PATTERNS INFERRED FROM WILLS PROBATED IN THE HUSTING COURT

DEMOGRAPHIC PATTERNS IN MEDIEVAL LONDON INFERRED FROM WILLS PROBATED IN THE COURT OF HUSTING, 1259–1688

By ALEXANDRA S. BUSHBY, B.Sc., B.Ed.

A Thesis Submitted to the School of Graduate Studies in Partial Fulfilment
of the Requirements for the Degree Master of Science

MASTER OF SCIENCE (2019) (Mathematics & Statistics)
McMaster University Hamilton, Ontario

TITLE:	Demographic patterns in Medieval London inferred from wills probated in the Court of Husting, 1259–1688
AUTHOR:	Alexandra Bushby, B.Sc. (Queen's University) & B.Ed. (Queen's University)
SUPERVISOR:	Dr. David J.D. Earn
NUMBER OF PAGES:	[xiv], 82

LAY ABSTRACT

Historical records have been used to further understand (i) the social and demographic characteristics of various human civilizations throughout history and (ii) demographic patterns of epidemics.

We use the Calendar of Wills Proved and Enrolled in the Court of Husting, London to describe various cultural characteristics of Medieval London. Such characteristics include, but are not limited to, the proportion of testators who were women (10.5%), the most common occupations (with most common being fishmongers) and that wills were most commonly written on Saturdays.

Additionally, we explore how the temporal patterns of the four plague epidemics in London from 1348–1376 appear to differ when counting wills according to when they were written versus when they were probated. Using will dates seems to provide a more plausible indicator of epidemic patterns, presumably due to highly variable lags between writing and probating wills.

ABSTRACT

The Calendar of Wills Proved and Enrolled in the Court of Husting, London, 1258–1688 (Husting wills) is exploited (i) to characterize, using statistics, the social and demographic characteristics of Medieval London and (ii) to analyze the temporal patterns of the four plague epidemics that occurred in London between 1348 and 1376.

The Husting wills were digitized by British History Online (BHO) in 2017. We created an R package that uses the BHO version of the Husting wills and provides tools for analysis of these wills.

Statistical analyses performed on the 4110 Husting wills reveal that 10.9% of testators were women. There is no clear evidence of bias of writing wills on particular weekdays. However, wills were least and most commonly written on Thursdays (11.72%) and Saturdays (16.18%), respectively. 51.2% of wills mention the career of the testator. By categorizing careers into one of four classes (business, church, city or nobility), we were able to determine that most testators were in the business category (80.2%). Among these individuals, the five most common occupations were fishmonger, merchant, goldsmith, draper and skinner.

Further analyses of the Husting wills strongly suggest that the temporal patterns of plague epidemics can be estimated more accurately from the dates wills were written rather than the dates they were probated. We identify two probable factors that make probate dates harder to interpret: First, the Court of Husting probated wills only on Mondays. Second, highly varying lags between the writing and probating of wills adds noise to statistics based on probate dates. The observed lags for the Husting wills are well approximated

by a lognormal distribution.

Keywords: Medieval London, fourteenth-century plague, epidemic growth rate

ACKNOWLEDGEMENTS

Firstly, I cannot express enough gratitude to Dr. David Earn, my supervisor. He worked tirelessly with me throughout the course of my degree. I am incredibly appreciative of all that he has taught me. Thank you, David, for not only being a supervisor but a friend. I value all of our conversations about mathematics, but also about our everyday happenings. Thank you for giving me the opportunity to study under your guidance.

Thank you to my examining committee members, Dr. Benjamin Bolker and Dr. Jonathan Dushoff. A special thank you to Dr. Bolker for our various conversations about my thesis.

I would also like to thank my friends, Jocelyn, Rebekah, Andrea, and Ladawn, who have encouraged and uplifted me more than words can say.

To my sisters, Katy and Beka, and my grandparents, cousins, aunts, and uncles; thank you for your prayers throughout this degree, but also over the course of my life.

And to my parents, Debbie and Doug, who have always pushed me to do my best in all areas of life.

To God be the glory.

Contents

List of Figures

List of Tables

Abbreviations and Symbols

AIC	Akaike Information Criterion
CI	Confidence interval(s)

DECLARATION OF ACADEMIC ACHIEVEMENT

I, Alexandra Bushby, declare that the work in my thesis is, to the best of my knowledge, my own, with contributions from my supervisor, Dr. David Earn. All sources of information within the body of my thesis have been properly acknowledged.

Chapter 1

A statistical description of the wills probated in the Court of Husting, London

1.1 Introduction

Historical records of epidemics in human populations are valuable for improving our understanding of the ecology and evolution of infectious diseases [1]. Plague, which is caused by the bacterium *Yersinia pestis*, has impacted human civilizations through three distinct pandemics [2]. The first pandemic, known as the Justinian plague, spread across locations around the Mediterranean Sea from the 6th to 8th century [2]. The second pandemic, beginning with the appearance of the Black Death in the mid 14th century, affected Europe until the 17th century [2, 3]. Currently, we are in the third pandemic, which has affected human populations on a global scale [3]. Here, we describe demographic patterns in London, England, during the second plague pandemic.

Registration of deaths in England began in 1538 [4]. Consequently, from 1538 onward, death records—e.g., original parish registrations or (later) the London Bills of Mortality—can be used to quantify the structure of epidemics of fatal diseases [5]. The Black Death first appeared in London in 1348, long before the death registration era. We must turn to alternative sources to investigate the epidemic of 1348 and subsequent plague epidemics until 1538.

Historians studying epidemics in the pre-death-registration era have used surviving last wills and testaments to obtain an impression of demographic patterns [6, 7, 8]. By using such documents for understanding epidemics, historians assume that the number of wills written during a specific time period reflect mortality counts during that time. The Calendar of Wills Proved and Enrolled in the Court of Husting, London (Husting wills) [9] includes thousands of wills written by the citizens of London from 1259 to 1688. This book has recently been digitized and made available online [10], which makes it possible

to examine many details of the Black Death epidemic patterns, as well as social and demographic characteristics of Medieval and Renaissance London.

Wills that were presented to the Court of Husting include the date the will was written by the testator (*will date*) and the date the will was approved in the court following the testator's death (*probate date*). We use these dates to describe the 1348 and subsequent plague epidemics in London, England, as well as the social and demographic characteristics of London. Many Husting wills contain other demographic information of interest, such as the gender, occupation, location of properties, spouse and offspring of the testator.

Our goal here is to provide a statistical description of the demographic patterns that can be inferred from the digitized Husting wills [9, 10], and shed light on the characteristics of London, England, during the period that the court was active (1259–1688).

1.2 Structure of individual wills

The wills probated by the Court of Husting vary in length, as well as information provided about the testator. Two excerpts from the Husting wills [9, 10] are provided below. The first excerpt contains two short wills and the second contains one slightly longer will.

ANNO 16 EDWARD I.
Monday next before Feast of Purification of V. Mary [2 Feb.]

Machinge (Adam de).—To Lora his wife his house in Wodestrate for life; remainder in default of heirs to pious uses. A charge on the said house of two shillings annual quitrent for maintaining one "torche" at the elevation of the Host in the church of Hoggenelane. No date. Roll 18 (7).

Brewere (Richard le).—To Elena his daughter seventeen shillings annual quitrent in the parish of S. Michael de Candle-wikestrate. Matilda mentioned as relict and one of the executors of the testator. No date. Roll 18 (12).
—Taken from pp. 83 – 85 of [9, 10]

ANNO 31 EDWARD III.
Monday next after F. of S. John ante portam Latinam [6 May].

Yakesley (John de), late tentmaker to the king.—To be buried in the parish church of S. Martyn de Oteswych before the altar of S. John the Baptist, to the high altar, belfry, and ministers of which church he makes bequests. To Isabella his wife his mansion (fn. 3) with four shops for life; remainder to Thomas de Cauntebrigge, carpenter, on payment of a certain sum, otherwise the same to be sold for pious uses. Dated the Feast of H. Innocents [28 Dec.], A.D. 1356. Roll 85 (38).
—Taken from pp. 694 – 701 of [9, 10]

We have written an `R` [11] package (`willsr`, described in Chapter 3) that scrapes the BHO web site [10] to extract the text of all of the wills from both volumes (1 and 2) of the Husting wills [9, 10]. The excerpts above were extracted using `willsr`.

The `willsr` package also provides tools for identifying characteristics of each will and its testator and creating a data set that is convenient for statistical analyses. In particular, for each will, the data set contains the following elements, which are explained below with reference to the sample wills above.

1.2.1 Will date

The Husting wills [9, 10] are organized by court dates. The date on which a will was written is indicated for a large but incomplete subset of the wills.

Wills that do not record the date of writing have *no date* written in the associated entry in the Husting wills [9, 10]. For example, neither of the wills in the first excerpt above provides a will date. Wills that do include the date of writing have a statement "*Dated . . .*" in the Husting wills entry. For example, the will in the second excerpt above was written on 28 December 1356. It should be noted that while the Court of Husting was open, New Year's Day occurred on the Feast of the Annunciation (March 25) [12]. Consequently, we relabeled the years of will dates, with dates recorded between 1 January and 24 March, by adding a year to write all years in terms of the Gregorian year.

1.2.2 Probate date

The dates on which the Court of Husting was open are stated indirectly in the Husting wills [9, 10], as in the first excerpt above. The date of an important event (usually a feast) is given, and the court date is indicated as either the Monday before or after this event.

The court date on which the two wills in the first excerpt above are listed occurred in the 16th year of the reign of Edward I, which was from 20 November 1272 to 7 July 1307. Therefore, these wills were probated between 20 November 1287 and 19 November 1288. The month and day are always indicated in square brackets next to the feast name, which was "[2 Feb.]" in the example above. In this case, we record the probate date as 2 February 1288, which is approximate (though wrong by at most 7 days). In this particular case, we

know—since 2 February 1288 was itself a Monday—that the probate date was actually 26 January 1288.

For the second excerpt above, employing the same approach, we record the probate date of the will of John de Yakesley as 6 May 1357, which was a Saturday (so the true probate date was Monday 8 May 1367).

It was not difficult to write code that extracts the approximate probate dates as above. Determining the exact probate date for each of the 4110 Husting wills would be possible, but would require much more effort.

1.2.3 Name and gender

The name of the testator is always the first item in the will. The name also provides insight into the gender of the testator. If the gender of the testator is not clear from the name, we manually checked the testament and used pronouns in the testament to determine gender.

1.2.4 Career

If the occupation of the testator is indicated in the testament, it immediately follows the name. In the first excerpt above, neither will indicates an occupation for the testator, but the will in the second excerpt refers to the testator as a tentmaker to the King. See Tables 1 to 4 for a full list of all the careers recorded in the Court of Husting wills.

1.2.5 Roll number

Each entry in the calendar of Husting wills ends with a reference. For example, in the will of Thomas Orpedeman below, the reference is "Roll 20 (59)". Also shown in the excerpt below is an associated footnote, in which another will is referenced as "Roll 104 (33)".

> Orpedeman (Thomas).—To Thomas his firstborn son the reversion of his capital messuage, enclosed by a wall, after the decease of Custance his wife. To Robert, William, and John his sons divers shops, rents, &c., in the parish of S. Dunstan, as well as in Breggestrate and Tamesestrate. To the aforesaid Custance a wardrobe (fn. 13) situate outside the curtilage belonging to the above capital messuage. To John his brother his house at Cornhull. No date. Subsequently it was agreed by the Mayor and Aldermen that the said testament should be delivered to John and Henry, sons of the testator; and it was delivered to them and to Master John, son of William le Mareschal, who married Alice their sister. Roll 20 (59).
> *fn. 13. Or privy. In a deed enrolled in the Husting we find quedam latrina vocata Wardrope—Roll 104 (33). It is not improbable, says Riley, that the word was used originally as a euphemism for public places of this nature from the necessity of "guarding the clothes" ('Lib. Custum.,' Glossary, s.v. "Garderoba").*
> —Taken from pp. 95 – 103 of [9, 10]

The meaning of a reference to "Roll n (m)" is that the will begins on membrane m of roll n. Each roll consisted of a number of individual animal skins (membranes) that were sewn together. Membrane numbers functioned similarly to how we use page numbers in modern books. Individual wills sometimes covered multiple membranes.[1]

[1] I am indebted to Jonathan Blaney from British History Online [10] for explaining these points. He also noted that "if you look at footnote 5 here, you will see that the membranes are transposed and the numbers go down and then go up again."

1.3 Temporal pattern of wills written and probated

The most basic patterns that can be extracted from the Husting wills [9, 10] are, for each day, the number of wills written and the number probated. On any given day, these numbers were usually small (and frequently zero), so temporal patterns are easier to see if the daily counts are aggregated. In order to determine a reasonable time interval for aggregation of will counts, we show in Fig. 1.1 (for will dates) and Fig. 1.2 (for probate dates) histograms associated with aggregation time intervals of one day (top left panel), one week (top right panel), two weeks (middle left), one month (middle right), three months (bottom left), and one year (bottom right). The counts shown in each histogram are the number of time intervals of the specified length during which the number (or range of numbers) of wills written or probated occurred.

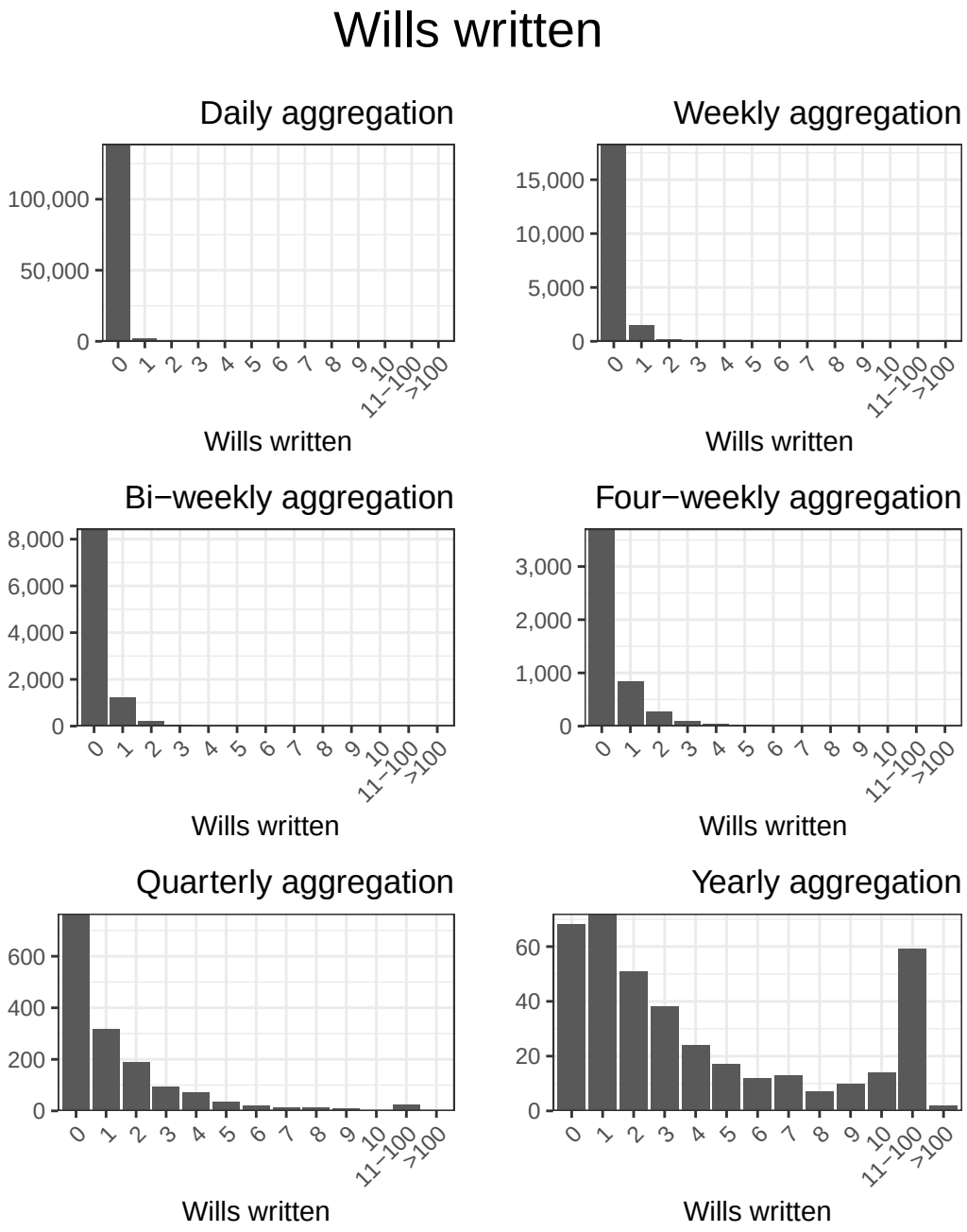


Figure 1.1: For time intervals of one day, one week, two weeks, one month, quarter of a year, and one year, we show the number of counts of wills written between 0 and 9, 10 and 100 and greater than 100.

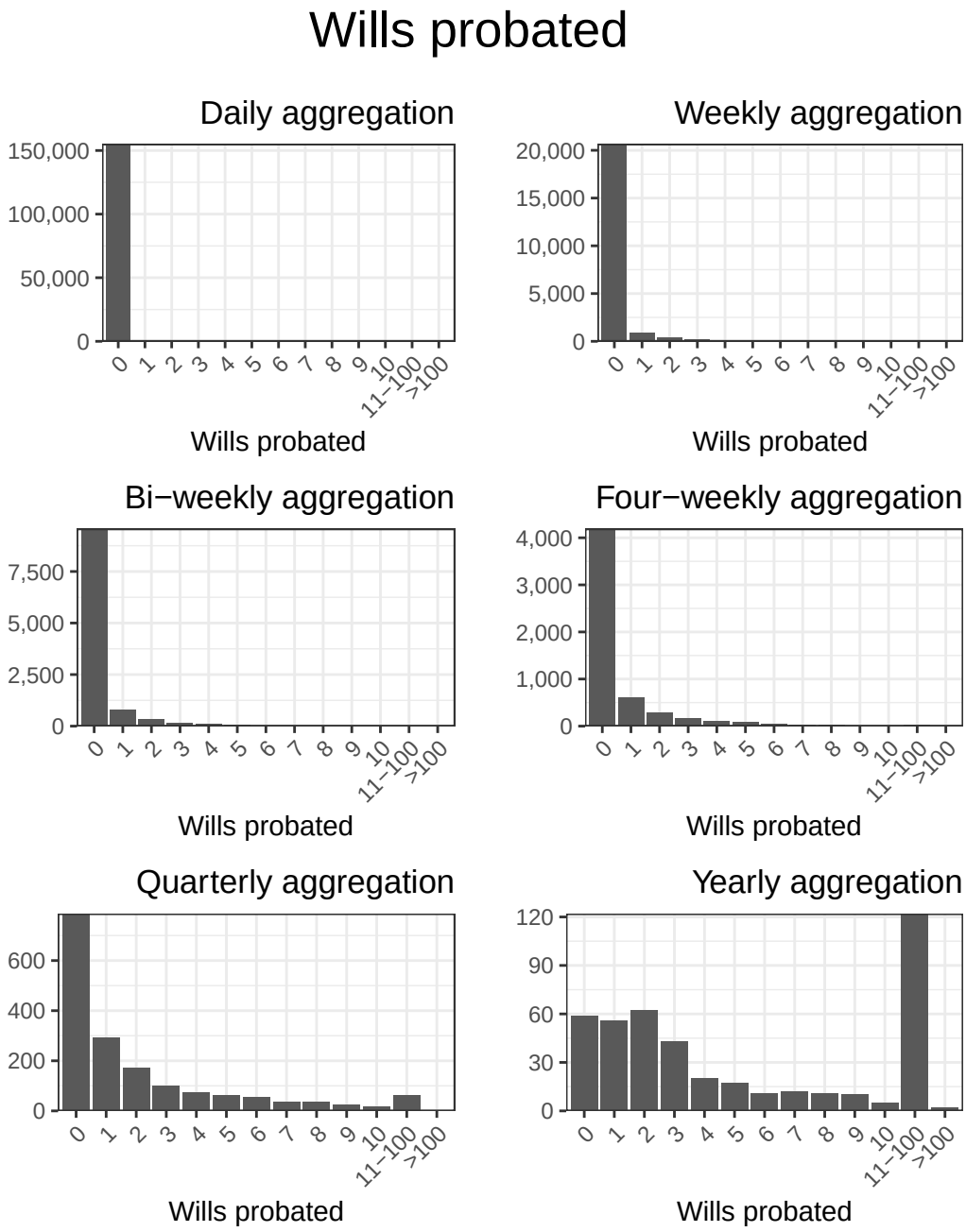


Figure 1.2: For time intervals of one week, two weeks, one month, quarter of a year, and one year, we show the number of counts of wills probated between 0 and 9, 10 and 100 and greater than 100.

From Figs. 1.1 and 1.2 it is clear that the temporal pattern of wills written

or probated on time scales less than a year was extremely noisy. Consequently, we show in Fig. 1.3 the temporal pattern of counts of wills, aggregated yearly.

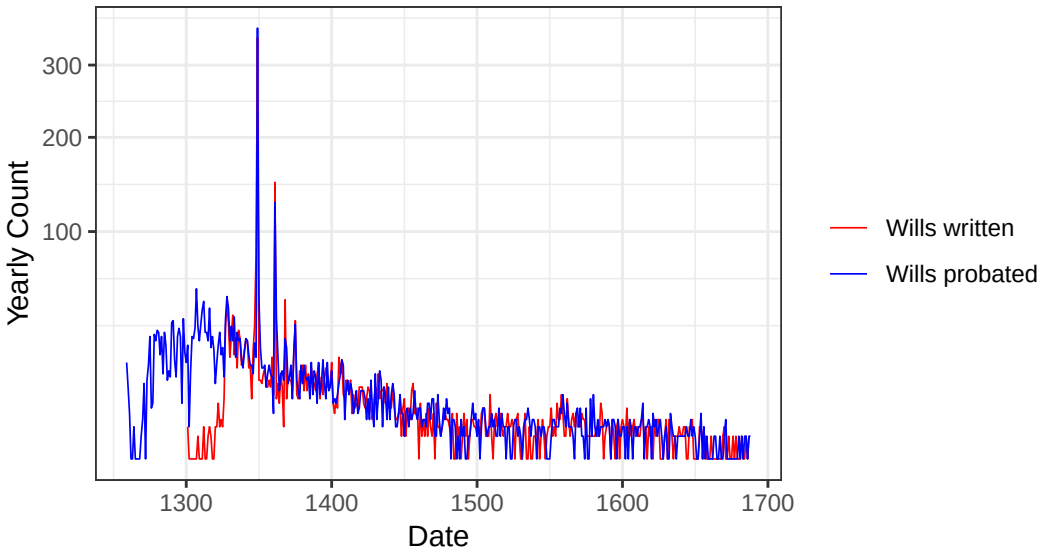


Figure 1.3: The number of wills written and probated each year from 1259-1688. The y-axis is scaled on a square root scale.

A number of features of Fig. 1.3 are important to note:

- The probate date of every will is known, but the practice of dating wills when they were written did not become common until well into the 14th century. The first will to include the date of writing was that of Thomas de York, whose will is dated 5 June 1301. There is also a sudden increase of wills having a will date recorded in 1328.

- The strongest peaks occur during years in which plague epidemics are known to have occurred (1348, 1361, 1368 and 1375). The period from 1345 to 1380 is shown in Fig. 1.4 (aggregated weekly, because there are sufficient wills during this period for weekly data to be informative). Additionally, Fig. 1.5 is a four-panel plot for the four plague epidemics.

- There seems to be a sudden increase in the annual number of wills probated around 1290, and then a steady decline afterwards.

- The annual pattern of probates can be explained by the frequency of the court being opened (while ignoring the years in which a plague occurred). For each year during this period, Fig. 1.6 shows the number court dates and the number of wills probated. For most of our analyses, we focused on the years 1290–1385 as these years have a higher number of court dates (approximately 9.5) per calendar year.

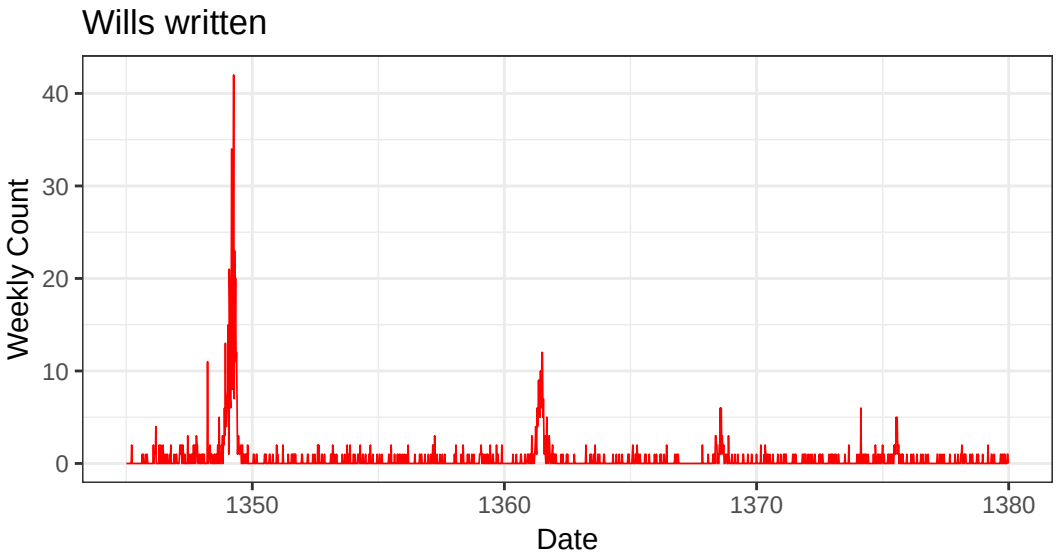


Figure 1.4: The number of wills written each week from 1345-1380.

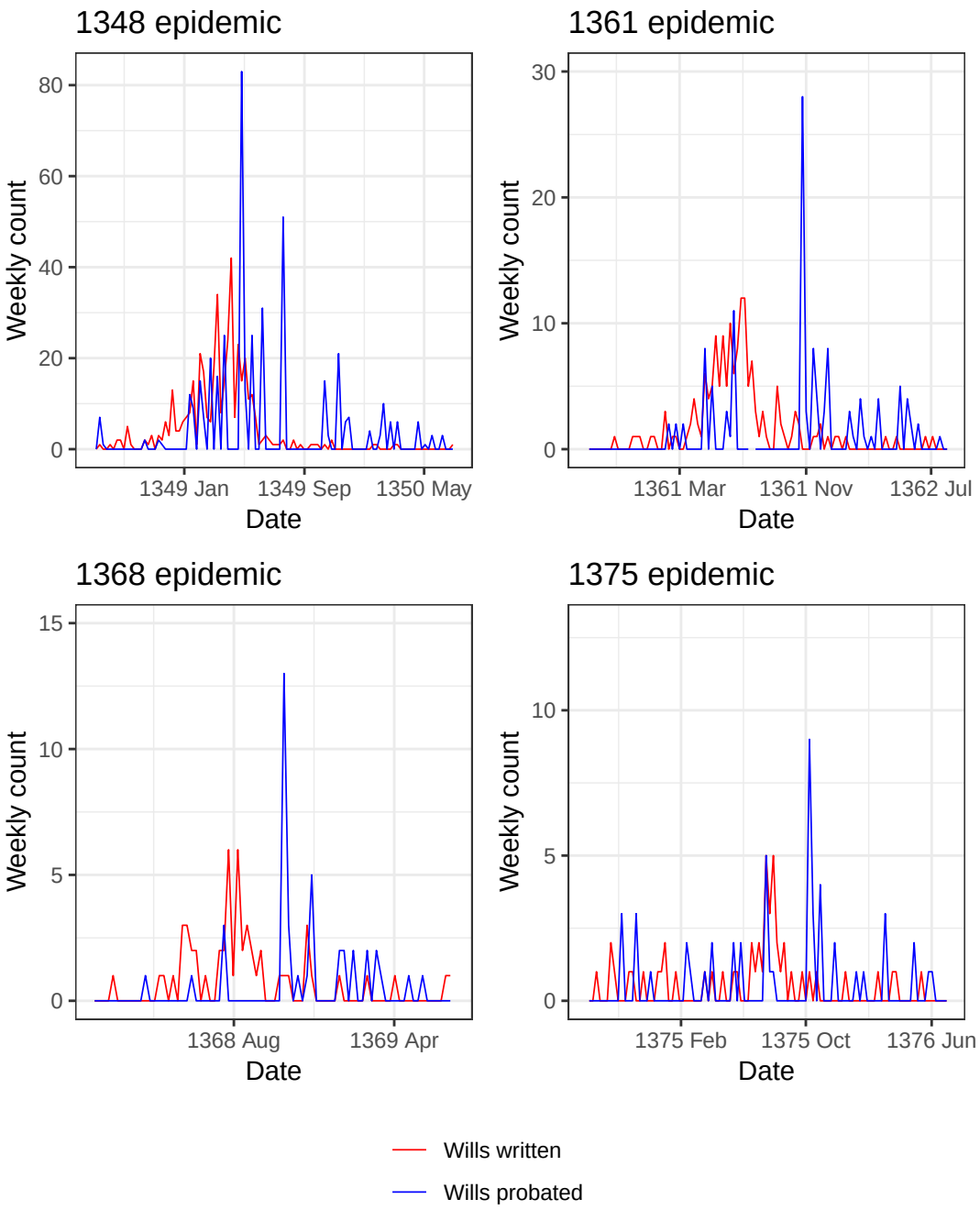


Figure 1.5: Weekly numbers of wills written and probated by the Court of Husting during each of the four plague epidemics from 1345–1380.

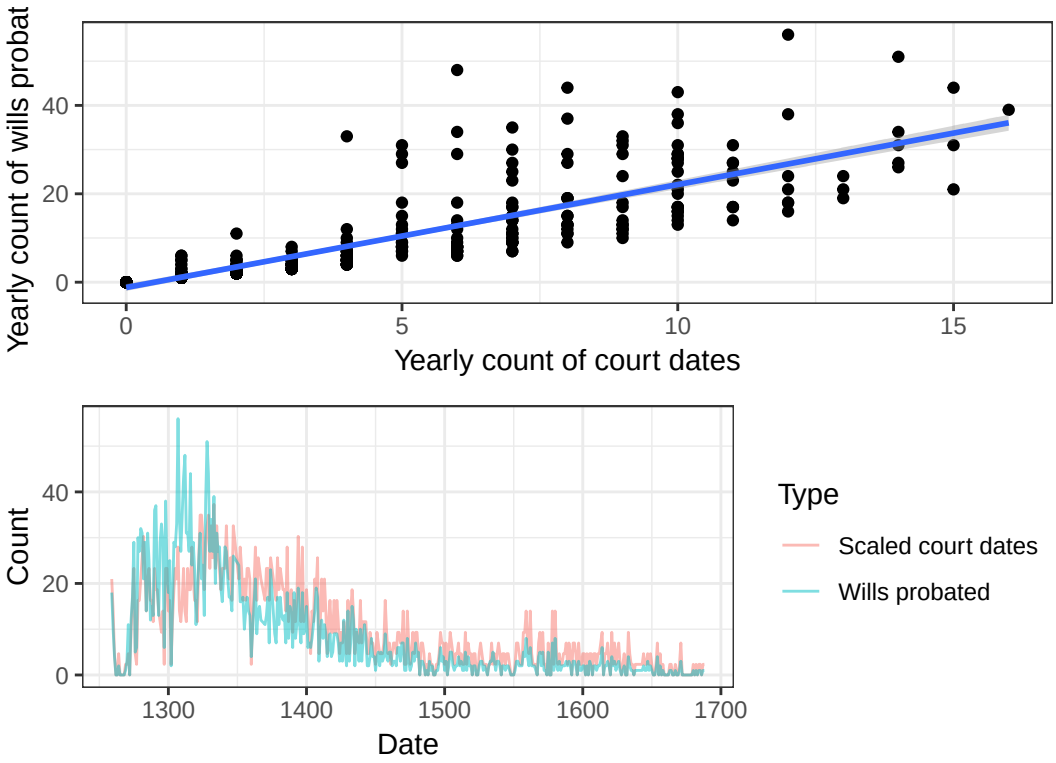


Figure 1.6: The number of wills probated each year as well as the number of recorded court dates (bottom figure). The years in which a plague occurred are not included. We fit a linear model, as seen in the figure on the bottom, and determine that the approximate number of wills probated per court date is 2.33 (2.16, 2.47) (95% confidence interval). The yearly count of court dates is scaled by a factor of 2.33.

1.3.1 Relevance to understanding epidemics

When interpreting Fig. 1.5 as the temporal pattern of the 14th century plague epidemics, we were assuming implicitly that writing or probating a will has a causal relationship with infection or death from the disease.

However, wills are not death records. Historians have typically used the date on which a will was probated as a proxy for the date of death [13], since it is at least certain that the testator had died. However, any given testator might have died long after their will was written.

Earn *et al.* [5] suggest that during severe epidemics, counts of wills written are a reasonable proxy for epidemic patterns. The basis of this proposed association is that testators might have been either on their deathbed, or at least aware of many deaths from disease in the community, which would have increased fear that they might soon be infected and die. This hypothesis is supported by a comparison of temporal patterns of wills written and deaths during a later period when both exist: Earn *et al.* [5] compared 17th century mortality data for London during plague epidemics with the temporal pattern of numbers of wills written (and later probated by the Court of Canterbury). This work confirms that counts of wills written do display the same temporal patterns as death counts and, moreover, that this consistency in pattern is clear in spite of the small size of the sub-population that wrote wills.

1.4 Day of week

Table 1.1 displays the number of wills written on each day of the week for the time period that the Court of Husting was open. There is no clear bias for writing wills on a particular day of the week.

Day of week	Count	Proportion
Saturday	424	16.18%
Sunday	377	14.39%
Monday	367	14.01%
Tuesday	382	14.58%
Wednesday	414	15.8%
Thursday	307	11.72%
Friday	349	13.32%

Table 1.1: The count and proportion of wills written on each day of the week

Figs. 1.7 and 1.8 are temporal plots of the proportion of wills written on each day of the week. With these plots, we observe that there is no clear pattern throughout the time series.

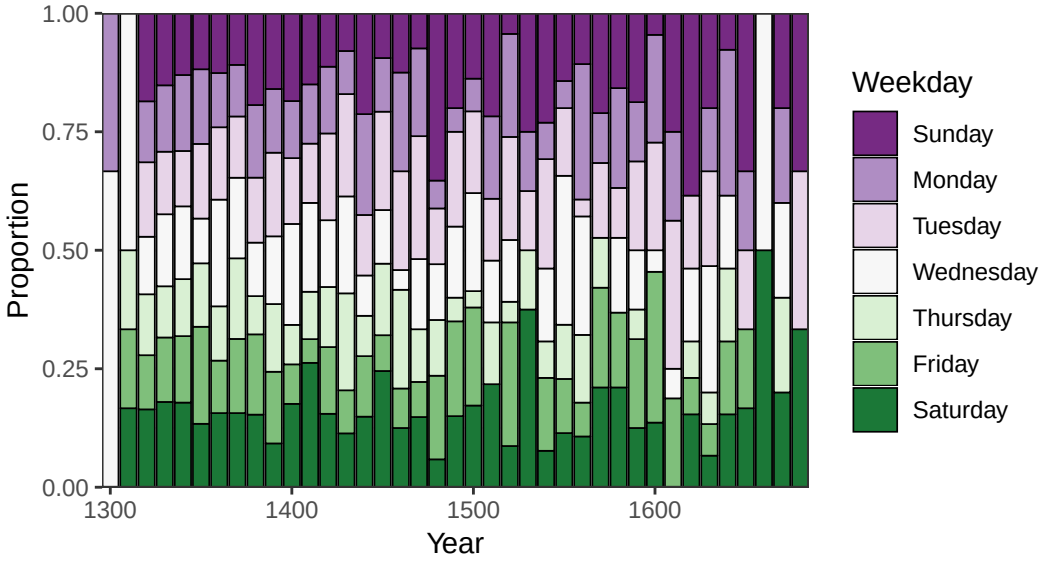


Figure 1.7: The proportion of wills written on each day of the week for each ten year period from 1300 to 1690.

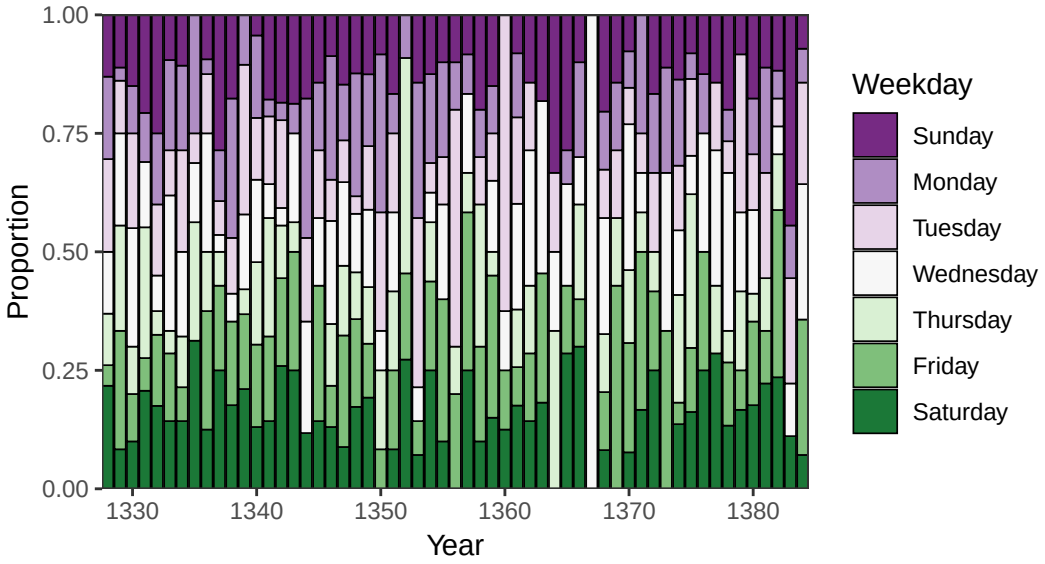


Figure 1.8: The proportion of wills written on each day of the week for each one year period from 1328 (when will dating appears to have become common) to 1385.

1.5 Wills of women

Of the 4110 wills probated in Court of Husting, only 446 (11%) were written by women. We use the wills probated from 1290 to 1385 to perform simple statistical analyses. As in Section 1.3, we consider this subset of dates because of the lower yearly counts of wills probated beyond this subset.

The difference between the yearly proportion of wills written by women and its five year moving average will allow us to observe when the proportion varies from the underlying trend [14]. To find years in which this variation occurs, we use the methods described in Section 1.4 to determine which years were outliers, if any.

Fig. 1.9 shows that there were three years in which outliers occurred: 1300 (5/17 wills by women), 1324 (8/21 wills by women) and 1373 (2/7 wills by

women). There seems to be no indication that the proportion of wills probated by each gender changed during the plague years. This is consistent with DeWitte's statistical analysis of graveyard records from before and during the Black Death, which concluded that gender did not impact individual mortality [15].

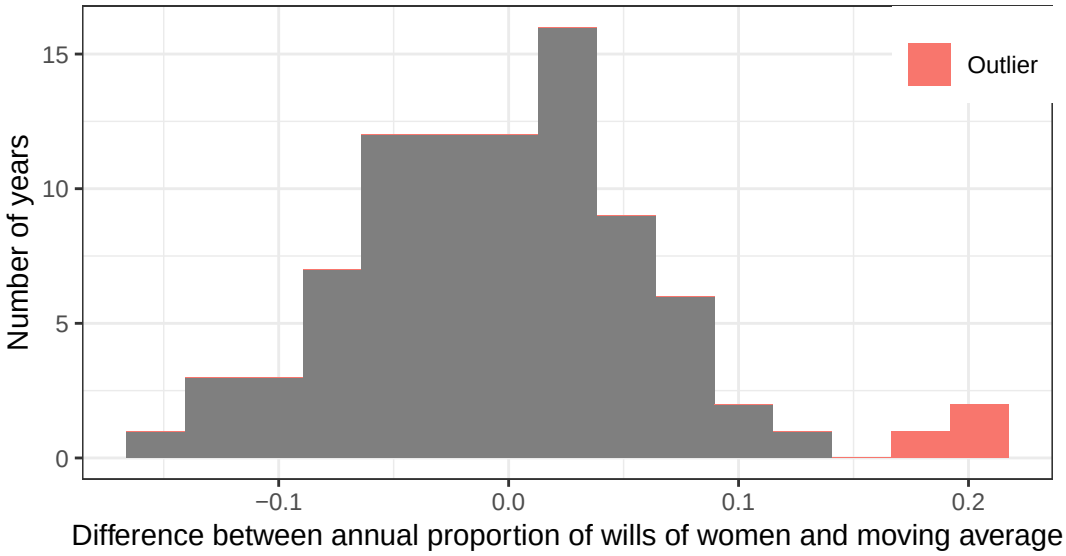


Figure 1.9: A histogram of the difference between the proportion of wills probated each year by women and its corresponding 5 year moving average from 1290–1385.

In the 14th century, women were considered property of men, and there were very few circumstances in which women could claim rights themselves, which seems likely to explain the low percentage of wills written by women (11%) [16, pp. 1079, pp. 1083]. Women of royalty and *femes sole* (widows, sailors' wives and women who were abandoned by their husbands) were able to own property, buy clothing and food, *etc* [16, pp. 1083].

The will of Emma Wylekyn [9, Vol. 1, pp. 182–188] (presented to the court on 20 November 1307) gives a glimpse of what life was like for a woman in

Medieval London. Because she was a *testatrix* (a female testator) [17, pp. 6] who also happened to be a *feme covert* (a married woman) [18], her will had no legal implications.

> Wylekyn (Emma), wife of Henry de Greneford. Testament annulled because the testatrix was a feme covert at the time of making it as well as at the time of her decease, &c. Et celte consignatur, &c. Roll 35 (98).
> —Will taken from volume 1, page 182–188 of [9, 10]

1.6 London in 1307 and 1328

By using a five year moving average, we are able to see underlying trends in the yearly time series of probate dates, while also determining which years deviate from the underlying trends [14]. We take the difference between the yearly count from the time series and the moving average function at that time. We can then use this difference to determine when anomalies occur by using the outliers, as in Section 1.4. We have ignored the years in which the plague occurred because we are interested in finding anomalies in the time series that are unexplained by a plague outbreak. As Fig. 1.10 shows, there were two years in which an outlier occurred (1307 and 1328). The number of wills probated in 1307 and 1328 is 56 and 51 respectively and the difference between these counts and the moving average is 23.8 and 21.6 respectively. We consider possible historical events that might be related to the anomalies in these two years.

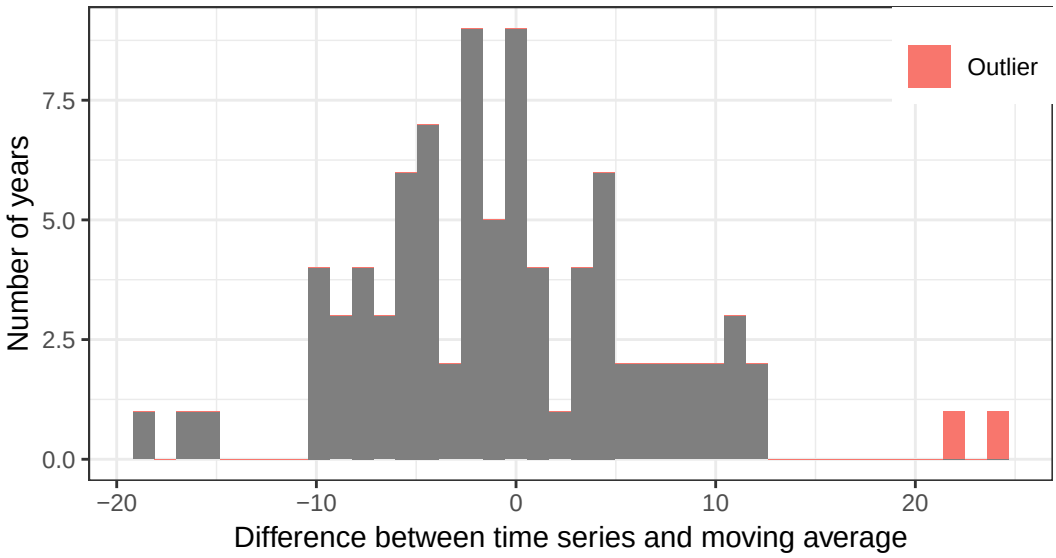


Figure 1.10: A histogram of the difference between the number of wills probated each year and its corresponding 5 year moving average.

1.6.1 London in 1307

More wills were probated in 1307 than in 1316, which was the peak of Europe's most devastating famine: The Great European famine [19]. The fall of the economy and food sources has been suggested as a possible reason that the Black Death devastated London to the extreme that it did [19]. The reason why 1307 had more wills than 1316 and was an anomaly to the time series is certainly an interesting question worth exploring in future work.

There were two particularly notable events in 1307, the Battle of Loudoun Hill (Scotland) and the the death of King Edward I [9, 10, 20]. Although battles were common, the Battle of Loudoun Hill was important as the Scots won and their independence was regained [20]. The battle in conjunction with the death of England's king could possibly be cause for why there was a sudden increase in the number of wills probated in 1307.

1.6.2 London in 1328

On March 27, 1328, England and Scotland ended 33 years of war and signed the Treaty of Edinburgh and the Disinherited [21]. This treaty was a sign of peace between these two countries, though the peace lasted only five years [21]. Whether the end of the war was coincidental or had some causal connection with the increased number of wills probated in London in 1328 is unclear.

1.7 Occupations in Medieval and Renaissance London

There are 156 different careers mentioned in the 4110 wills listed in the Calendar of Husting wills [9, 10]. Some of these careers are still common today, such as a grocer, tailor or jeweller. The will of a clerk, John Lawefare, is shown below:

> Lawefare (Sir John de), clerk.—To Alice, sister of Otho de Lawefare, all his houses in the suburb of London, with all their appurtenances, rendering therefor to the lords of the fee the service due and accustomed. No date. Roll 2 (49).
> —Will taken from volume 1, page 1–5 of [9, 10]

The most common careers among those who wrote wills are listed in Table 1.2. Definitions for all the careers mentioned in the wills probated by the Court of Husting can be found in Tables 1 to 4, which are organized according to four categories of careers: church, city, business and nobility.

Of the 4110 wills probated by the Court of Husting, 2105 wills (51.2%) included information about the testator's career. Table 1.3 provides a breakdown

Career	Frequency	Percentage
fishmonger	200	9.5%
merchant	120	5.7%
goldsmith	118	5.6%
draper	103	4.9%
skinner	79	3.8%
vintner	73	3.5%
clerk	69	3.3%
grocer	68	3.2%
knight	66	3.1%
cordwainer	50	2.4%

Table 1.2: The ten most common careers among those who wrote wills that were probated in the Court of Husting.

Career Category	Count	Percentage
business	922	80.2%
church	38	3.3%
city	116	10.1%
nobility	73	6.4%

Table 1.3: The percentage of wills (with a career recorded) in each career category

of what percentage was in each career category.

Fig. 1.11 shows how the proportion in each career category changed over the four hundred year period that the Court of Husting was open.

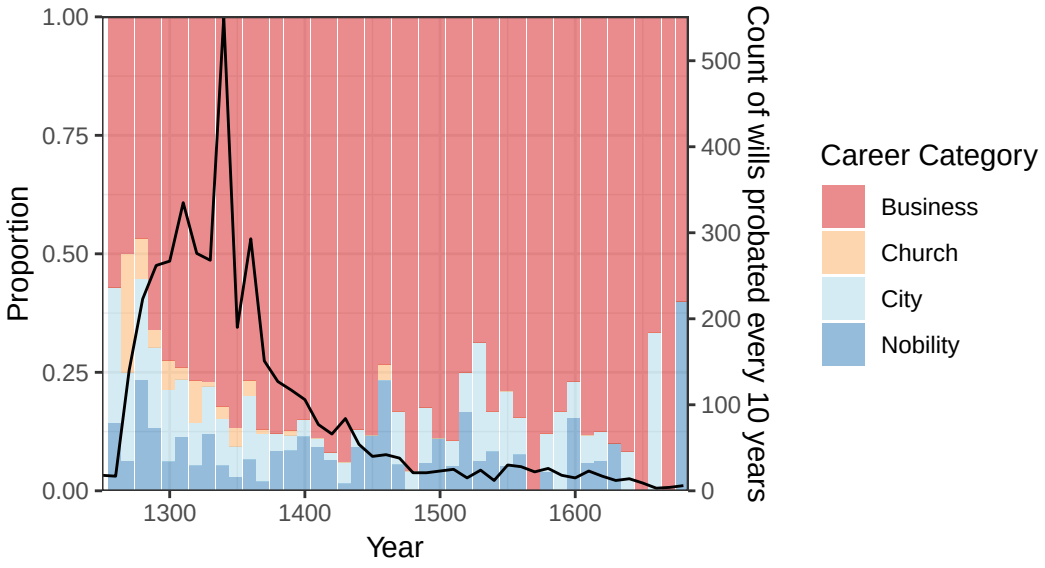
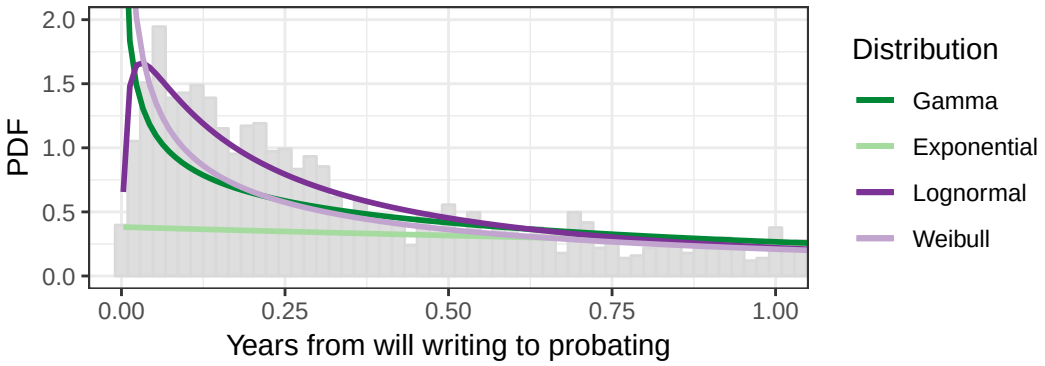


Figure 1.11: The proportion of testators, according to career category, who wrote wills over time, with each bar representing ten years. The black line represents the number of wills probated each decade from 1259 to 1688.

1.8 Relationship between probate date and will date

To study the relationship between probate date and will date, we found the difference in time between the two dates and created a histogram of these values. This histogram is shown in Fig. 1.12. Four distributions were fit, using the function `fitdistr` in the `R` package `MASS` [22], to the histogram; lognormal, Weibull, exponential and gamma. In Fig. 1.12, it appears that the lognormal distribution fits best. To determine statistically which is the best fit for the distribution, we used the Akaike information criterion (AIC). Lower AIC values correspond to better fits, and differences in AIC of more than 10 units ($\Delta\text{AIC} > 10$) are considered to be significant [23]. Table 1.4 shows that there is a clear difference between the quality of fit for each of the four distributions we considered, and the lognormal provides by far the best



[b]

Figure 1.12: Years from writing to probating wills in the Court of Husting. Histogram of observations (grey) and fits of four continuous distributions (solid curves). Any delay from will writing to probating that exceeds a year is not shown.

Distribution	ΔAIC
lognormal	0.00
Weibull	383.85
gamma	780.69
exponential	2327.39

Table 1.4: The ΔAIC for four different distributions, with respect to the log-normal distribution, fit to the histogram of the difference between the probate date and will date.

fit (consistent with the visual impression from Fig. 1.12).

1.9 Conclusion

Using the Husting wills [9, 10] we have explored and described characteristics of the population of Medieval London, from 1290–1385, a century during which four plague epidemics occurred. Such characteristics include:

- the process of dating wills appears to have become common in 1328
- 11% of testators were women

- Saturday was the most common day of the week to write wills and Thursdays was the least common

- 51.2% of testators mentioned their occupation. Of these, a majority were in business, with the most common occupation being fishmongery.

The data only provide direct insight into the lives of the testators in Medieval London, i.e., wealthier individuals who owned property or items worth passing on to others.

Additionally, we have found that the lag time from will date to probate date can be described by a lognormal distribution. Why the observed distribution of delays between writing and probating wills is so close to a lognormal distribution is an interesting question for further research.

The scope of this project has been restricted to the Husting wills, but the surviving records from the Court of Canterbury, and many other ecclesiastical courts that were opened after 1385, provide opportunities for further research. Analyses similar to those conducted in this paper could be performed on wills probated in these other courts to gain insight into various historical questions such as:

- How did the proportion of wills written by women change from 1400–1900? Are changes in the proportion correlated with improvements in women's rights?

- In conjunction with the Husting wills and other court documents, how did popular names change over a 600 year period?

- Did the occupations of testators (in London) change from 1400–1900?

The `R` package we have written for extracting and analyzing the contents of the wills probated in the Court of Husting should facilitate further research on these valuable historical documents.

Chapter 2

Do demographic patterns of epidemics differ when inferred from dates wills were written versus probated?

2.1 Introduction

The study of historical epidemics in human populations is important for understanding the evolution and dynamics of infectious diseases [1]. The plague, caused by the bacterium *Yersinia pestis*, has resulted in devastation across human civilizations throughout three pandemics [2]. The Justinian plague impacted civilizations around the Mediterranean Sea from the 6th to 8th century [2]. The Black Death affected Europe from the 14th to 17th century [2, 3]. We are currently in the third pandemic (Modern Plague), which has impacted countries around the world [3]. Here, we consider plague epidemic patterns during the second pandemic in London, England.

Registration of deaths in England began in 1538 [4]. Weekly bills of mortality, summarizing deaths by cause, began to be published later (a continuous weekly record survives from 1662 onward). In order to study demographic patterns in the 14th century when the Black Death first appeared, alternative sources are required.

Historians studying epidemics before the death registration era (e.g., [6, 7]) have described the temporal structure of epidemics based on the assumption that numbers of wills dated in a given time period reflect patterns of death from disease. The date on which a will was probated (i.e., brought before a court of law and approved so the estate could be distributed) is typically available based on court records. In contrast, the date on which a will was written was not always recorded.

If both the dates on which wills were written and probated are available, which should we use if we wish to describe epidemic patterns? One could argue that probate dates are more appropriate because we know testators

must have died before their wills were brought before a court. However, a long time might have elapsed between the date when the will was written and when it was probated, so the testator's death might have nothing to do with an epidemic that was occurring either at the time of writing or of probating. Earn *et al.* [5] argue that the dates on which wills were written are more appropriate for the study of epidemics because people may have been more likely to write their will if they became ill—or feared that they might soon become ill—during a deadly epidemic. For 17th century plague epidemics in London, for which both wills—proved in the Prerogative Court of Canterbury (PCC [24])—and mortality records are available, Earn *et al.* [5] show that the temporal pattern of wills written follows the recorded pattern of deaths from plague.

Our goal in this paper is to determine the relationship between will dates and probate dates—i.e., to determine the distribution of the times between writing and probating a will—and to examine how apparent epidemic patterns differ when described using will dates or probate dates. The online source for the PCC wills [24] provides only the will date, not the probate date. We use The Calendar of Wills Proved and Enrolled in the Court of Husting, London [9], which contains 4110 wills probated from 1259 to 1688. This book, which we refer to as the *Husting wills*, has recently been digitized as part of the British History Online (BHO) project [10]. Entries in the Husting wills always provide the probate date, and beginning in 1301 the date the will was written is sometimes indicated. From 1328 onward, most entries contain both the will date and probate date (see Chapter 1).

2.2 Methods

2.2.1 New Year's Day

Throughout the era when the Court of Husting was in existence, New Year's Day occurred on the Feast of the Annunciation (March 25) [12, pp. 80]. This was taken into consideration when determining the dates when the wills were written and probated. For example, the first probate date recorded in the Husting wills was January 25 1258. According to the Gregorian year, this was January 25 1259. We express all dates using the Gregorian year, so we say the Court of Husting was open from 1259 (not 1258 as recorded in the wills themselves) to 1688.

2.2.2 Distribution of lag from date of will writing to probate

Lag models fitted to different epochs

The number of Husting wills probated per unit time varies enormously over the 430 years that the court was active. In particular, many more wills were written and probated in the years surrounding known plague epidemics. Consequently, we considered subsets of the full time span from 25 January 1259 to 6 May 1688 and fit the lag distribution models to each subset as well as to the entire data set. The subsets we considered were:

All time (one distribution)	
25 Jan 1259 – 06 May 1688	
All plague years and all non-plague years (two distributions)	
Plague years	Non-plague years
15 Jan 1348 – 15 Dec 1349	25 Jan 1259 – 15 Jan 1348
15 Jan 1361 – 15 Dec 1361	15 Dec 1349 – 15 Jan 1361
01 Jan 1368 – 01 Jan 1369	15 Dec 1361 – 01 Jan 1368
15 Jan 1375 – 15 Dec 1375	01 Jan 1369 – 15 Jan 1375
	15 Dec 1375 – 06 May 1688
All possible time periods (nine distributions)	
25 Jan 1259 – 15 Jan 1348	
15 Jan 1348 – 15 Dec 1349	
15 Dec 1349 – 15 Jan 1361	
15 Jan 1361 – 15 Dec 1361	
15 Dec 1361 – 01 Jan 1368	
01 Jan 1368 – 01 Jan 1369	
01 Jan 1369 – 15 Jan 1375	
15 Jan 1375 – 15 Dec 1375	
15 Dec 1375 – 06 May 1688	

Lag model types

Since a will cannot be probated before it is written, the underlying distribution of delays from will date to probate date must have positive support. We considered four common probability distributions with positive support listed in Table 2.1 and used the method of maximum likelihood [25] to estimate the parameters for each model (fitted to a histogram of the observed delays from will date to probate date). We used the `fitdistr` function in the `R` package `MASS` [22].

We selected the best model based on the Akaike Information Criterion (AIC [26, 27]), which is a measure of badness of a fit. If the likelihood of a model with K parameters $[\theta = (\theta_1, \ldots, \theta_K)]$ given n data points $[y = (y_1, \ldots, y_n)]$ is $\mathcal{L}(\hat{\theta}|y)$ then

$$\mathrm{AIC} = -2 \log \mathcal{L}(\hat{\theta}|y) + 2K \,, \tag{2.1}$$

where $\hat{\theta}$ refers to the maximum likelihood estimate of θ. We used the `AIC`

Distribution	PDF	Mean	Standard deviation
Exponential	$\lambda e^{-\lambda x}$	$\frac{1}{\lambda}$	$\frac{1}{\lambda}$
Gamma	$\frac{1}{\Gamma(k)\theta^k} x^{k-1} e^{-\frac{x}{\theta}}$	$k\theta$	$\sqrt{k}\theta$
Weibull	$\frac{k}{\lambda}(\frac{x}{\lambda})^{k-1} e^{(\frac{x}{\lambda})^k}$	$\lambda\Gamma(1+\frac{1}{k})$	$\lambda\sqrt{\Gamma(1+\frac{2}{k}) - [\Gamma(1+\frac{1}{k})]^2}$
Lognormal	$\frac{1}{x\sigma\sqrt{2\pi}} \exp\left[-\frac{(\log x - \mu)^2}{2\sigma^2}\right]$	$\exp(\mu + \frac{\sigma^2}{2})$	$\sqrt{(\exp(\sigma^2) - 1)(\exp(2\mu + \sigma^2))}$

Table 2.1: The four distributions that were considered for describing the lag time of will writing to probating with their corresponding probability density functions, mean and standard deviation.

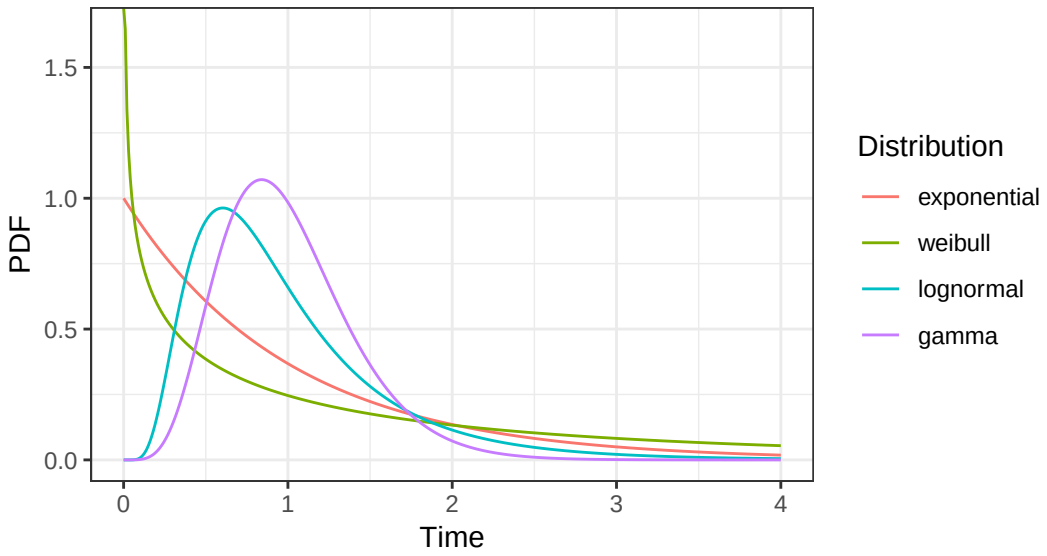


Figure 2.1: The four distributions (discussed in Table 2.1) presented with their PDFs with the same mean (1) and standard deviation (0.4).

function in the `R stats` package. Note that the corrected AIC [27],

$$\mathrm{AIC_c} = \mathrm{AIC} + \frac{2K(K+1)}{n-K-1}\,, \tag{2.2}$$

is negligibly different from the AIC since the number of parameters is $K \leq 2$ and the sample size $n > 34$ (the minimum number of Husting wills for which both will date and probate date are known for the different time periods mentioned in Section 2.2.2).

We present comparisons using the difference in AIC between a given model and the model with the lowest AIC,

$$\Delta\mathrm{AIC} = \mathrm{AIC} - \mathrm{AIC_{min}}\,. \tag{2.3}$$

A value of $\Delta\mathrm{AIC} > 10$ is typically interpreted as meaning that there is essentially no empirical support for the given model in comparison with the best model with the lowest AIC. If $\Delta\mathrm{AIC} < 2$ then there is strong support for the model in comparison to the one with the lowest AIC [27, §2.6, p. 70].

2.2.3 Temporal pattern of wills

To obtain an overall visual impression, we constructed time plots of will counts, and compared the results based on will dates with those based on probate dates.

2.2.4 Estimation of epidemic growth rate

An issue that is important when attempting to make epidemiological inferences based on will counts is whether inferred epidemic characteristics depend on the

type of dates (will or probate) used for analysis.

A fundamental characteristic of an epidemic is the initial rate of exponential growth of cases. We use the approach of Ma *et al.* [28] to estimate initial growth rates, and compare results based on will dates and probate dates.

Briefly, the method of Ma *et al.* [28] is to fit a phenomenological model to the observed cumulative counts (of wills in our case). The phenomenological model we used was a logistic curve combined with a fixed baseline (b wills per unit time) that represents the average number of wills per unit time under normal circumstances (i.e., outside unusual time periods such as epidemics). Thus, we model the cumulative counts as

$$C(t) = \frac{K}{1 + \frac{K - C_0}{C_0} e^{-rt}} + bt\,, \tag{2.4}$$

where K and C_0 are positive. In Eq. (2.4), C_0 is the initial cumulative will count, r is the initial epidemic growth rate, and K is the final size of the epidemic. Following Ma *et al.* [28], we fit interval counts

$$C(t + \Delta t) - C(t)\,, \tag{2.5}$$

where, for us, the aggregation interval Δt is one day. By using interval counts, rather than cumulative counts, we can avoid the correlation among the cumulative counts [5, 28].

We found maximum likelihood estimates of growth rates and associated confidence intervals using an `R` package (`epigrowthfit` [29]) that implements the methodology of Ma *et al.* [28].

2.2.5 Theoretical relationship between growth rates of will counts and probate counts

In addition to the practical issue of whether estimated rates of growth of will counts depend on whether will dates or probate dates are used, we considered what should be expected theoretically. Assuming pure exponential growth of the number of wills written, we derived an expression for the expected rate of growth of wills probated.

2.3 Results

2.3.1 Distribution of lag from will to probate

Figs. 2.2 to 2.4 display histograms of the lag time from will date to probate date for the different epochs mentioned in Section 2.2.2, together with fits obtained using the four distributions listed in Table 2.1. We determine from Table 2.2 that the lognormal distribution is the best fit for all epochs. Maximum likelihood parameter estimates for the lognormal distribution, for each of the temporal subsets listed in Section 2.2.2 are presented in Table 2.3.

2.3.2 Temporal pattern of epidemics

Fig. 2.5 shows time plots of the will counts during each of the four 14th century plague epidemics. Compared with the epidemic pattern that is suggested by the counts based on will dates (red), if probate dates are used (blue) the epidemics appear to occur over much longer time spans.

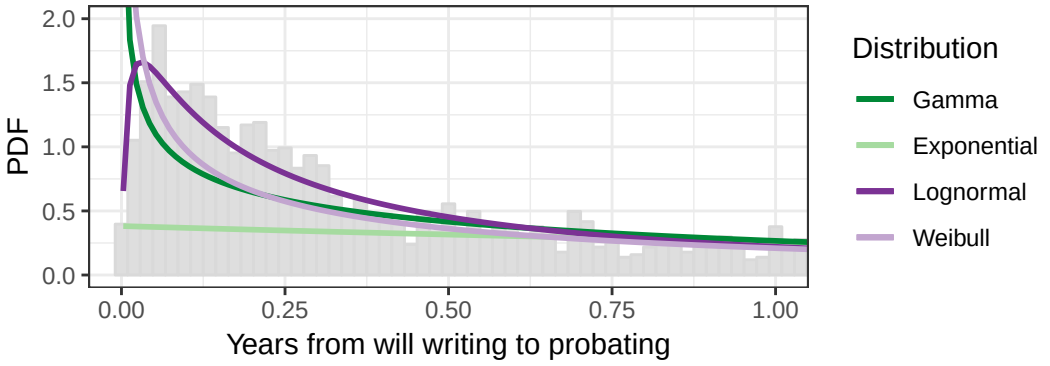


Figure 2.2: The distribution of the lag time from writing to probating wills in the Court of Husting. The raw data are shown as a histogram (in grey), and fits using the four distributions listed in Table 2.1 are shown as solid curves. Any delay from will writing to probating that exceeds a year is not shown.

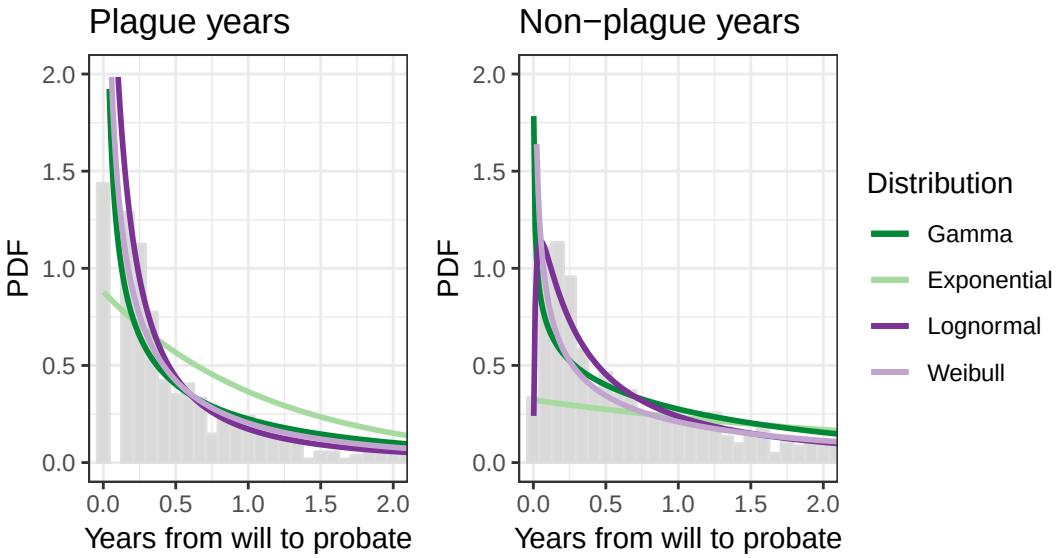


Figure 2.3: The distribution of the lag time from writing to probating wills, for the plague versus non-plague epochs, in the Court of Husting. The raw data are shown as a histogram (in grey), and fits using the four distributions listed in Table 2.1 are shown as solid curves.

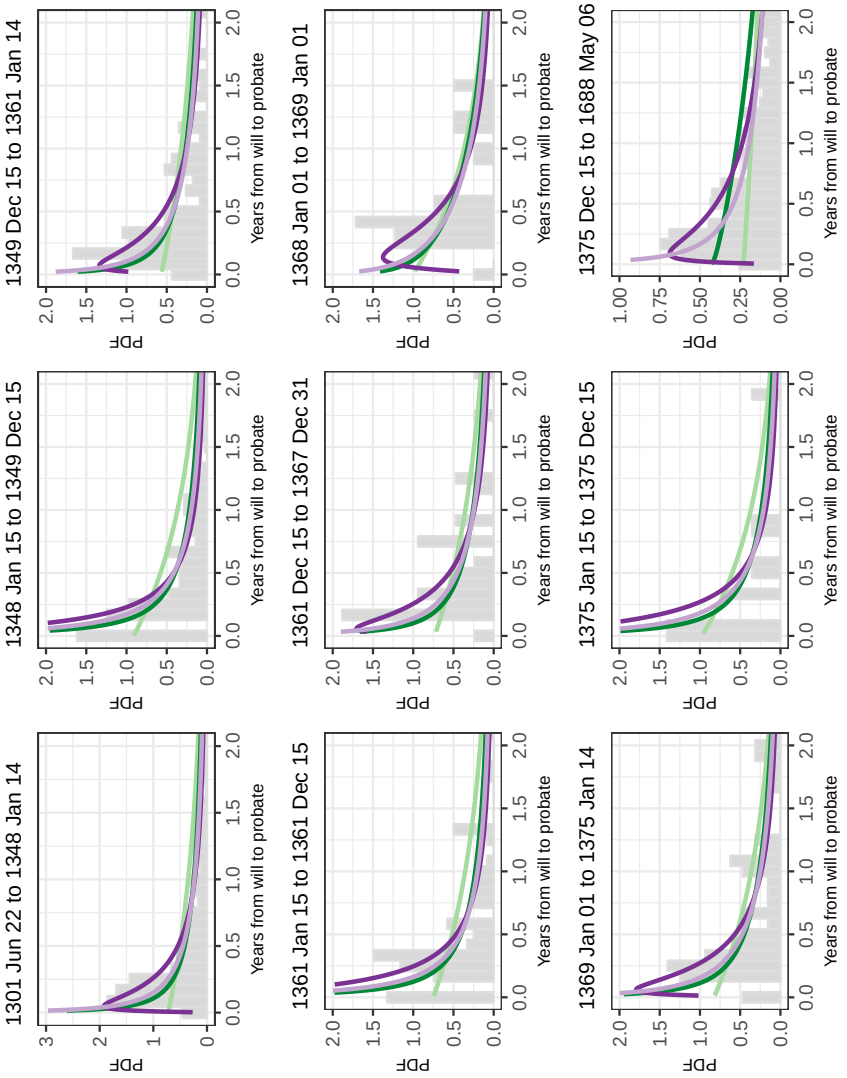


Figure 2.4: The distribution of the lag time from writing to probating wills, for all epochs mentioned in Section 2.2.2. The raw data are shown as a histogram (in grey), and fits using the four distributions listed in Table 2.1 are shown as solid curves.

	lognormal	Weibull	gamma	exponential	size
Plague					
1348–1350	0	80	170	477	423
1361–1362	0	43	80	182	145
1368–1369	0	14	16	16	49
1375	0	11	18	33	34
all plague years	0	137	275	695	651
No plague					
1258–1348	0	148	265	480	575
1350–1361	0	26	43	77	137
1362–1368	0	12	18	29	51
1369–1375	0	18	29	45	77
1375–1689	0	73	163	523	1129
all non-plague years	0	286	542	1452	1969
All years					
1258–1689	0	384	781	2327	2620

Table 2.2: The ΔAIC values for four different distributions fit to the histogram of the difference in time from the will to probate date for the different epochs mentioned in Section 2.2.2. The ΔAIC values are always in increasing order from left to right.

	Meanlog	Sdlog	Mean (yrs.)	Median (yrs.)	St. dev. (yrs.)
Plague					
1348–1350	-1.45	1.75	1.08	0.23	4.29
1361–1362	-1.25	1.62	1.06	0.29	3.94
1368–1369	-0.72	1.12	0.91	0.49	2.63
1375	-1.3	1.48	0.81	0.27	2.82
all years when plague occured	-1.34	1.68	1.07	0.26	4.1
No plague					
1258–1348	-0.89	1.46	1.19	0.41	4.08
1350–1361	-0.52	1.46	1.73	0.59	5.91
1362–1368	-0.78	1.44	1.29	0.46	4.38
1369–1375	-0.86	1.39	1.11	0.42	3.67
1375–1689	0.32	1.65	5.37	1.38	20.21
all years when plague didn't occur	-0.17	1.67	3.4	0.84	12.93
All years					
1258–1689	-0.46	1.75	2.92	0.63	11.54

Table 2.3: The parameters for various time periods, found by fitting the lognormal distribution to the difference (in years) of the will date to probate date.

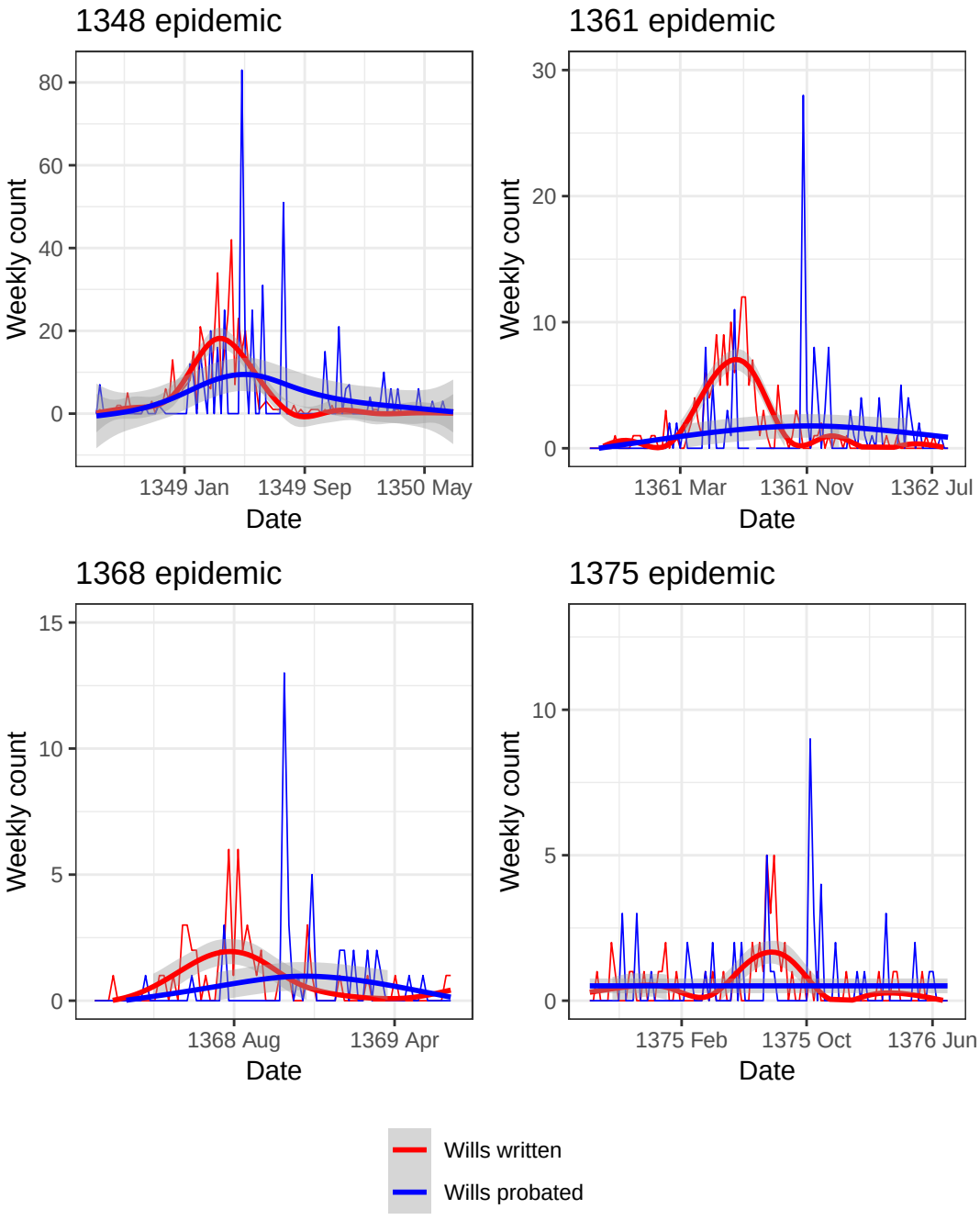


Figure 2.5: Weekly counts of wills during the four plague epidemics from 1348 to 1375. Counts based on will dates (probate dates) are shown in red (blue). We fit the heavy curves by using the LOESS (locally estimated scatterplot smoothing) method. The grey bands are the 95% confidence intervals for the heavy curves.

2.3.3 Estimation of epidemic growth rate

	Growth rate [1/year]		Doubling time [days]	
Plague	Will dates	Probate dates	Will dates	Probate dates
1348	4.62 (3.46, 6.52)	12.85 (2.79, 19.79)	54.74 (38.78, 73.21)	19.69 (12.78, 90.58)
1361	9.26 (4.92, 15.52)	NA	27.32 (16.30, 51.43)	NA
1368	8.89 (3.30, 21.78)	51.9 (0.00, 66.2)	28.47 (11.62, 76.75)	4.87 (3.82, ∞)
1375	20.57 (6.18, 43.57)	0.00 (0.00, 23.63)	12.30 (5.81, 40.95)	∞ (10.71, ∞)

Table 2.4: Estimated growth rates and doubling times using aggregated will dates and probate dates, with a 95% confidence interval.

Table 2.4 lists and Figs. 2.6 and 2.7 display growth rate and doubling time estimates based on will dates and probate dates for the four plague epidemics from 1348 to 1375. We fit the phenomenological model to the observed counts for both wills written and wills probated (Fig. 2.8).

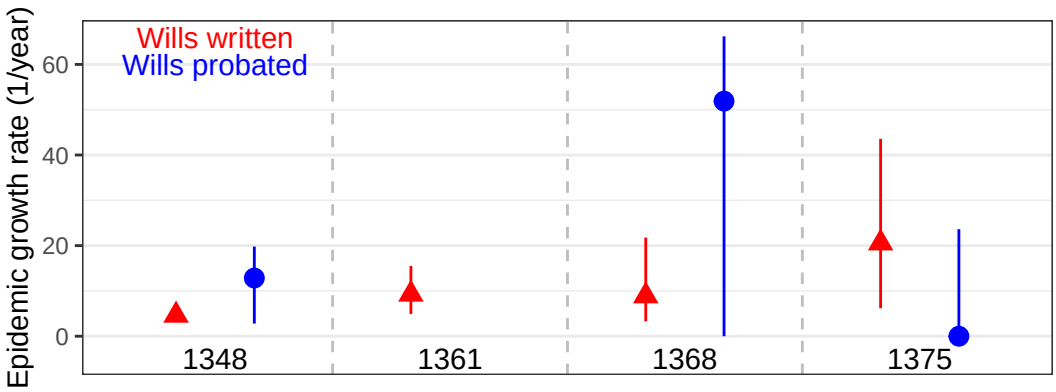


Figure 2.6: 95% confidence interval for estimated growth rate of the four plague epidemics.

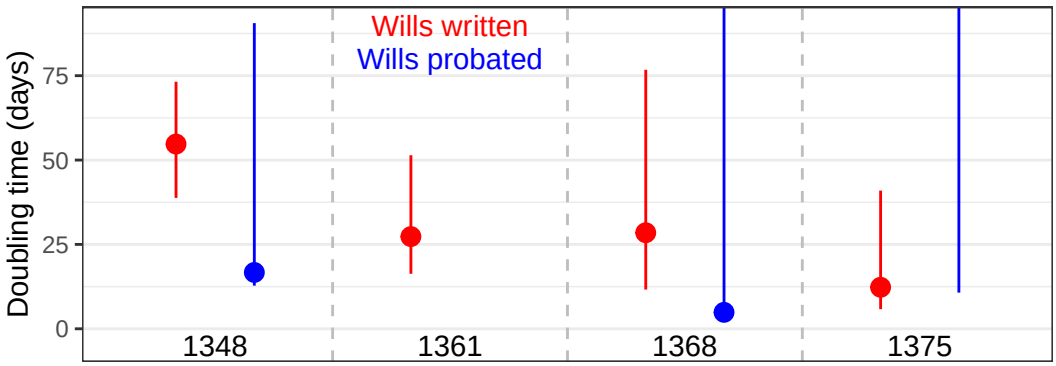


Figure 2.7: 95% confidence interval for doubling times of the four plague epidemics.

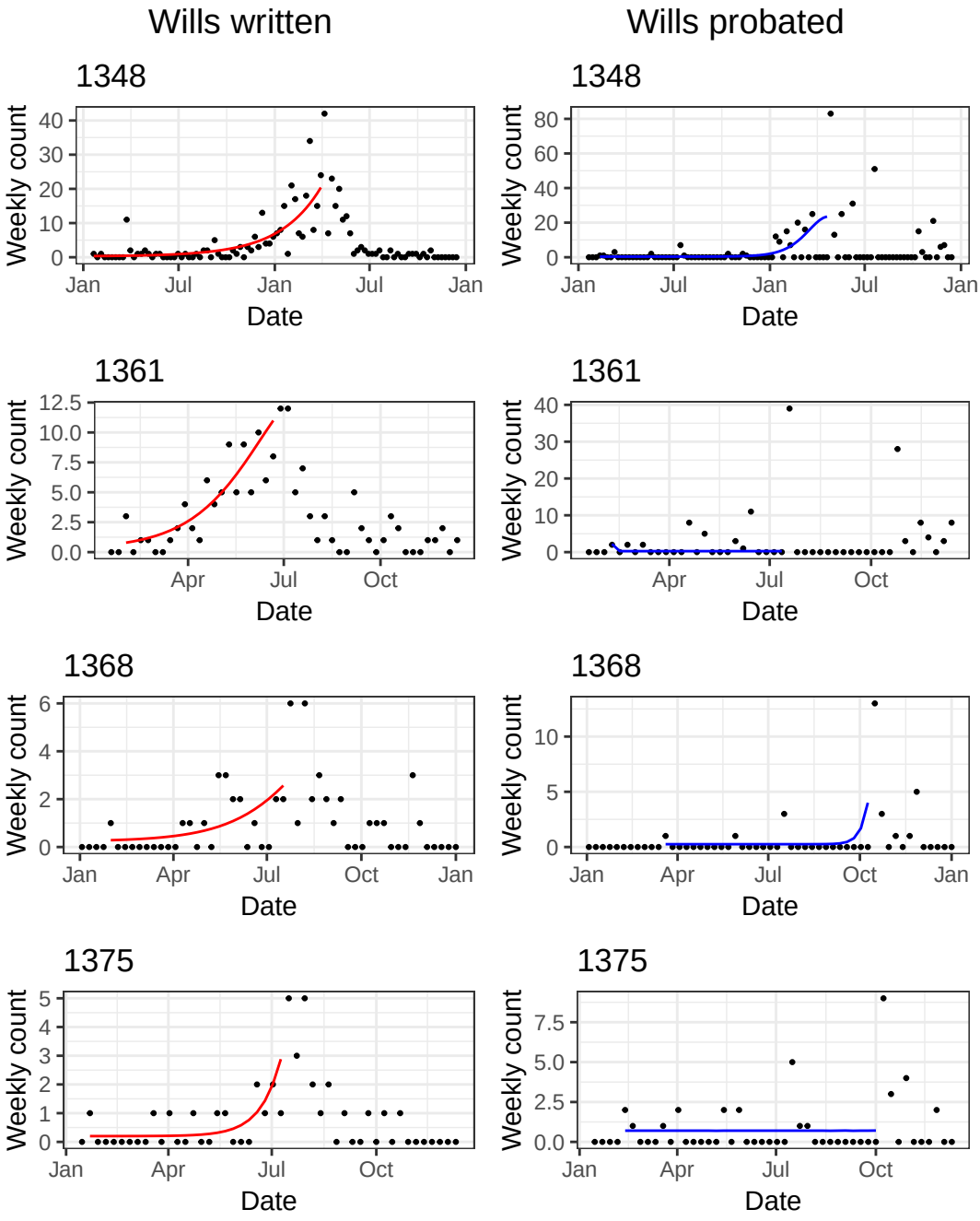


Figure 2.8: Weekly counts of wills written and probated (points) with their respective fitted logistic model (lines).

2.3.4 Theoretical relationship between growth rates of will counts and probate counts

By ignoring the saturation of the epidemic, we are able to assume that, initially, the aggregated will dates grow exponentially:

$$W(t) = W_0\, e^{r_{\mathrm{w}} t} \tag{2.6}$$

If f is the distribution of lag times from writing to probating a will (which we found in Section 2.3.1 is approximately lognormal), then a will written at time u is probated at time t with probability $f(t-u)$. Therefore, the expected number of wills probated by time t is

$$P(t) = \int_0^t W(v) f(t-v)\, dv\,.$$

Letting $u = t - v$, we can also write

$$\begin{aligned} P(t) &= \int_t^0 W(t-u) f(u)(-du) \\ &= \int_0^t W(t-u) f(u)\, du \\ &= W_0 e^{r_{\mathrm{w}} t} \int_0^t e^{-r_{\mathrm{w}} u} f(u)\, du\,. \end{aligned}$$

The exponential growth rate of probates at time t is

$$\begin{aligned}\frac{d\log P(t)}{dt} &= \frac{1}{P(t)}\frac{dP(t)}{dt} \\ &= \frac{W_0 r_{\mathrm{w}} e^{r_{\mathrm{w}}t}\int_0^t e^{-r_{\mathrm{w}}u}f(u)\,du + W_0 e^{r_{\mathrm{w}}t}[e^{-r_{\mathrm{w}}t}f(t)]}{P(t)} \\ &= \frac{r_{\mathrm{w}}P(t) + W_0 f(t)}{P(t)}\,,\end{aligned}$$

which gives

$$r_{\mathrm{p}} = r_{\mathrm{w}} + \frac{W_0 f(t)}{P(t)}\,. \tag{2.7}$$

Eq. (2.7) and Fig. 2.9 show that:

- if, initially, the wills grow exponentially, then the probates grow approximately exponentially at approximately the same rate
- At time zero (the time from the start of the epidemic to probating a will), the probate growth rate approaches infinity. Because we have assumed a lag time distribution between probate date and will date and we are considering the case that all wills are probated by time zero, the probate growth rate must approach infinity.
- if the wills have been growing exponentially forever, $W_0 \to 0$ and therefore, $r_{\mathrm{p}} = r_{\mathrm{w}}$.
- We expect all wills to be probated by time infinity. As the time to probate wills approaches infinity, $f(t) = 0$ and $P(t) \to \infty$ and therefore $r_{\mathrm{p}} \to r_{\mathrm{w}}$.

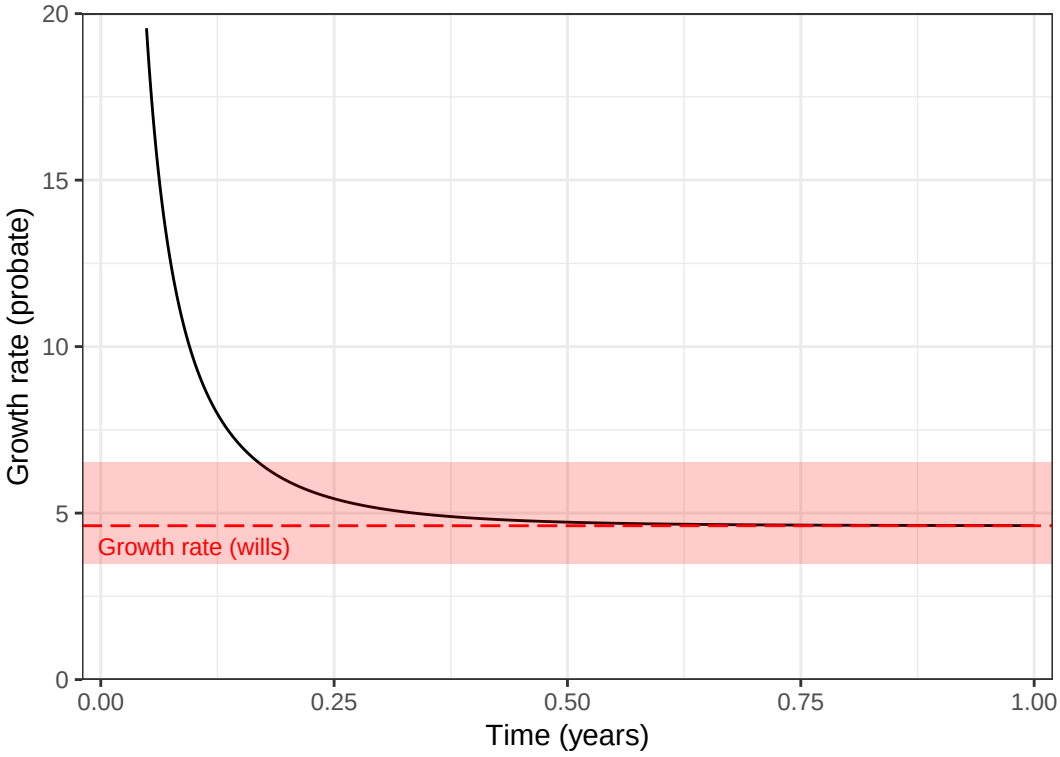


Figure 2.9: Using Eq. (2.7), we model the estimated initial probate growth rate of the 1348 epidemic as a function of time, in years, since the *estimated* start of exponential growth. To model the estimated probate growth rate, we used the parameters of the lognormal distribution recorded in Table 2.3 for the 1348 plague epidemic in conjunction with the estimated initial will growth rate found in Table 2.4. The red band represents the 95% confidence interval of the estimated growth rate of the wills.

2.4 Discussion

2.4.1 Distribution of lag from will to probate

It is visually clear from Figs. 2.2 to 2.4 that the lognormal distribution provides by far the best fit for all epochs discussed in Section 2.2.2, an impression that is strongly supported by the ΔAIC values [Eq. (2.3)] presented in Table 2.2. The mean, median and standard deviation of the lognormal distribution (fitted to the lag time from will to probate date) are generally smaller for the plague epochs compared with the non-plague epochs. This means that the time between will writing and probating decreased during the plague years, supporting the hypothesis that writing of wills during plague epidemics was associated with plague infection.

2.4.2 Using probate dates in place of will dates

Comparing the confidence interval (CI) for the probate date epidemic growth rate with the will date epidemic growth rate for the 1348 epidemic in Table 2.4 and Figs. 2.6 and 2.7, we notice that (i) the will date CI is contained in the probate date CI and (ii) the will date CI is much smaller than the probate date CI. However, the CI of the growth rate for probate dates from the latter epidemics are not reasonable. The larger CI associated with estimation from probate dates in 1348 and the unreasonable estimation of the CI for the other epidemics probably arises from a number of sources of noise. In particular:

- Wills were dated on any day of the week, whereas probates always occurred on Mondays because the Court of Husting was only ever open on Mondays. Additionally, there was no guarantee that the court was

open every single Monday, possibly leading to long periods of time, even during the epidemics, when there were no wills probated.

- During epidemics, the date a will was written could have been associated with fear of death or perception of the danger of death due to awareness of the epidemic. In contrast, probate dates would have depended on a variety of factors that did not necessarily reflect anything about the transmission process that gave rise to exponential growth of cases (e.g., whether the death actually occurred as a result of plague infection, the nature and complexity of the estate, which of the intended beneficiaries survived the epidemic, *etc.*).

When we compare the phenomenological model fits of the will and probate counts in Fig. 2.8, we conclude that demographic patterns of epidemics are better inferred from dates wills were written based on the assumption that plague epidemics occurred in 1348, 1361, 1368 and 1375. The fitted phenomenological model predicts an epidemic for all four epidemics when using will counts. In comparison, an epidemic is predicted for only two of the epidemics when using probate counts.

2.4.3 Relationship between the initial exponential growth rate of probate date and will date time series

The calculation in Eq. (2.7) is based on the implicit assumption that no wills were written before time 0. This assumption leads to divergence of the probate growth rate as $t \to 0$ (see Fig. 2.9). Alternative assumptions yield different results. In particular, if we assume exponential growth of numbers of wills written for all time then we obtain $r_{\mathrm{p}} = r_{\mathrm{w}}$.

It should be noted that we have not taken into account the discrete nature of the aggregation interval. We have assumed infinite population size and ignored saturation and issues that arise from poor sampling. Lastly, we have not explored alternative fitting windows that may influence the approximation of the epidemic growth rate.

2.5 Conclusion

We have determined that the lag time distribution from will date to probate date can be described as a lognormal distribution. By assuming that will dates grow exponentially initially, we derived an equation for the initial epidemic growth rate of probate dates which depends on (i) initial epidemic growth rate of will dates (ii) lag time distribution from will date to probate date (which, in this case, is lognormal) (iii) the number of probates and (iv) the initial will count at the beginning of the epidemic. If the count of wills written grows exponentially initially, we can determine that the count of wills probated will grow approximately exponentially.

Additionally, we have determined that the date the will was written should be used, rather than probate dates when calculating the initial epidemic rate of the plague epidemics from 1348–1376 in London, England. When using will dates, we were able to predict all four epidemics from 1348–1376. However, when using probate dates, only two of the four epidemics were predicted. The poor prediction, when using probate dates, is likely a result of noise associated with (i) the varying lag from writing to probating wills, (ii) the fact that wills were only probated on Mondays and (iii) poor fitting windows.

We have written an R package, which can be used to extract and analyze

the Husting wills.

Chapter 3

Introduction to `willsr`

3.1 Introduction

The Calendar of Wills Proved and Enrolled in the Court of Husting, London [9] includes 4110 wills written by citizens of London, England, from 1258 to 1689. All these wills were digitized by the University of London as part of the "British History Online" (BHO) project [10]. The `willsr` R package provides a number of tools that facilitate statistical analyses of the Husting wills.

3.2 Required packages

A number of `R` packages are used in this vignette:

```
library(willsr)
library(Hmisc) # nice tables
library(dplyr) # piping
library(tidyr) # spread
library(ggplot2) # nice graphics
```

3.3 Creating a convenient data frame from the online source

To get started, there is a function `scrape_HustingWills` that extracts all the Husting wills from British History Online [10] using `R` packages rvest and xml2, which are designed to facilitate web scraping. This function needs to be run only once, unless there is an update to BHO. The file `"wills.RData"` then just needs to be loaded subsequently.

`scrape_HustingWills()` takes approximately 10–15 minutes to run with a fast internet connection. It checks if the required `RData` file exists before

creating it, so no scraping is done unnecessarily. If you are running this for the first time and therefore actually scraping the data, you will need to reinstall the `willsr` package afterwards in order for the `wills` data frame to be available automatically when the package is loaded.

```
wills <- scrape_HustingWills(outfile = "data/wills.RData")

## data/wills.RData already exists
## wills data frame is available
```

The `wills` object that is saved to `"wills.RData"` is an object of class `"wills"`, which means it is a data frame that has a number of helpful attributes that provide information about when and how it was constructed. The data frame itself is a long list of all the Husting wills.

```
dim(wills)

## [1] 4110   18
```

The 18 columns are:

```
colnames(wills)

##  [1] "Will"             "Volume"           "ProbateYear"
##  [4] "ProbateMonth"     "ProbateDay"       "Name"
##  [7] "Career"           "WillYear"         "WillMonth"
## [10] "WillDay"          "Roll"             "ProbateDate"
## [13] "WillDate"         "WillDayOfWeek"    "ProbateDayOfWeek"
## [16] "Gender"           "CareerCleaned"    "CareerCategory"
```

The first column contains the raw data, i.e., the complete text of each will. For example, the 113th will in the list is:

```
cat("\\singlespacing \\begin{tcolorbox}",
    wills$Will[113],
    "\\end{tcolorbox} \\doublespacing")
```

> Moyne (Nicholas le).—TO Cristiana his wife his capital house in the lane of S. Martin Orgar for life; remainder to John his firstborn son. Also to the said John his tenement called the New Rent in Tamesestrete, parish of S. Michael de Candelwicstrate, saving to Martin his son, Matilda his daughter, and to the infant en ventre sa mèrecertain annual quitrents. Also to the said infant, whether son or daughter, certain houses in the lane of S. Michael aforesaid. Provision made for payment of debts. No date.Roll 8 (25).

Columns 2–18 of `wills` contain information that is automatically extracted for convenience by `scrape_HustingWills()`.

There is a `summary` method for objects of class `"wills"`. This returns, in particular, the date when the data frame was created by scraping the BHO website.

```
summary(wills, career = TRUE, dayofweek = TRUE)

##
## Date and time when wills were scraped: 2019-03-18 17:17:57
##
## DATE RANGES:
##  min.probate.date min.will.date max.will.date max.probate.date
##        1259-01-25    1301-06-22    1687-04-06       1688-05-06
##
## OTHER CHARACTERISTICS:
##  n.wills n.probate.dates n.will.dates prop.women
##     4110            4110         2620  0.1085158
##
## WEEKDAY COUNTS (WILL DATES):
##  sun mon tue wed thu fri sat
##  377 367 382 414 307 349 424
##
```

```
## WEEKDAY COUNTS (FEAST DATES):
##  sun mon tue wed thu fri sat
##  581 531 495 707 594 578 624
##
## CAREER COUNTS:
##  prop.career church city business nobility
##    0.5085158   1709   48      175      154
```

There is a convenient `latex_subtable` function for creating LaTeX tables of sections of the `wills` data frame. These tables can be customized further by giving additional arguments, which are passed on to `Hmisc::latex`.

Columns to be included in a subtable can be specified with a vector of column names:

```
latex_subtable(
    wills, rows = 2000:2009,
    columns = c("Name", "WillDate", "ProbateDate"))
```

WillNumber	Name	WillDate	ProbateDate
2000	Knopwede (Roesia	1348-09-13	1348-11-11
2001	Langelee (Robert de)	1348-08-29	1348-11-20
2002	Brauncestre (Gilbert de).	1348-12-13	1349-01-13
2003	Penthogg (Geoffrey)	1348-12-29	1349-01-13
2004	Hecham (Richard de)		1349-01-13
2005	Sampford (John de)	1348-12-13	1349-01-13
2006	Asshe (Robert de).	1348-09-20	1349-01-13
2007	Sackere (Johanna	1347-10-18	1349-01-13
2008	Cotoun or Cotum (William)	1349-01-03	1349-01-13
2009	Shirreve (Simon).	1348-01-20	1349-01-13

Alternatively, columns can be selected by the column number:

```
latex_subtable(
    wills,
    rows = 3450:3500,
    columns = c(6, 12, 16),
    head.length = 4) # number of rows to include in table
```

WillNumber	Name	ProbateDate	Gender
3450	Weston (John) de Okham	1423-11-11	male
3451	Asshcombe (Robert)	1423-11-23	male
3452	Norton (John)	1423-11-23	male
3453	Westyerd (fn. 1) (John)	1424-02-02	male

3.4 Correcting and categorizing careers

The `Career` column of the `wills` data frame contains text that `scrape_HustingWills()` identifies as the career of the testator. This "raw" career text has many problems, including inconsistent spelling (e.g., stokfisshmongere, stokfisshemongere, stokfisshmonger, *etc.*) and alternative names for the same occupation (e.g., mercer vs merchant).

The function `categorize_careers()` adds two new columns to the `wills` data frame: `CareerCleaned` contains a cleaned version of the career column and `CareerCategory` contains the name of one of four categories into which the career has been assigned (`"business"`, `"church"`, `"city"`, or `"nobility"`). It is convenient to run this function once and save the resulting data frame in `"willsCareers.RData"`.

```
wills.career <- categorize_careers(wills)
save(wills.career, file = "willsCareers.RData")
```

Before cleaning, there are 501 *unique* careers listed in `wills`, whereas after cleaning there are only 179 unique careers.

The following table shows the new columns for a sample of wills.

```
latex_subtable(
    wills.career,
    rows = 48:55,
```

```
    columns = c("Name", "CareerCleaned", "CareerCategory"),
    col.just = c("p{2in}", "p{0.8in}", "p{0.8in}"),
    rowname = NULL)
```

Name	CareerCleaned	CareerCategory
Notingham (Walter le)	fishmonger	business
Rychemund (William)	skinner	business
Godchep (Philip).		
Duket (Laurence		
Derkin (John)	apothecary	business
Thomas Cyrugicus. (fn. 3)		
Tanyngtone (Gillebert de)	chaplain	church
Ambresbure (Geoffrey de)	goldsmith	business

3.5 Creating conveniently reduced data

There are also functions that create convenient data frames based on aggregating the full `wills` data frame in various ways. It is convenient to run these functions once and save the resulting data frames in `"willsReduced.RData"`, which can be loaded subsequently.

```
## aggregates by date type (probate date or will date) and time
count.day <- aggregate_data_frame(wills, time.length = "day")
count.week <- aggregate_data_frame(wills, time.length = "week")
count.year <- aggregate_data_frame(wills, time.length = "year")
```

The aggregated data frames are produced in long format, since this is required for `ggplot` routines.

```
start.date <- as.Date('1374-01-16')
end.date <- as.Date('1374-02-06')
dat <- subset(count.week,
              Date >= start.date & Date <= end.date)
latex_subtable(dat, rowname = NULL)
```

Date	Count	Type
1374-01-16	0	WillDate
1374-01-16	0	ProbateDate
1374-01-23	1	WillDate
1374-01-23	0	ProbateDate
1374-01-30	0	WillDate
1374-01-30	0	ProbateDate
1374-02-06	0	WillDate
1374-02-06	0	ProbateDate

A more standard style of table can be obtained as follows:

```
latex_subtable(spread(data = dat, key = Type,
                      value = Count, fill = 0),
               rowname = NULL)
```

Date	WillDate	ProbateDate
1374-01-16	0	0
1374-01-23	1	0
1374-01-30	0	0
1374-02-06	0	0

```
## aggregates by career category and time
career.yearly <- tabulate_by_time_and_career(wills.career,
    time.length = "years",
    type.date = "ProbateDate") %>%
  mutate(Year = substr(Date, 1, 4))
latex_subtable(career.yearly,
               column = c("Year", "CareerCategory", "Count",
                    "TotalCountForYear", "Prop"),
               head.length = 8,
               rowname = NULL)
```

Year	CareerCategory	Count	TotalCountForYear	Prop
1259	Church	0	5	0.0
1259	City	2	5	0.4
1259	Business	2	5	0.4
1259	Nobility	1	5	0.2
1260	Church	0	2	0.0
1260	City	0	2	0.0
1260	Business	2	2	1.0
1260	Nobility	0	2	0.0

```
## aggregates by gender and time
gender.yearly <- wills %>%
  tabulate_by_time_and_gender(time.length = "years") %>%
  mutate(Prop = round(Prop, digits = 2)) %>%
  mutate(Year = substr(Date, 1, 4))
latex_subtable(gender.yearly,
               column = c("Year", "Gender", "Count",
                    "TotalCountForYear", "Prop"),
               head.length = 6,
               rowname = NULL)
```

Year	Gender	Count	TotalCountForYear	Prop
1259	female	1	18	0.06
1259	male	17	18	0.94
1260	female	0	10	0.00
1260	male	10	10	1.00
1261	female	0	4	0.00
1261	male	4	4	1.00

```
## aggregates by day of week over entire time period
count.dayofweek <- tabulate_by_year_and_day_of_week(wills)
latex_subtable(count.dayofweek, rowname = NULL)
```

DayOfWeek	Count
Mon	367
Tue	382
Wed	414
Thu	307
Fri	349
Sat	424
Sun	377

```
# can change arguments so aggregation is done over a
# specific time period. for example, the first plague epidemic
# in London occured from 1348 to 1350:
dayofweek.plague1348 <- wills %>%
  tabulate_by_year_and_day_of_week(start.year = 1348,
                                   end.year = 1350)

save(count.day,
     count.week,
     count.year,
```

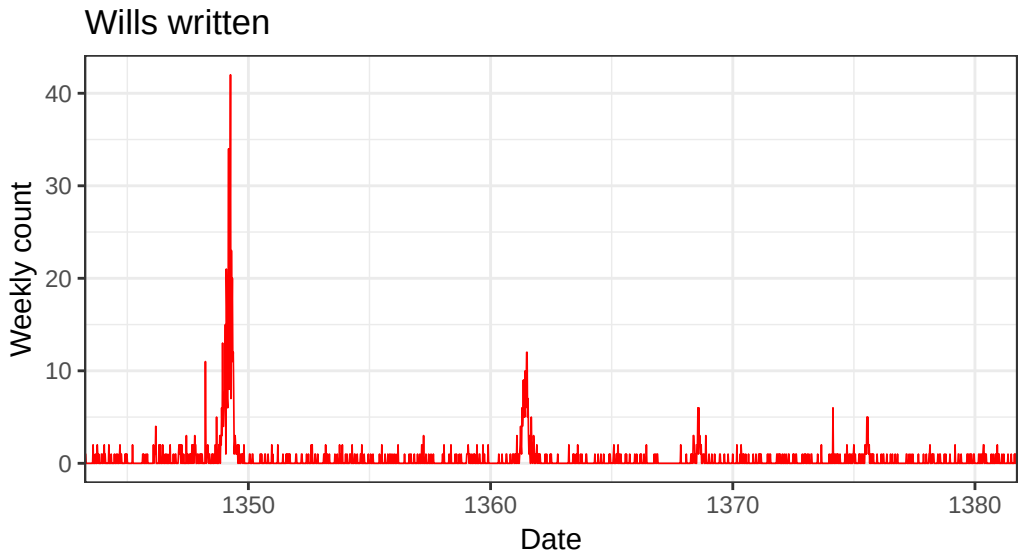
```
    career.yearly,
    gender.yearly,
    count.dayofweek,
    file = "reducedData.RData")
```

3.6 Creating graphs with reduced data

There are functions that create graphs with the reduced data above, as well as other data frames that are created from `willsr` functions. All functions that generate plots in `willsr` return a ggplot object. You can customize graphs further by adding onto the `willsr` function with `ggplot2` functions. For example:

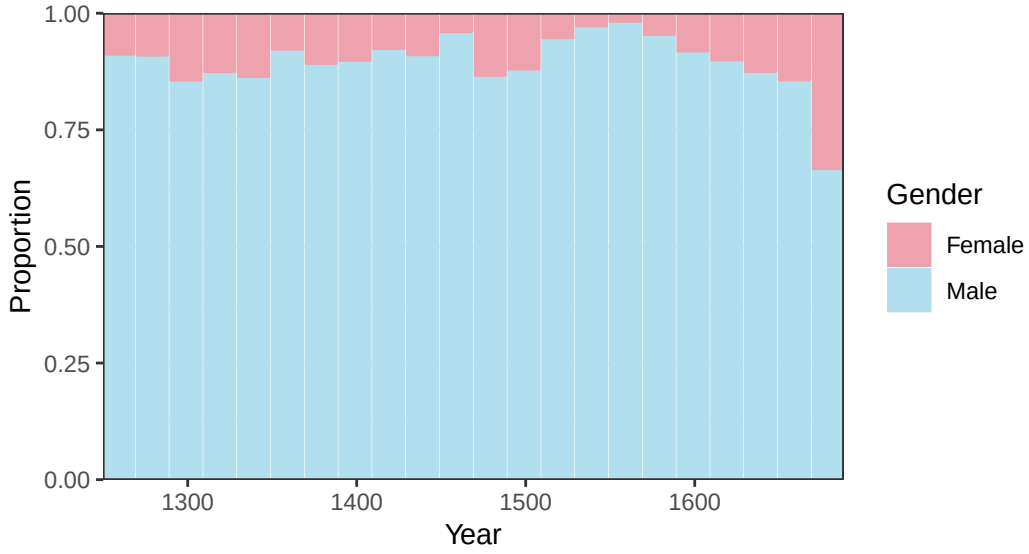
```
plague.begin <- as.Date('1345-01-01')
plague.end <- as.Date('1379-12-31')

plot(count.week, plot.date = "WillDate") +
  coord_cartesian(xlim = c(plague.begin, plague.end)) +
  ylab("Weekly count")
```



Another more in depth example of using `ggplot2` functions with `willsr` functions and data frames is as follows:

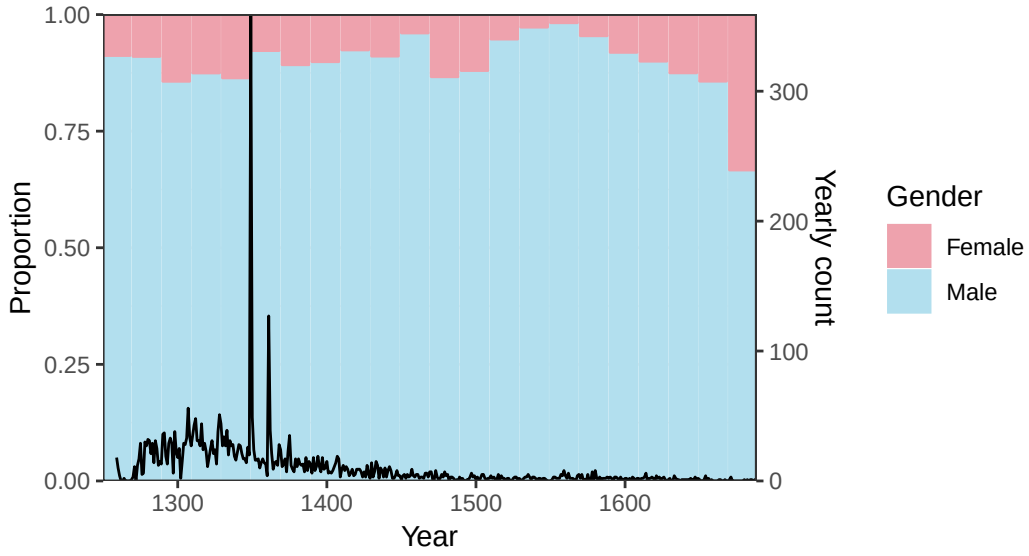
```
female.colour <- "lightpink2"
male.colour <- "lightblue2"
colours <- c(female.colour, male.colour)
gg1 <- stacked_bar_plot_gender(gender.yearly, year.width = 20) +
  scale_colour_manual(values = colours) + # changes line colour
  scale_fill_manual(values = colours) # changes fill colour
gg1
```



To add the yearly time series to `gg1`, we can utilize the data frame `gender.yearly` as it contains a yearly count. In order for the yearly time series to fit appropriately onto `gg1` (which has a y-axis limit of 1), we must divide all yearly counts by the maximum yearly count. This means all counts will be less than or equal to 1, and will be able to fit onto `gg1`:

```
max.gender <- max(gender.yearly$TotalCountForYear)
scaled.count <- gender.yearly$TotalCountForYear/max.gender
scaled <- data.frame(Date = gender.yearly$Date,
                     ScaledCount = scaled.count)
```

```
# sec_axis transforms the (right) y-axis
gg1 +
  geom_line(data = scaled,
            aes(x = Date, y = ScaledCount, colour = NULL)) +
  scale_y_continuous(sec.axis = sec_axis(~.*max.gender,
                                         name = "Yearly count"))
```



Appendices

Tables 1 to 4 list all careers found in the Court of Husting wills [9, 10], along with their definition and how many times each career occurred in the wills. Careers with similar spellings or similar definitions were grouped into one career definition. For example, "mercer" and "merchant" are the same and have been grouped together and "fishmonger", "stockfishmonger", "stokfishmongere", "fresshfisshmongere", ..., have been grouped together.

A Careers sorted into the church category

Table 1: Definitions and occurrences of the careers sorted into the church category

	Definition or role	Counts	Source
Advocate	defends another	1	Wikipedia
Almoner	chaplain responsible for the distribution of money (particularly to the poor)	1	Wikipedia
Archdeacon	senior pastor in a church	2	Wikipedia
Bishop	ordained member of the church	3	Wikipedia
Canon	priest	9	Wikipedia
Cellarer	responsible for the monastary's food supply	1	Victoria and Albert Museum
Chaplain	a priest	17	University of Michigan
Dean	church chairman	3	Wikipedia
Diocese	bishop	1	Wikipedia
Frater	monk	1	Wikipedia
Nun	vowed to being a part of a religious community	1	Wikipedia
Pleader	advocate	1	University of Michigan
Priest	religious leader	2	Wikipedia
Vicar	parish priest	6	Wikipedia

B Careers sorted into the nobility category

Table 2: Definitions and occurrences of the careers sorted into the nobility category

	Definition or role	Counts	Source
Chevaler	a knight	1	University of Michigan
Coffrer	responsible for the wages of the servants of the royal household	6	Wikipedia
Dame	knighthood (feminine)	1	Wikipedia
Earl	member of nobility	2	Wikipedia
Esquire	ranks under a knight	12	University of Michigan
Gentleman	born into nobility	15	University of Michigan
Janitor	responsible for castle entrance	1	Ancient Fortresses
Knight	warrior	55	University of Michigan
Lord	master of servants	3	University of Michigan
Servant to the Countess of Pembroke Wardrobe keeper	household official	1	Wikipedia

Table 2: *(continued)*

	Definition or role	Counts	Source
Servant to the King			
Artilleryman	uses artillery	1	Wikipedia
Poulterer	deals poultry	16	Wikipedia
Sergeant	protective duty	6	Wikipedia
Sergeant-at-arms	armed men	4	Wikipedia
Smith	works with metals	135	University of Michigan
Tailor	makes or repairs the King's clothing	65	Wikipedia
Tentmaker	performs various duties as well as evangelizes	1	Wikipedia
Yeoman			
	household official	1	University of Michigan

C Careers sorted into the city category

Table 3: Definitions and occurrences of the careers sorted into the city category

	Definition or role	Counts	Source
Alderman	member of a municipal assembly	46	Wikipedia
Burgess	municipality official	1	Wikipedia
Clerk	responsible for taking the minutes of council meetings	70	Wikipedia
Ferrour	politician	7	Wikipedia
Marshal	officer of royal court	3	University of Michigan
Notary	scribe	1	University of Michigan
Parish Clerk	carries out duties in a parish	1	Dictionary
Parishioner	a part of a parish	1	University of Michigan
Rector	responsible for the tithes of a parish	42	Oxford Dictionary
Registrar of the Court of Canterbury	in charge of the registration of wills	1	Wikipedia
Scrivener	scribe	2	Wikipedia
Sergeant	protective duty	6	Wikipedia
Toloser	toll gatherer	3	University of Michigan

D Careers sorted into the business category

Table 4: Definitions and occurrences of the careers sorted into the business category

	Definition or role	Counts	Source
Amailler			
	enameller	1	Sharpe 1889, v1, pg. 256–262, fn 3
Apothecary			
	pharmacist	16	Wikipedia
Armourer			
	creates armour	20	Wikipedia
Baker			
	bakes and sells bread	24	Wikipedia
Barber			
Barber	cut, shave or trim hair	9	Wikipedia
Barber Surgeon	performs minor surgeries	2	Wikipedia
Batour			
	beater of cloth	4	House of Names
Belyeter			
	bell founder	1	Worchester Cathedral Library
Bladesmith			
	makes blades	10	Wikipedia
Bokelsmyth			
	makes buckles	0	Walter Besant
Bottlemaker			
	makes bottles	1	University of Michigan
Bowier			
	makes and sells bows	4	University of Michigan
Brasier			
	works with brass	6	University of Michigan
Brauderer			
	cloak maker	1	University of Michigan
Brewer			
	prepares liquors	45	Wikipedia

Table 4: *(continued)*

	Definition or role	Counts	Source
Brouderer	decorator	4	University of Michigan
Bureller	maker of cloth	8	University of Michigan
Burler	fixes cloth	2	University of Michigan
Burser	makes purses	2	University of Michigan
Butcher	slaughters and sells meat	42	University of Michigan
Capper	makes and sells hats	2	University of Michigan
Carpenter	builder	26	Wikipedia
Carter	makes carts	1	University of Michigan
Ceynturer	makes belts	1	University of Michigan
Chaloner	blanket maker or seller	1	Surname Database
Chandler	candlemaker	51	One Name
Clothworker	works with textiles	14	Wikipedia
Cobbler	mends shoes	1	University of Michigan
Cook	prepares food	7	Wikipedia
Cooper	makes containers	2	University of Michigan

Table 4: *(continued)*

	Definition or role	Counts	Source
Coppersmith	makes items from copper	1	Wikipedia
Corder	makes ropes	18	University of Michigan
Cordwainer	shoemaker	50	Wikipedia
Corser	horse trader	1	Sharpe 1889, v2, pg. 566, fn 2
Cotiler	cutler	2	Roberta Magnusson
Couper	wooden casks maker	2	Oxford Dictionary
Currier	leather carrier	17	Wikipedia
Cutler	Makes knives	18	University of Michigan
Dier	dyes cloth	12	University of Michigan
Doctor of physic	a highly qualified practicioner	2	Oxford Scholarship
Draper	makes and sells cloth	104	University of Michigan
Drouere	delivers livestock to the market	1	Oxford Dictionary
Flecher	arrow maker	1	Sharpe 1889, v2, pg. 406–409, fn 8
Forbour	maker of armour	5	Sharpe 1889, v1, pg. 355–362, fn 1

Table 4: *(continued)*

	Definition or role	Counts	Source
Foundour	builds buildings	2	University of Michigan
Foystour	saddle maker	1	Sharpe 1889, v2, pg. 385–390, fn 11
Fripperer	deals clothes	10	University of Michigan
Fruiter	sells fruit	3	University of Michigan
Fuller	cleans wool	3	Wikipedia
Furbour	armour or weapon maker	0	Oxford Dictionary
Fuster	saddle maker	3	Sharpe 1889, v1, pg. 248–256, fn 10
Gildestere	gilder (feminine)	1	Sharpe 1889, v1, pg. 512–578, fn 115
Girdler	makes metal objects, including belts	33	Wikipedia
Glover	makes gloves	7	University of Michigan
Goldbeater	hammers gold into a thin sheet	8	Wikipedia
Goldsmith	works with gold and other metals	118	Wikipedia
Grocer	deals food and other items	68	University of Michigan

Table 4: *(continued)*

	Definition or role	Counts	Source
Haberdasher	sells various items	25	University of Michigan
Haftere	maker of handles for knives	1	Sharpe 1889, v1, pg. 272–277, fn 7
Hakenayman	rents out horses	1	University of Michigan
Hatter	sells hats	3	University of Michigan
Hekenayman	horse rider	0	Oxford Dictionary
Homer	knocker	1	University of Michigan
Horner	makes horns	1	University of Michigan
Horse dealer	buy and sell horses	2	Wikipedia
Hosier	stocking dealer	6	Wikipedia
Hosteler	innkeeper	1	University of Michigan
Hurer	sells hats	4	University of Michigan
Jeweller	make and repair jewellery	3	Wikipedia
Joiner	builder (using wood)	7	Wikipedia
Kissere	makes thigh armor	1	University of Michigan
Longbowstringemaker	makes strings for arrows	1	Wikipedia

Table 4: *(continued)*

	Definition or role	Counts	Source
Lyndraper			
	makes linen	1	University of Michigan
Malemaker			
	bag maker	1	Sharpe 1889, v2, pg. 289–295, fn 1
Marbeler			
	works with marble	5	University of Michigan
Megucer			
	maker of leather	1	Forebears
Merchant			
Leather merchant	trades leather	8	Wikipedia
Merchant	businessman	145	University of Michigan
Merchant tailor	businessman in cloths	17	University of Michigan
Moneyer			
	banker	5	University of Michigan
Monger			
Cheesemonger	trades cheese	3	Wikipedia
Felmonger	hide dealer	9	Wikipedia
Fishmonger	sells seafood	200	Wikipedia
Ironmonger	deals iron	30	University of Michigan
Maltmongere	sells malt	1	University of Michigan
Timbermonger	sells wood	2	Wikipedia
Woodmonger	sells firewood	8	University of Michigan
Woolmonger	sells wool	27	Wikipedia
Nayler			
	makes nails	1	University of Michigan
Netmaker			
	makes nets	1	University of Michigan

Table 4: *(continued)*

	Definition or role	Counts	Source
Ointer	melts grease	1	Sharpe 1889, v1, pg. 303–308, fn 3
Painter	paints pictures	11	University of Michigan
Parmenter	tailor	1	University of Michigan
Pasteler	makes pastries	3	University of Michigan
Paternosterer	rosary maker	4	Oxford Dictionary
Pepperer	sells pepper	31	University of Michigan
Pewterer	pewterware maker	9	Wikipedia
Peyverer	maker of pepper	1	Sharpe 1889, v1, pg. 189–199, fn 2
Plasterer	plasters buildings	2	University of Michigan
Plumber	works with lead	5	University of Michigan
Potter	makes vessels	13	University of Michigan
Poulterer	deals poultery	16	Wikipedia
Purcer	pouch maker	6	Sharpe 1889, v2, pg. 105–123, fn 19

Table 4: *(continued)*

	Definition or role	Counts	Source
Ropere	makes ropes	1	University of Michigan
Saddler	makes saddles	29	Wikipedia
Salter	trades salts	9	Wikipedia
Seal-maker	makes seals	1	Merriam-Webster Dictionary
Servant	hired to perform duties of a household	1	Wikipedia
Setter	stone or brick layer	3	Ancestry
Sherman	shears cloth	4	Sharpe 1889, v2, pg 594–614, fn 49
Shipwright	crafts ships	7	University of Michigan
Skinner	works with animal skins	79	University of Michigan
Smith	works with metals	135	University of Michigan
Spicer	sells spices	1	University of Michigan
Spurrier	makes spurs (used for riding horses)	7	Wikipedia
Stationer	sells books	2	University of Michigan
Surgeon	performs surgery	6	Wikipedia

Table 4: *(continued)*

	Definition or role	Counts	Source
Tabourer	small drum maker	1	Sharpe 1889, v1, pg. 417–425, fn 7
Tailor	makes or repairs clothing	65	Wikipedia
Talloughchaundler	oil and candle trader	6	Wikipedia
Tanner	uses skin of animals to make leather	38	Wikipedia
Tapicer	to make tapestry	11	The Free Dictionary
Tiler	makes tiles	6	University of Michigan
Tiller	farmer	2	University of Michigan
Turner	makes objects with wood	1	University of Michigan
Upholder	dealer (particularly second-hand items)	1	BHO
Vintner	maker of wine	73	Merriam Webster Dictionary
Waterlader	carrier of water	2	Sharpe 1889, v1, pg. 500–512, fn 17
Waxchandler	responsible for wax and candles in a medieval household	11	Wikipedia
Webbe	weaver	7	University of Michigan
Whittaghiere	maker of leather	4	University of Michigan

Table 4: *(continued)*

	Definition or role	Counts	Source
Wirdrawer			
	wire maker	1	University of Michigan
Ymaginour			
	image-maker	2	Sharpe 1889, v1, pg. 512–578, fn 81

Bibliography

[1] Anderson RM, May RM. Infectious Diseases of Humans: Dynamics and Control. Oxford: Oxford University Press; 1991.

[2] Drancourt M, Raoult D. Molecular history of plague. Clinical Microbiology and Infection. 2016;22(11):911 – 915. Available from: http://www.sciencedirect.com/science/article/pii/S1198743X16303809.

[3] Perry RD, Fetherston JD. Yersinia pestis - etiologic agent of plague. Clinical Microbiology Reviews. 1997;10(1):35–66.

[4] Cummins N, Kelly M, Ó Gráda C. Living standards and plague in London, 1560–1665. The Economic History Review. 2016;69(1):3–34.

[5] Earn DJD, Ma J, Poinar H, Dushoff J, Bolker B. Acceleration of plague outbreaks in the second pandemic; 2018.

[6] Cohn Jr SK. The Black Death Transformed: Disease and Culture in Early Renaissance Europe. London, United Kingdom: Arnold; 2003.

[7] Cohn JR SK. Epidemiology of the Black Death and Successive Waves of Plague. Medical History Supplement. 2008;27:74–100.

[8] Slack P. Plague a very short introduction. Oxford University Press; 2012.

[9] Sharpe RR. Calendar of Wills Proved and Enrolled in the Court of Hustings, London. London: John C. Francis, Took's Court, E.C.; 1889.

[10] Office LHMS. Sharpe RR, editor. Calendar of Wills Proved and Enrolled in the Court of Husting, London. British History Online; 1889. Available from: https://www.british-history.ac.uk/court-husting-wills/.

[11] R Development Core Team. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing; 2012.

[12] Elman BA. On their own terms: Science in China, 1550-1900. Harvard University Press; 2005.

[13] Gottfried RS. Epidemic disease in fifteenth century England : the medical response and the demographic consequences. Rutgers University Press; 1978.

[14] Mac Berthouex P, Brown LC. Statistics for Environmental Engineers. Lewis Publishers; 2002.

[15] DeWitte SN. The effect of sex on risk of mortality during the Black Death in London, A.D. 1349–1350. American Journal of Physical Anthropology. 2009;139(2):222–234. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1002/ajpa.20974.

[16] Geddes R, Lueck D. The Gains from Self-Ownership and the Expansion of Womens Rights. The American Economic Review. 2002 Sep;92(4):1079–1092.

[17] Hower DR, Kahn P. Wills, trusts, and estates administration. 7th ed. Delmar, Cengage Learning; 2011.

[18] Women and the Law. President and Fellows of Harvard College; 2010. Available from: https://www.library.hbs.edu/hc/wes/collections/women_law/.

[19] Kershaw I. The Great Famine and Agrarian Crisis in England 1315–1322. Past and Present. 1973;(59):3–50. Available from: http://www.jstor.org/stable/650378.

[20] Historic Environment Scotland. Battle of Loudoun HillBTL36;. Online; accessed 19 December 2018. Available from: http://portal.historicenvironment.scot/designation/BTL36.

[21] Cameron S, Ross A. The Treaty of Edinburgh and the Disinherited (1328–1332). History. 1999;84(274):237–256. Available from: http://www.jstor.org/stable/24424414.

[22] Venables WN, Ripley BD. Modern Applied Statistics with S. 4th ed. New York: Springer; 2002. ISBN 0-387-95457-0. Available from: http://www.stats.ox.ac.uk/pub/MASS4.

[23] Burnham KP, Anderson DR. Model selection and multimodel inference a practical information-theoretic approach. Springer; 2010.

[24] National Archives (UK). Research guides: Wills 1384-1858 [text];. Available from: http://www.nationalarchives.gov.uk/help-with-your-research/research-guides/wills-1384-1858/.

[25] Bolker BM. Ecological models and data in R. Princeton University Press; 2008.

[26] Akaike H. In: Parzen E, Tanabe K, Kitagawa G, editors. Factor Analysis and AIC. New York, NY: Springer New York; 1998. p. 371–386. Available from: https://doi.org/10.1007/978-1-4612-1694-0_29.

[27] Burnham KP, Anderson DR. Model selection and multimodel inference: A practical information-theoretic approach. 2nd ed. New York: Springer; 2002.

[28] Ma J, Dushoff J, Bolker BM, Earn DJD. Estimating Initial Epidemic Growth Rates. Bulletin of mathematical biology. 2014;76(1):245–260.

[29] Ma J, Dushoff J, Bolker BM, Earn DJD. epigrowthfit;. R package version 0.0.3.0.