

Momentum of Judgement

The Progression of the Salem Witch Trials

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1 Introduction

The Salem witch trials have always been a poster child for mass hysteria. The momentum of the movement to convict and execute innocent women and men has been interesting for many different individuals from different fields. Much of the public is also privy to the details of the Salem trials due to Arthur Miller’s play *The Crucible*. [6] In this analysis, we hope to analyze the momentum and character of the executions during the Salem witch trials in reference to the people accused of being witches.

Specifically, the Salem witch trials were a series of events in 1692 New England where the settlers within modern Essex County, Massachusetts, convicted and executed women and men based on “spectral evidence”, or the dreams of others. The legal process of a fair trial was circumvented. The Salem trials are therefore touted as representative of a breakdown of a modern justice system.

The Salem trials also represent an outburst of a society under pressure. In the years before the witch trials, Essex County had a large influx of refugees from recent wars against the French and Native Americans. The English settlers were beaten badly, resulting in a state of societal anxiety due to the resettled refugees and uncertainty whether their current settlement would survive if another war broke out.

The hysteria began when three young girls started having fits and acting strangely. The doctor who treated them suspected a supernatural cause, which the girls confirmed. The three young girls then accused individuals of witchcraft, which the two neighbor communities of Salem Village and Salem Town investigated.

It’s important to note that “witch” does not necessarily refer to a woman in the context we are using it. Men were accused and executed for practicing witchcraft along with women. As witch is the most common term when referring to the Salem incidents, we will refer to men being accused of being witches.

The goal of our analysis is to model the momentum of the Salem witch trials. We do so by fitting two models to estimate different trends during 1692. First, we fit a model to the proportion of executions to accusations, in order to gauge how willing townsfolk in Essex County were to execute their accused neighbors. Second, we fit a model to the total number of accusations in areas where people had already been accused, to estimate how accusations increased once witchcraft accusations were present in a township.

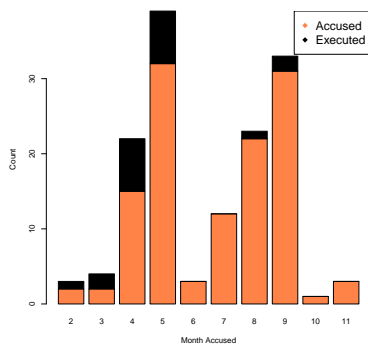
These two models will be illustrative in explaining the speed and scope of the trials. We will presumably need to account for temporal correlation, as the trials happened in a contiguous block of time. However, all of the accused from outside of Salem Town were extradited to Salem Town and tried there. As the witch-hunt did not geographically move, we don’t expect to account for spatial correlation.

The end of the Salem trials are of primary interest in this analysis. The trials may have ended abruptly due to respectable women in the community being accused of witchcraft. Or, the trials lost momentum and the residents of Salem Village and Salem Town mounted a resistance against the trials after losing friends and loved ones. The proposed analyses will illustrate how the vindictive frenzy progressed, if it ended suddenly or gradually.

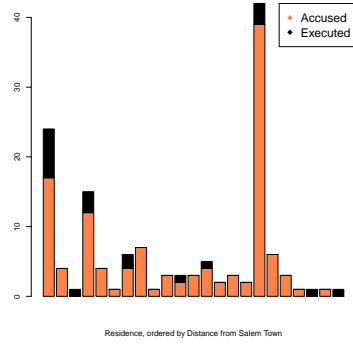
We focus on the momentum of the Salem witch trials from February to October 1692, and ignore all accusations of witches after October 1692. Executions had practically ended in October when the

Table 1: Summary Statistics for Salem With Trials Data Set After Data Cleaning

n	Total # Townships	Total # Executions	# Accusation Months	Total Proportion Executed Witches	Average Accusations per Township per Month
97	22	17	8	0.18	2.62

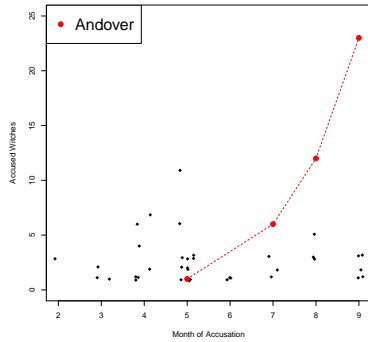


(a) Accusations & Executions by Month

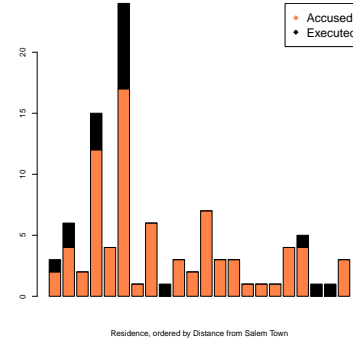


(b) Accusations & Executions by Distance from Salem Town

Figure 1: Exploratory Data Plots



(a) Total Accusations by Township by Month



(b) Accusations & Executions by Distance from Salem Town Excluding Andover

Figure 2: Examination of Outliers

colonial governor dissolved the court responsible for witchcraft trials.[2] The witchcraft accusations after October, when no more executions were possible, we therefore exclude from the dataset.

From Professor Richard Latner of Tulane University through Kaggle we've obtained a dataset containing every person ever accused of being a witch during the trials.[9] The dataset includes the month of accusation and imprisonment, and the month of execution if applicable. There are few missing values or accusations where the month is not known, which were removed from the dataset. Also, accused witches who died while incarcerated are not included. It is noteworthy to add that the latitude and longitude measurements of the accused witches' residence are not included.

In order to account for distance, we find the latitude and longitude of the current locations of the city centers where accused witches resided. The distance was then calculated from the Salem Town Common in kilometers. The distance is somewhat general, as the size and scope of each township is not accounted for. However, without extremely detailed primary source material, we are unable to get a more exact bearing on where each accused witch resided.

The data demand examination before we proceed further in an analysis. Figure 1a shows how the proportion of executions among accused witches and the total number of accusations change over time. Note that the sixth month, June, has very few accusations and no executions. The courts in Salem Town were in recess during June, accounting for the lack of court activity. However, in examining the distribution of the data, the data points from June do not appear to be extreme outliers.

Other data attributes are interesting. It appears that as distance from Salem Town increases, the number of accusations and the proportion of executions and accusations decrease by distance. However, it is unclear how these statistics change over distance.

Observe in Figure 2a that the accusations in Andover follow a different trend than the rest of the data. Over time, accusations increased dramatically, such that two of the four data points we have from

Andover are significant outliers. Andover was singular of the local towns because it had two Puritan pastors, Francis Dane and Thomas Bernard.[8] Thomas Bernard was enthralled by the witch-hunt, but Francis Dane made brave attempts to quash the rising hysteria. It seems Reverend Dane failed, because the resulting frenzy saw a tithe of the town's residents accused of being witches at one time. Also, unlike many other towns, the Salem Village pastor took the troubled little girls whose fits started the witch trials to Andover and encouraged them to accuse residents.[5] Because of the political and religious divide in the town caused by the competing pastors, along with the forcible examination of witchcraft the Salem Village pastor and Thomas Bernard encouraged, Andover may prove a different population than the rest of the data.

2 Methods

To begin our analysis, we remove the observations in Andover from the data set. It is regrettable to do this, as we do not have very much data. However, inclusion of Andover in our analysis changes the results in significant ways. As there is evidence Andover is not similar to the rest of the population, we remove the accusations and executions in Andover from the data set to further understand the rest of the Salem witch trials.

To achieve the first goal of our analysis, we fit a binomial regression. We assume the likelihood is binomial, such that for every accused person i , $y_i \sim \text{Binomial}(\pi_i)$, such that

$$\log\left(\frac{\pi_i}{1 - \pi_i}\right) = \beta_0 + \beta_1 * (\text{Accusation Month})_i.$$

where $y_i = 1$ indicates person i was executed with $i = 1, \dots, n$.

Note that this model is extremely simple. We consider adding a temporal correlation component among the accusation month for each person y_i . However, we observed that the temporal correlation is not significant, and adding random effects for township was not recommended by the Akaike Information Criterion (AIC), nor by a deviance test. As we are interested in the fixed effect of accusation month, we find no need to add a random effect for accusation month. Also, in considering other models, distance from Salem Town is not found to have a significant effect on the proportion of accused witches that were executed. Therefore, the simple model above is considered the best model to answer our first research question.

Notice also that we only keep a linear effect. It appears there could be a nonlinear relationship between accusation month and execution probability in Figure 1a, perhaps due to the courts' activity in June. However, when quadratic, cubic, and quartic accusation month effects are added to the model, they aren't significant, nor does AIC recommend their inclusion. Further, by performing likelihood ratio tests we see that adding nonlinear effects does not change the deviance significantly. Therefore, the simple linear logistic regression model is our best model.

The model to answer the second research question is more complex. The number of accused persons in towns where persons had already been accused is count data. We therefore assume that for a community that had z_{ij} witchcraft accusations,

$$z_{ij} \sim \text{Poisson}(\lambda_{ij}) \text{ and}$$

$$\log(\lambda_{ij}) = \beta_0 + \beta_1 * (\text{Distance From Salem Town})_{ij} + u_i$$

$$\mathbf{u} \sim N(\mathbf{0}, \phi(I_8 - \rho W)^{-1})$$

where, $i = 1, \dots, 8$ months, $j = 1, \dots, n_i$ communities with accused persons out of total n_i in month i , and

$$W = \begin{pmatrix} 0 & 1 & 0 & \dots & 0 & 0 \\ 1 & 0 & 1 & \dots & 0 & 0 \\ 0 & 1 & 0 & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \\ 0 & 0 & 0 & \dots & 0 & 1 \\ 0 & 0 & 0 & \dots & 1 & 0 \end{pmatrix}.$$

W illustrates the correlation structure we choose after considering multiple options. Every month is correlated with the months adjacent in time to it. In effect, we allow that the momentum of witch-hunting can spill over from month to month. A parameter α is used to calculate ϕ and ρ , so we can use our estimate of α to evaluate the significance of our correlation structure.

Using likelihood ratio tests, we determine that this is the best model. It incorporates temporal correlation, as we supposed at the beginning of the analysis, and fits the progress of the Salem witch trials over time and space.

3 Results

For these analyses, we must justify a few assumptions. We assume that all people involved in the trials were being truthful, and that the little girls actually were experiencing fits. Further, even though the trials are touted as a outlet of social, political, and religious prejudice, we ignore these aspects for our analyses.

We claim that many people were sincere in their accusations based on an article by Caporael.[3] Caporeael claims that historical records confirm the little girls really did have fits, foaming at the mouth and suffering convulsions. Furthermore, she claims that other individuals in Salem Village also suffered similar effects, possibly due to the unknown presence of poison in the rye supply produced by the fungus ergot. While certain accusations are claimed to be insincere, no historians have made a comprehensive list or agreed extensively on accusations that were motivated by hate or prejudice. Because of the lack of historical clarity and the soundness of Caporael’s claim, we assume the sincerity of settlers in Essex County.

Claims are also made to fit our specific models. For the first model, we assume that every individual accused is independent of one another. From the historical record, this assumption should be untrue, as witches were sometimes accused in batches with three or four accused at the same time. We attempted to account for dependence in the data by including a temporal correlation component. However, the temporal component is found to be insignificant, and is not included. Although citizens were accused in batches, accused witches stood trial to be executed individually. It appears this product of due process justifies us in assuming independence.

We also claim that the relationship between probability of execution and the numeric variable accusation month is linear in on the log-odds scale. The proportion in Figure 1a appears to shrink before June and then expand after June. We therefore relaxed the linearity assumption when performing model selection. However, as no nonlinear components were significant, and inclusion of nonlinear elements did not improve the deviance of the model significantly, we assume that the proportion of accused witches that were executed changes linearly on the log-odds scale in relation to the linear variable accusation month.

The value of the coefficients, along with 95% confidence bounds, are found in Table 2. We see that $\hat{\beta}_1 = -0.58$. That is, as the accusation month increases by one month, the log-odds an accused witch will be executed decreases by 0.58, implying that as the month of accusation increases, an accused witch is less likely to be executed. Also, we learn from this that proportion changed gradually, debunking the common idea that the Salem witch trials halted suddenly when the colonial governor swept in and saved the day. An estimated probability for every month is shown in Figure 3.

For our second model, we claim that every community was independent of one another. This is altogether justified, as the witch-hunt hysteria did not spread extremely far. Rather, individuals within Salem or the surrounding area would accuse individuals farther away. Since all accusations were originating at the same source, we can assume that accusations in one area would not affect whether accusations are made in surrounding areas. However, if the Salem settlers had systematically accused people by township throughout the region (which is a plausible scenario) this assumption is unjustified. We assume that no such systematic approach to accusing witches was taken.

We also assume the average λ_{ij} changes linearly relative to the numeric distance from Salem Town. Figure 2b shows how the average accusations change over distance. One the large observation for Andover

Table 2: Coefficients for Logistic Regression

	Estimate	LB	UB
(Intercept)	1.33	-0.72	3.37
Accusation Month	-0.58	-1.01	-0.15

this vindictive hysteria lasted, the less violent the population grew. Also, the frequency of unjust claims decreases as one was farther away from the epicenter of the frenzy.

Further work on this subject could be extensive, much of it hindered by a lack of data that reflects a consensus of historians. A further examination of Andover and the effects each pastor had on the progress of the trials would be informative. This study could also inform a researcher enough to justify prior distributions in a Bayesian analysis. Or, a comparison between Mccarthyism in America, the Reign of Terror in Revolutionary France, and the Salem witch trials could be made.

Also, a future analysis would hopefully make the models more general. Currently, the first model only applies to those accused of witchcraft in New England from February to October 1692, and the second model only applies to those communities where accusations of witchcraft were made. If a more comprehensive list of the residents and townships in New England could be found, a more general analysis would be possible.

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