothesis that the family tomb of Jesus contains Mary, James, Joses, Judah, and Simon, (as well as "Jesus son of Joseph" and "Judah son of Jesus"), then that leaves only 3 ossuaries to be filled with persons whose names are randomly chosen. So the statistical ensemble for the J hypothesis is "enriched" with more Marys, more Jameses, etc., than the statistical ensemble for the ~J hypothesis. Some of these family members might be in uninscribed ossuaries.

The calculations therefore depend on the number of men and the number of women in the four uninscribed ossuaries. We have no data on this gender distribution. There are five possible cases:

- 4 men, 0 women
- 3 men, 1 woman
- 2 men, 2 women
- 1 man, 3 women
- 0 men, 4 women

As a baseline calculation, we'll take the most likely case with 2 men and 2 women. Then we'll compute the other four options as variants. We don't expect a large difference in the results.

Analytic Results

We are interested in computing

$$\beta \equiv \frac{P(T \mid \sim J)}{P(T \mid J)}$$

The numerator and denominator have a similar structure. Each has:

1) A factor representing the probability that the "Jesus son of Joseph" should have a son named Judah.
2) A factor representing the probability that the "Jesus son of Joseph" should be buried in a rock-cut tomb.
3) A factor representing the probability of getting a "hit" (a collection of names that is in the equivalence class of the Talpiot tomb) given a random draw from the statistical ensemble of tombs for the given hypothesis.

The ratio of factor #1 for the numerator and denominator is $1/\rho_{son}$, where we defined ρ_{son} earlier as the relative probability that Jesus of Nazareth should have a son, as compared to a randomly chosen man of Jerusalem.

The ratio of factor #2 for the numerator and denominator is $1/\rho_{tomb}$, where we defined ρ_{tomb} earlier as the relative probability that Jesus of Nazareth should be reburied in a rock-cut tomb, as compared to a randomly chosen man of Jerusalem.

Both ρ_{son} and ρ_{tomb} are very hard to quantify. We argued earlier that both should lie on the interval [0,1]. Most historians would likely argue that both numbers should be closer to 0 than to 1, but some might well argue for values near 1. These are historical questions that are best left to historians. Our approach will be to define both of these as random variables with unknown probability density distributions on the interval [0,1]. Our baseline simulation will model these as uniform distributions. It is easy to then consider variant simulations with other distributions.

The third factor in computing P(T|J) and P(T|~J) involves simple computations using the probabilities of finding various names. The precise computations depend on what one considers a "hit," but all the computations are trivial.

The computations are slightly different for the J case versus the ~J case. The ~J case is simpler, because the distribution of names in the tomb is then identical to the distribution of names in Jerusalem. We need the following values for the probabilities of the various names, taken directly from Feuerverger's article [4], who got them from Ilan [6]:

$$P_{Mary} = \frac{74}{317}$$

$$P_{James} = \frac{43}{2509}$$

$$P_{Joseph} = \frac{221}{2509}$$

$$P_{Judah} = \frac{171}{2509}$$

$$P_{Simon} = \frac{249}{2509}$$

The probability for finding a "Yoseh" is slightly complicated. "Yoseh" is a short form for "Yehosef." The value for P_{Joseph} given above is the probability of finding *any* variant of the name, including "Yehosef" and "Yoseh" and all others. The probability of finding a "Yoseh" in the general population of Jerusalem is known to be about 15.2% of P_{Joseph}. We can define the ratio:

$$\rho_{Yoseh} = \frac{P_{Yoseh}}{P_{Joseph}}$$

In the statistical ensemble of all families having a patriarch named Joseph, we expect this ratio to be larger than 15.2%, because a "Joseph son of Joseph" would likely go by the short

form "Yoseh" to distinguish him from his father. This is also true if the younger Joseph were a nephew or a grandson. Unfortunately, we have no data that can measure this effect. Our approach will be to model ρ_{Yoseh} as a random variable on the interval [.152, 1]. Since we lack information, the least-biased approach is to model this as a uniform probability density distribution. We can then run a numerical simulation and the above equation defines P_{Yoseh}. Obviously, this is not an ideal situation, but the fact is that we lack data.

The above definitions give us all the information required to compute P(T|~J) in all six of the equivalence classes that we defined earlier. For example, the probability of finding at least one Mary and at least one Yoseh in a random draw of two females and two males is given by:

$$\left[1-(1-P_{Mary})^2\right]\left[1-(1-P_{Yoseh})^2\right]$$

All six equivalence classes are simple and involve similar calculations.

It is not quite so simple for the computations of P(T|J). The reason is that the probabilities of drawing the various names in a random draw depend on the composition of the hypothesized "Jesus family tomb." We have already made some stipulations on the composition of the tomb when we defined our statistical ensembles. Obviously, the probability of drawing certain names is different, depending on which of the 32 hypotheses we are considering and how many men and women are assumed to be in the uninscribed ossuaries.

As an example, suppose our hypothesis says that Mary is in the tomb and that there are two women and two men in the four uninscribed ossuaries. Then the tomb contains a total of six men and four women, as follows:

- Jesus son of Joseph
- Judah son of Jesus
- 2 inscribed ossuaries with men

- 2 uninscribed ossuaries with men
- 2 inscribed ossuaries with women
- 2 uninscribed ossuaries with women

If Mary is in the tomb, then she might be in one of the inscribed ossuaries (which will count as a hit) or one of the uninscribed ossuaries (which will not count as a hit). But the other three ossuaries might well contain some other Mary. The expected number of Marys in the tomb is easily calculated as:

$$E_{Mary} = 1 + (n_{women} - 1)P_{Mary}$$

Therefore, the probability of drawing a Mary for each of the inscribed ossuaries is:

$$P^*_{Mary} = P_{Mary} + \frac{(1 - P_{Mary})}{n_{women}}$$

Not surprisingly, the probability of drawing a Mary is "enriched" in a tomb known to contain one Mary. Similar enrichment factors hold for drawing a James, a Joseph, a Yoseh, a Simon, or a Judah.

Having calculated the enriched probabilities for a specific tomb hypothesis and a specific gender distribution for the uninscribed ossuaries, it is a simple matter to compute P(T|J) using similar formulae to those used in computing P(T|~J).

Random Variables

The approach sketched in the previous sections explains how to calculate P(J|T) given the following choices which must be made:

1) Choice of a "tomb hypothesis" that tells which family members are expected to be inside a "Jesus family tomb." We have defined 32 such hypotheses.

2) Choice of an equivalence class that tells which randomly drawn names taken from the statistical ensembles shall be counted as equivalent to the Talpiot tomb. We have defined six such equivalence classes.
3) Choice of the number of men and women in the four uninscribed ossuaries. We have defined five possible gender distributions.
4) Choice of the random variable ρ_{son} defining the relative probability that Jesus of Nazareth would have a son, as compared to other men of Jerusalem. This takes values on the interval [0,1].
5) Choice of the random variable ρ_{tomb} defining the relative probability that Jesus of Nazareth would be buried in a rock-cut tomb, as compared to other men of Jerusalem. This takes values on the interval [0,1].
6) Choice of the random variable ρ_{Yoseh} defining the conditional probability of a "Joseph" having his name inscribed as "Yoseh," given that he belongs to a family with a patriarch named Joseph. This takes values on the interval [.152, 1].

Choices #1, #2, and #3 are discrete, and our calculations will simply exhaust all possibilities. Choices #4, #5, and #6 involve continuous random variables and a good simulation requires a large number of random draws.

We wrote a program in Java using a hierarchy of classes to encapsulate particular distributions for the random variables. This allows us to easily change the distribution without changing the structure of the calculation. For example, it is simple to change one of the random variables from a uniform distribution to a triangular distribution or a delta-function.

The program computes P(J|T) for 192 cases and reports all results. (The 192 comes from the 32 "Jesus tomb" hypotheses multiplied by the 6 equivalence classes for defining "hits.")

Numerical Results

Baseline Calculation

The baseline calculation was performed for P(J|T) as follows:

- All 32 possible "Jesus family tomb" hypotheses were tested.
- All 6 equivalence classes were tested.
- Two men and two women were assumed in the four uninscribed ossuaries.
- ρ_{son} has a uniform distribution on [0,1].
- ρ_{tomb} has a uniform distribution on [0,1].
- ρ_{Yoseh} has a uniform distribution on [.152, 1].

For each of the 32 hypotheses and each of the six equivalence class, P(J|T) was computed and averaged for 10,000 choices of the three random variables. This is still too much data to display here, so the 32 means (for each set of 32 hypotheses) were aggregated into a mean, a min, and a max. For each of the equivalence classes, these results are tabulated below. For each hypothesis, the standard deviation was approximately equal to the mean, so we do not tabulate this data.

Equivalence Class	Min Mean	Mean Mean	Max Mean
Mary/Yoseh	1.95E-03	1.00E-02	2.18E-02
Mary/Joseph	1.93E-03	5.85E-03	1.14E-02
Mary/Brother(Yoseh)	1.96E-03	7.67E-03	1.57E-02
Mary/Brother(Joseph)	1.96E-03	6.89E-03	1.38E-02
Any Two (Yoseh)	1.94E-03	9.50E-03	1.90E-02
Any Two (Joseph)	1.96E-03	8.36E-03	1.67E-02

Table 1: Results of baseline calculation.

We think the Max Mean is the most relevant number to look at, since it generally represents the mean result of a tomb hypothesis with all five of the core family members in the tomb.

Here is a reminder of the definitions of the equivalence classes:

1) Mary/Yoseh: a hit means finding at least one Mary and at least one Yoseh
2) Mary/Joseph: a hit means finding at least one Mary and at least one Joseph
3) Mary/Brother(Yoseh): a hit means finding at least one Mary and at least one member of the set {James, Yoseh, Judah, Simon}
4) Mary/Brother(Joseph): a hit means finding at least one Mary and at least one member of the set {James, Joseph, Judah, Simon}
5) Any Two(Yoseh): a hit means finding at least two different members of the set {Mary, James, Yoseh, Judah, Simon}
6) Any Two(Joseph): a hit means finding at least two different members of the set {Mary, James, Joseph, Judah, Simon}

Reducing ρ_{son} or ρ_{tomb}

Most historians will likely prefer that we reduce the range of ρ_{son} (the relative probability that Jesus had a son). Most archaeologists will likely want us to reduce the range of ρ_{tomb} (the relative probability that Jesus was buried in a rock-cut tomb). The results of P(J|T) scale down almost linearly when one does either of these reductions.

For example, if one assigns ρ_{son} a uniform distribution on [0, 0.1], then the results of the baseline calculation scale down by a factor of about 10.

Likewise, if one assigns ρ_{tomb} a uniform distribution on [0, 0.1], then the results of the baseline calculation again scale down by a factor of about 10.

Changing both distributions in this way causes the baseline calculation to scale down by a factor of about 100.

1 Man, 3 Women Calculation

If we redo the baseline calculation, but hypothesize 1 man and 3 women in the uninscribed ossuaries, the results increase slightly as follows:

Equivalence Class	Min Mean	Mean Mean	Max Mean
Mary/Yoseh	1.95E-03	1.19E-02	2.58E-02
Mary/Joseph	1.93E-03	6.64E-03	1.31E-02
Mary/Brother(Yoseh)	1.96E-03	8.96E-03	1.84E-02
Mary/Brother(Joseph)	1.96E-03	7.97E-03	1.61E-02
Any Two (Yoseh)	1.94E-03	1.26E-02	2.76E-02
Any Two (Joseph)	1.96E-03	1.10E-02	2.40E-02

Table 2: Results of calculation with 1 man and 3 women.

0 Men, 4 Women Calculation

If we redo the baseline calculation, but hypothesize 0 men and 4 women in the uninscribed ossuaries, the results increase even more for the tomb hypothesis:

Equivalence Class	Min Mean	Mean Mean	Max Mean
Mary/Yoseh	1.95E-03	1.58E-02	3.47E-02
Mary/Joseph	1.93E-03	8.42E-03	1.72E-02
Mary/Brother(Yoseh)	1.96E-03	1.18E-02	2.46E-02
Mary/Brother(Joseph)	1.96E-03	1.04E-02	2.14E-02
Any Two (Yoseh)	1.94E-03	2.02E-02	4.86E-02
Any Two (Joseph)	1.96E-03	1.73E-02	4.20E-02

Table 3: Results of calculation with 0 men and 4 women.

3 Men, 1 Woman and 4 Men, 0 Women Calculations

Changing the baseline calculation to have 3 or 4 men in the uninscribed ossuaries reduces the results for P(J|T). Since we are most interested in finding cases which increase the results, we'll not tabulate the results here.

Reducing the range of ρ_{Yoseh}

We referred earlier to the article by Kevin Kilty and Mark Elliott, which did a Bayesian calculation and estimated a probability of 49% for P(J|T) [9]. They achieved these high results in part by choosing the most favorable values of the random variables, as follows:

- $\rho_{son} = 1$
- $\rho_{tomb} = 1$
- $\rho_{Yoseh} = .152$

We do not think the historical or archaeological evidence warrants the first two of these choices. However, it is interesting to consider the effects of the third choice, fixing ρ_{Yoseh} to its lowest possible value.

We redid the baseline calculation but changed the following assumption:

ρ_{Yoseh} is a delta-function distribution centered on .152.

The results were as follows:

Equivalence Class	Min Mean	Mean Mean	Max Mean
Mary/Yoseh	1.95E-03	2.42E-02	5.67E-02
Mary/Joseph	1.93E-03	5.85E-03	1.14E-02
Mary/Brother(Yoseh)	1.96E-03	8.62E-03	1.80E-02
Mary/Brother(Joseph)	1.96E-03	6.89E-03	1.38E-02
Any Two (Yoseh)	1.94E-03	1.09E-02	2.22E-02
Any Two (Joseph)	1.96E-03	8.36E-03	1.67E-02

Table 4: Results of calculation with ρ_{Yoseh} fixed to .152.

The highest value for P(J|T) we are able to achieve is 5.67%, far below the 49% quoted by Kilty and Elliott. Part of this discrepancy is due to our more realistic treatment of both ρ_{son} and ρ_{tomb}. The rest is due to differences in our application of Bayes' Theorem. The Kilty/Elliott paper uses an extremely simplified procedure for computing P(T|J). While we do not agree with this procedure, we thank them for pointing out the wide range of options in choosing a tomb

hypothesis. This was a significant observation that we missed in our earlier paper [3]. In that paper, we defined the J hypothesis to mean that Mary, James, Joses, Judah, and Simon should all be in a Jesus family tomb. While this often gives the highest result for P(J|T), there are some cases where it does not. In this paper, we are now finding the hypothesis that gives the highest estimate of P(J|T).

Conclusion

Bayes' Theorem provides a powerful framework for analyzing the alleged "Jesus family tomb." While there are many variations on the tomb hypothesis, and several different ways of defining equivalence classes, the fundamental equations are actually quite simple.

Our baseline calculation shows that the odds are at most about 2% that the Talpiot tomb might have been the family tomb of Jesus of Nazareth. The standard deviation on this upper bound is about 2%. We expect that most historians and archaeologists will adopt assumptions that lower this estimate.

Historians will likely argue that the probability that Jesus might have had a son is quite a bit lower than we have assumed here. Archaeologists will probably argue that the probability that Jesus ended up in a rock-cut tomb like Talpiot is significantly less than we have assumed.

Given the data we have now, the 2% figure should be regarded as a likely upper bound for P(J|T).

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