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IZA DP No. 17164

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ISSN: 2365-9793

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ABSTRACT

When Beer Is Safer than Water: Beer Availability and Mortality from Waterborne Illnesses*

We investigate the impact of beer on mortality during the Industrial Revolution in 18th century England. Due to the brewing process, beer represented an improvement over available water sources during this period prior to the widespread understanding of the link between water quality and human health. Using a wide range of identification strategies to derive measures of beer scarcity driven by tax increases, weather events, and soil quality, we show that beer scarcity was associated with higher mortality, especially in the summer months when mortality was more likely to be driven by waterborne illnesses related to contaminated drinking water. We also leverage variation in inherent water quality across parishes using two proxies for water quality to show that beer scarcity resulted in greater deaths in areas with worse water quality. Together, the evidence indicates that beer had a major impact on human health during this important period in economic development.

JEL Classification: N33, I15, Q25
Keywords: beer, water quality, mortality, industrial revolution

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* We thank Brian Beach, Trevon Logan, Daniel Rees, and participants at the Economic History Association and European Economic Association annual meetings for helpful comments.

1. Introduction

The importance of access to clean water for human health has been underscored in policy circles (UN General Assembly (2015)) and economic research alike (Kremer et al. (2011); Galiani et al. (2005); Devoto et al. (2012); Ashraf et al. (2021); Alsan and Goldin (2019)). However, much less attention has been paid to alternatives to drinking water, which may have contributed to human health long before the availability of modern water purification technologies. In areas of the world where widespread adoption of water improvement technologies remain out of reach, much can still be learned from this historical experience. For example, recent work has shown the importance of milk inspections in preventing water and foodborne illnesses in early 20th century America (Anderson, Charles, and Rees (2022), Anderson, Charles, McKelligott, et al. (2022), Komisarow (2017)). This paper provides the first quantitative estimates into another well-known water alternative during the Industrial Revolution in England.

Although beer in the present day is regarded as being worse for health than water, several features of both beer and water available during this historical period suggest the opposite was likely to be true. First, brewing beer requires boiling the water, which kills many dangerous pathogens often found in drinking water. As Bamforth (2004) puts it, "the boiling and the hopping were inadvertently water purification techniques." Second, alcohol itself has antiseptic qualities. Homan (2004) notes that "because the alcohol killed many detrimental microorganisms, it was safer to drink than water" in the ancient near-east.[1]

This property of beer could thus benefit drinkers even if contaminated water was consumed from another source as beer drinkers could have been protected due to the alcohol content in their stomachs (Sheth et al. (1988), Brenner et al. (1999), Desenclos et al. (1992), Bellido-Blasco et al. (2002)). Third, beer in this period was generally much weaker than it is today, and thus would have been closer to purified water. Accum (1820) found that common beers in late 18th and early 19th century England averaged just 0.75% alcohol by volume, a fraction of the content of the beers of today. Beer in this period was therefore far less harmful to the liver. Taken together, these facts suggest that beer had many of the benefits of purified

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[1] Similarly, when describing how beer protected drinkers during the London cholera epidemic, Glaeser (2012) notes that "nearby ale imbibers remained healthy; alcohol's ability to kill waterborne bacteria had long helped city dwellers avoid illness."

water with fewer of the health risks associated with beer consumption today.

In contrast, plain drinking water in this period would have been much more likely to be contaminated by sewage and pathogens. Poor water quality contributed to cholera and typhoid outbreaks which were mistakenly thought to be caused by miasmas (Johnson (2006)) until John Snow's famous discovery that contaminated water was behind the spread of cholera in the 1840s (Snow (1855)). Thus, even though people did not recognize beer as a safer choice, drinking beer would have been an unintentional improvement over water, and thus may have contributed to improvements in human health and economic development over the period we investigate.

We estimate the impact of beer on mortality in 18th-century England by focusing on factors which would limit its availability. These include a large hike in the malt excise tax, data on annual rainfall which would have impacted the growth of the barley crop, a necessary ingredient in the production of beer, and the suitability of a parish's soil for growing barley. Following Antman (2023), we also compare areas where water quality was inherently worse to areas where it was inherently better based on two alternative geographic measures and observe more severe impacts of beer scarcity on mortality in areas with worse baseline water quality.

To address concerns that our identification strategy may be picking up the effects of food scarcity, we show that these effects are concentrated in the summer months, when waterborne mortality crises were at their peak, and not winter months, when deaths from starvation were more likely. Event studies showing mortality in parishes with low and high water quality before and after the malt tax increase show larger increases in mortality in low water quality parishes after beer became more expensive. We control for regional wages and tea imports to rule out correlated effects driven by the availability of tea which would have been another improvement over drinking water (Antman (2023)). Through all these approaches, we find evidence that the relative scarcity of beer resulted in higher mortality, consistent with the hypothesis that beer played a critical role in protecting human health during this important period of economic development.

This paper connects closely with the literature examining the importance of drinking water sources for human health and economic development. However, quantifying the role of water in shaping economic development is complicated by the fact that its importance is so well-known, thus raising the specter of selection bias in many estimated treatment effects. While explicitly randomized controlled trials may be feasible to evaluate short-term impacts in some settings (Kremer et al. (2011)), costly barriers to adopting water quality interventions often remain (Zinn et al. (2018)) and thus raise questions about their long-term impacts. Historical evaluations of large-scale water interventions in the U.S. present an alternative empirical approach (Alsan and Goldin (2019); Beach et al. (2016); Ferrie and Troesken (2008); Anderson, Charles, and Rees (2022); Cutler and Miller (2005); Troesken (2004)), however, the simple fact that they were implemented as public health interventions suggest that the link between water and health was established by the period of time in which they were undertaken, raising the issue of potential endogeneity.

Here, we provide an important research alternative, since the period under study precedes the modern understanding of the germ theory of disease and the widespread acceptance of the link between water and human health (Johnson (2006)). As such, it connects closely with Antman (2023) which shows the impact of tea on mortality in England. We follow a similar approach, but in examining the impact of beer, shed light on an important alternative to water with a long history in England that helped pave the way for economic development. While our paper is similar in spirit to Antman (2023), it differs in important ways, as we leverage a wider array of data sources for identification (e.g., rainfall and soil suitability), and exploit variation in summer versus winter deaths. Since beer is widely consumed in developing countries where water quality issues remain, the evidence we bring to light has potential implications for continued economic development today. While we are not the first ones to hypothesize the impact of beer on economic development (see for example Standage (2006)), to our knowledge this paper represents the first quantitative analysis.

The paper proceeds as follows. Section 2 provides background on the history of beer in human societies, focusing specifically on beer production and consumption in England. Section 3 presents the data used in the analysis. Section 4 presents the methodology and results. Section 5 concludes.

2. Background

2.1. The History of Beer Brewing and Drinking

Humans have been brewing and drinking beer for millenia. Evidence of beer brewing has been found as far back as 13,000 years ago in modern day Israel (Liu et al. (2018)), and beer was a popular drink in both ancient Egypt and Mesopotamia (Samuel (1996) and Paulette (2021)). Beer has played a particularly important role in the history of England. Because beer in the 18th century was not very strong, it could be drunk throughout the day, and this was common among the English working class. For this reason, beer was seen more as a substitute for water than for harder liquors like gin, which generally could not be drunk throughout the day without inebriation. Working class people in this period were likely consuming both beer and water. When beer becomes more expensive, we would expect consumers to substitute towards water on the intensive margin. This could increase risk of waterborne illness both because of the increased consumption of potentially contaminated water and because there would be less alcohol in the drinker's stomach which could kill the bacteria before it does any harm.

Of course, it is also possible that people substituted towards milk, tea, or another beverage. While we cannot rule this out, it is worth noting that milk and tea are more costly than water, so if beer consumption falls due to income and substitution effects, water would be the most likely alternative beverage. Also, it was common practice for milk to be diluted with water (Anderson, Charles, McKelligott, et al. (2022)), so even substituting towards milk could increase the risk of waterborne illness.

2.2. Beer Production

Our multiple identification strategies rely on several important facts about beer production and deaths related to waterborne diseases which we discuss here. First, beer production is largely dependent on the availability of malt, one of the four main ingredients in beer. According to Clark (1998), malt made up approximately two-thirds of the cost of beer production through the 19th century. Therefore, when malt is abundant and cheap, beer tends to be as well. Second, as malt is made of barley, malt production depends heavily on the yield of the barley crop. This means that the availability of beer for consumption is correlated with the suitability of a year's weather for growing barley. During overly wet growing seasons, barley yields decline, leading to less malt and less beer.

Third, barley grows best in fertile loam soil, which is most common in those characterized as gley soils.[2] Nearly half (48.4%) of parishes in the malt-producing hub East Anglia[3] are classified as having gley soil, while only 16.9% of parishes outside of East Anglia have gley soil. This means that beer would be more common in areas with gley soils. Before railroads became ubiquitous in the United Kingdom in the middle of the 19th century, it was difficult and expensive to transport barley long distances. Though we do not have data on the geographic variation in prices, it seems reasonable that this would cause beer to be cheaper and more abundant in areas where barley was grown. Moreover, because our causal mechanism relies on people substituting water with beer, this is likely most common in areas with gley soil, where beer was relatively more abundant in the first place. Thus, these areas should experience a relatively bigger increase in deaths from waterborne illnesses whenever there is a negative shock in beer availability. Fourth, the quality of available water is an important determinant of the likelihood of death from a waterborne illness. As argued in Antman (2023), parishes with few nearby sources of running water and parishes at relatively lower elevation have worse inherent water quality, thus they would have been more likely to experience a greater increase in deaths whenever beer became scarce.

2.3. *Seasonality of Waterborne Illnesses*

While starvation deaths from a poor crop yield occur throughout the year and may be especially pronounced during winter months, waterborne illness deaths are concentrated in the summer. This is because gram-negative bacteria, which include the most common causes of illness from drinking contaminated water, survive best during the warm summer months (Schwab et al. (2014), Eber et al. (2011), Richet (2012)). Specifically, studies have demonstrated summertime peaks for E. coli, Salmonella, Giardia, Campbylobacter, Leptospirosis, the bacteria which cause dysentery, and many others.[4]

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[2] https://www.landis.org.uk/downloads/downloads/Soil˙classification.pdf.

[3] This region includes the counties of Norfolk, Suffolk and Cambridgeshire in the east of England.

[4] See Al-Hasan et al. (2009), Freeman et al. (2009), Yun et al. (2016), Saad et al. (2018), Tangtrongsup et al. (2020), Ali-Shtayeh et al. (1989), Naous et al. (2013), Chen et al. (2019), Lee et al. (2017), Strachan et al. (2013), and Ward (2002)

To illustrate this pattern, Figure 1 compares average monthly deaths across England before and during the 1831-1832 cholera pandemic (Chan et al. (2013), Burrell and Gill (2005)) and around the pan-European famine, which took place from 1585-1587 and 1590-1598. The left panel of Figure 1 shows that from 1800-1830, average mortality peaked in the winter months of January-April before declining to a trough in the summer months of July-September.[5] Similarly, during the cholera pandemic (1831-1832), there is a mortality peak in the winter months, and deaths begin to decline in the springtime, however, deaths rise once again in the summer months of July-September during the cholera pandemic, while they reach their lowest points in those months in the non-cholera years. The right panel of Figure 1 shows average monthly mortality from 1580-1600 for famine years (1585-1587, 1590-1598) versus non-famine years (1580-1584, 1588-1589, 1599-1600).[6] Average mortality is higher in famine years across the board, though they reach their peak in the late-winter months of February, March, and April. Motivated by the trends in this figure, we define "summer deaths" for a parish as the total number of deaths occurring in July, August, and September of a given year. Likewise, we define "winter deaths" as the total number of deaths occurring in the late-winter months of February, March, and April.[7] We utilize this distinction in the seasonal patterns of mortality to separately estimate the effects of beer scarcity on deaths due to waterborne illness versus deaths from starvation or other factors which influence mortality year-round.

2.4. The Malt Excise Tax

In the seventeenth century the British Crown began looking for ways to tax the growing revenues of the major brewers. After a failed attempt taxing malt in the early 1600s, the tax was reinstated in 1697 at .5625 schillings per bushel of malt (Nye (2007)). The brewing industry tacitly agreed to the tax in exchange for protection from competition from imported substitutes like French wines. Increasing concentration in the brewing industry during this period both made it easier to monitor and collect the taxes and enabled brewers to pass on the majority of the tax onto consumers (Nye (2007)). The tax would remain at .5625 schillings per

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[5] A similar pattern emerges if we focus on a shorter period from 1820-1830.

[6] These crises are documented in Alfani and Gráda (2018) and McNicoll (2018).

[7] All of our results are qualitatively unchanged if we instead define "winter months" to be January, February, and March.

bushel until it was raised to .75 schillings per bushel in 1760, before a large increase to about 1.354 schillings per bushel in 1780.

It was advantageous to tax malt as well as beer because a malt tax was more difficult to avoid. Homebrewing is a simple exercise with finished malt, but making malt to use in brewing is difficult. By extracting the tax earlier in the production process, this made it more challenging for the everyday homebrewer to circumvent the tax.. Excise taxes like this one made up as much as 70 percent of total tax income by the start of the Napoleonic Wars (Hartwell (1981)). Beer was the largest revenue generator, with the combined beer and malt excise taxes making up 23.8% of total revenue by 1792 (Nye (2011)). In addition to the taxes on alcohol and tobacco, there were also taxes on heating, light and fuel (6.1% of revenue), construction materials (4.1%), and footwear (6.3%) (Nye (2011)). While there are plausible pathways through which these taxes could impact mortality, they would be unlikely to exhibit the same seasonal patterns we observe.

3. Data

We combine data from several sources in order to estimate the impact of beer availability on deaths from waterborne illness in 18th and 19th century England. We exploit two plausibly exogenous sources of variation in the availability of beer. First, we use the 1780 increase in the malt excise tax. If higher malt taxes lead to beer becoming more scarce, we might expect people to substitute from drinking beer to drinking water, leading to increased deaths due to waterborne illnesses, especially in areas where water quality is lower.

Our other source of variation in the availability of beer is due to weather. We use data from Briffa et al. (2009) which identifies historical weather patterns using the Palmer Drought Severity Index (PDSI). These data are available for London from 1697-2000. The PDSI measures regional moisture availability and has been used extensively to study historical wet and dry spells. The PDSI classifies each month on a scale from -4 (extremely dry) to 4 (extremely wet). As extremely wet growing seasons are detrimental to barley yield, we expect beer to be more scarce in years with a higher PDSI during the barley growing months. We construct mortality measures and other parish-level characteristics using Wrigley and Schofield (2003)'s collection of records on burials, baptisms, and marriages. These records include data on 404 parishes covering the years 1538-1849. Using these data, we follow the methodology from Wachter (1998) to impute population counts for each parish-year combination.

We proxy for water quality in multiple ways following Antman (2023). First, we use the average elevation of each parish, constructed by combining Shuttle Radar Topography images (Jarvis et al. (2008)) with historical parish boundaries (Southall and Burton (2004)). All else equal, higher elevation parishes are likely to have cleaner water because they will be less contaminated by runoff from their neighbors. Second, we use the number of running water sources available in an area, as given by the main rivers within three kilometers of the parish, which was calculated using data from the United Kingdom Environment Agency Statutory Main River Map of England overlaid on a map of historical parish boundaries (Burton et al. (2004); Southall and Burton (2004)). Our reason for using this measure is that having greater natural sources of running water would have been critically important for obtaining clean water. Of course, both of these geographic measures may be correlated with economic development independently, and thus, we control for parish fixed effects in all specifications and emphasize that we are focused only on the impact of the water quality measures on mortality through their interaction with measures capturing the availability of beer.

Appendix Table 1 displays summary statistics for parishes with varying levels of water quality, based on the number of nearby water sources, in the year before the malt tax increase. Low source parishes are defined as those in the bottom 25 percent of water sources. Middle source parishes are in the 25-75th percentile, while high source parishes are in the top 25 percent. The three types of parishes have a similar ratio of summer-to-winter deaths prior to the malt tax increase, and have similar altitude, distance to the nearest market, and likelihood of being landlocked. The biggest difference in the parishes is that high source parishes are larger, both in population and land area.

4. Methods and Results

4.1. Malt Tax Increase of 1780

We begin by analyzing the effects of a large increase in the malt tax, which occurred in 1780. Prior to 1780, the malt tax had not been raised since 1760 and was only .75 schillings per bushel, which represented about 20% of the 1779 selling price of brown malt (28.83 schillings according to Mathias (1959)). In 1780, the malt tax nearly doubled to about 1.354 schillings per bushel. At the time, this represented the largest hike in the tax since its inception in 1697. By focusing on what happened to summer and winter mortality in the years surrounding this large increase, we can gain a better understanding of the impact of beer on public health since waterborne diseases were more prevalent in the summer. Of particular interest is what happens in parishes with better versus worse water quality when beer becomes more scarce. If the tax caused individuals to substitute from beer to water, we would expect to see increases in summer deaths in parishes with poor water quality. We look into this by running models of the following form:

$$\begin{gathered} SmrDths_{it} = \beta_1 LoWaterQual_i * Post_t + \beta_2 HiWaterQual_i * Post_t + \\ X_{it}\beta_3 + \mu_i + \delta_t + \psi_i t + \epsilon_{it} \end{gathered} \tag{1}$$

where $SmrDths_{it}$ is the log of burials in parish i in the summer of year t, $LoWaterQual_i$ is an indicator for whether the parish is below the 25th percentile in the measure of water quality, $HiWaterQual_i$ is an indicator for being above the 75th percentile in water quality, and $Post_t$ is an indicator for being after the 1780 malt tax increase. We control for the impact of rising tea imports around this period by interacting national tea imports with the indicators for high and low water quality and including them in X_{it}, along with the log of the estimated parish population, regional wages by quinquennia from Clark (2001), and the number of deaths occurring in the winter to account for factors which influence parish mortality throughout the year.

Additionally, we include parish fixed effects, μ_i, year fixed effects, δ_t, and parish-specific time-trends, $\psi_i t$, in all specifications to ensure our estimates of interest are purged of any spurious correlations that affect specific parishes across time, specific years across parishes, or which may be growing over time at the parish level. We cluster standard errors at the parish level. After each set of estimates, we include in the appendix a falsification exercise where we replace summer deaths with winter deaths on the left-hand side and an additional table that recreates the main analysis allowing for arbitrary correlation of the residuals for parishes within 20, 50, and 80 kilometers of one another using the method of Colella et al. (2019).

We limit our sample to the years immediately surrounding the malt tax increase, i.e., $t = 1770, 1771....1790$. The parameters of interest, β_1 and β_2, therefore measure how well the low water quality and high water quality parishes did in comparison to the parishes with average levels of water quality in response to the tax increase. If better water leads to fewer deaths, we would expect summer deaths in the low water quality parishes to increase more in response to the malt tax relative to the change in deaths in higher water quality parishes. We would therefore expect a positive β_1 and a negative β_2. Results from estimating this model are displayed in Table 1.

Column 1 of the top panel of Table 1 shows the results for parishes with few available water sources compared with all others. In the years following the malt tax increase, these parishes see a 16.3 log points (about 18%) rise in summer deaths (p-value=.006).[8] Conversely, column 2 shows that parishes with the most available water sources, which should be more protected from the dangers of contaminated water, see summer deaths fall by 14.9 log points (about 16%) relative to all other parishes (p-value = .006). When both interaction terms are included in the model, we see that the difference between the two coefficients suggests that summer deaths in low water quality parishes increase by 22.2 log points (about 25%) relative to high water quality parishes, with a p-value on the equality of the two coefficients of .001.

Columns 4-6 replicate columns 1-3 with the ratio of summer versus winter deaths on the left-hand side, and the economic inference is similar. Appendix Table 2 displays a falsification version of this model, which replaces the log of summer deaths with the log of winter deaths on the left hand side and replicates columns 1-3 of Table 1. All of the interaction terms in the falsification exercise are statistically insignificant and close to zero, suggesting that the changes which took place in the years following the increase in the malt tax mainly affected summer deaths, consistent with our hypothesis.

The middle panel of Table 1 displays results replacing the number of nearby water sources with elevation as a measure of water quality. Results are similar qualitatively, with low water quality parishes seeing a relative increase in summer deaths. In this case, being in the bottom quartile of elevation was associated with

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[8] Percentage changes are calculated using the following transformation: [exp^(.01x)-1] *100, where x is the log point difference.

a 12.4 log point increase in summer deaths, while being in the top quartile of water sources was associated with a similar decrease in summer deaths. The difference between the coefficients in column three suggests that low elevation parishes saw summer deaths rise by 19.6 log points relative to high elevation parishes (p-value = .010). Columns 4-6 again replicate columns 1-3, switching summer deaths with the ratio between summer and winter deaths on the left-hand side. Again, the results are qualitatively similar, though the p-value on the difference between the two coefficients when both are included is now .174. Appendix Table 3 displays the falsification test, and once again all of the coefficients are much smaller in magnitude and statistically insignificant.

Finally, the bottom panel of Table 1 displays results on the intersection of the two water quality measures. $Low * Low * Post$ measures the change in summer mortality for the 31 parishes with both low elevation and a low number of water sources, while $High * High * Post$ tracks the 30 parishes with high elevation and a high number of water sources, with both estimates measured relative to the roughly 375 other parishes in the sample. The results are again consistent with our hypothesis, as all of the coefficients are larger in magnitude and statistical significance than their counterparts, suggesting that the parishes with the worst water quality were especially exposed to this increase in the malt tax. Appendix Table 4 displays the falsification version of this specification. While the estimate on the low water quality parishes is statistically significant at the 10% level, it is not statistically different from the estimate on high quality parishes. Appendix Table 5 demonstrates that the estimates discussed above are robust to concerns regarding spatial autocorrelation by allowing for an arbitrary correlation of the error term for parishes within 20, 50, and 80 kilometers of one another (Colella et al. (2019)), and by bootstrapping standard errors.[9]

While the main estimates appear large in magnitude, we emphasize that they should be interpreted within the structure of the research design, that is, as a percentage change in summer deaths between two types of parishes which vary in their relative levels of inherent water quality. This complicates comparing our es-

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[9] The resulting coefficient estimates are identical to those found in Table 1, with the exception of the estimates using the elevation of each parish. In that case, the procedure which adjusts the standard errors for potential serial autocorrelation caused some of the parish fixed effects to become collinear and they were dropped from the regression, resulting in some minor changes to the coefficient estimates, but the same economic interpretation.

timates with direct estimates of drops in mortality over time due to public health interventions as in Cutler and Miller (2005), Cutler and Miller (2022), and Anderson, Charles, and Rees (2022). Nevertheless, to give a sense for the size of the magnitudes of our estimates, Appendix Table 6 recreates Table 1 using the raw number of summer burials as opposed to the log.[10] While the log coefficients are large in magnitude, they translate to an increase of approximately one summer burial when going from a high water quality parish to a low water quality parish based on either of our two metrics, and an increase of approximately three summer burials when going from a parish with a high number of water sources and high elevation to one with a low number of water sources and low elevation.

4.2. Soil Suitability

Focusing instead on areas where beer production was most common, and therefore most vulnerable to malt tax increases, we run similar models to see whether parishes with gley soil suffered a relatively larger increase in summer deaths in response to the increase in the malt tax. We do this by estimating models of the following form:

$$SmrDths_{it} = \beta_1 GleySoil_i * Post_t + X_{it}\beta_2 + \mu_i + \delta_t + \psi_i t + \epsilon_{it} \tag{2}$$

where $GleySoil_i$ is an indicator for parish i having gley soil and all else is as described below equation (1). Results from this model are displayed in Table 2. In columns 1-3, parishes with gley soil experienced increases in summer deaths of about 18 log points after the malt tax was implemented relative to parishes without gley soil. Appendix Table 7 displays the falsification test, and the parameters of interest are all small in magnitude and statistically insignificant. Appendix Table 8 recreates the main specifications from Table 2 correcting for potential spatial autocorrelation, and the results are again similar. Appendix Table 9 recreates Table 2 using the raw number of deaths on the left-hand side as opposed to the log, and the results indicate that parishes with gley soil experienced an increase of approximately .8 summer deaths per year.

Taken together, the results from this section support our hypothesized mechanism operating through the availability of beer. In order for our hypothesis to be

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[10] The number of observations is higher in Appendix Table 6 because there are some parish-year observations with zero deaths, but our main specifications are robust to using alternative functional forms including the inverse hyperbolic sine, the square root, and taking the log plus one of all observations, in addition to using the raw count.

false, there would have to be some other factor which simultaneously precipitated an increase in summer deaths in low elevation parishes, parishes with few water sources, and parishes with gley soil, immediately after the increase in the malt tax in 1780. While impossible to completely rule out, this seems unlikely.

4.3. Event Study

We provide support for the parallel trends assumption inherent to our models by estimating event-studies of the following form:

$$SmrDths_{it} = \sum_{k=-5}^{6} \theta_k (ParishType_i * Year_{t+k}) + X_{it}\beta + \mu_i + \delta_t + \psi_i t + \epsilon_{it} \tag{3}$$

where the only difference from equation (2) is that now we estimate separate treatment effects for five years before and six years after the malt tax increase went into effect. We estimate models of this form, replacing $ParishType_i$ with separate indicators for low water source parishes, low elevation parishes, and parishes with gley soil. Ideally, the coefficients should all be close to zero and statistically insignificant in the periods before the intervention. Then, shortly after the malt tax was raised in 1780, we should see relative increases in summer deaths in each specification.

Figure 2 displays these estimates for all four groups. The top left graph displays the estimates for the parishes with few nearby water sources. From 1775-1778, the coefficients are all small in magnitude and statistically insignificant. A test of the joint significance of the 1775-1778 coefficients yields a p-value of .91. There is a slight uptick in 1780, but then a large and statistically significant increase of 20.0 log points in 1781. After that, all the subsequent coefficients are positive and remain between .04 and .25. A test of the joint significance of the 1781-84 coefficients yields a p-value of .049. The top right graph displays estimates on the low elevation parishes, and the results here are perhaps the weakest of the four, however, the coefficients are around zero and all statistically insignificant in the pre-period, with increases in summer mortality directly after the tax went into effect in 1780.

The bottom left graph repeats this exercise for the parishes with gley soil. There does not appear to be a pre-trend, though the 1776 coefficient is negative and borderline statistically significant on its own. A test of the joint significance of the 1775-78 coefficients yields a p-value of .78. After 1780, the coefficients are all positive and rise up to a peak in 1783 before leveling off and reverting somewhat. A test of the joint significance of the 1781-84 coefficients yields a p-value of .003. Finally, the bottom right graph estimates equation (3) on the parishes which have few water sources, low elevation and gley soil. As in the other three graphs, there is little evidence of pre-existing trends before 1780, and then a substantial increase in summer deaths for the most exposed parishes after the increase in the malt tax. A test of the joint significance of the 1775-78 coefficients yields a p-value of .195, while a similar test for the 1781-84 coefficients yields a p-value of .005. Appendix Figure 1 replicates Figure 2 replacing the log of summer deaths with the raw count on the left hand side, and results are similar.

4.4. Yearly Rainfall Interactions with Water Sources and Soil Type

Finally, we demonstrate that in rainier barley growing seasons, which are less conducive to barley growing, summer deaths rise relative to winter deaths, with these effects concentrated in areas where the most barley is produced and areas where water quality is poorest. We do this by estimating models of the following form:

$$\begin{aligned} SmrDths_{it} = \beta_1 Rain_t * LoWaterQual_i + \beta_2 Rain_t * GleySoil_i + \beta_3 Rain_t \\ * GleySoil_i * LoWaterQual_i + \beta_4 X_{it} + \mu_i + \delta_t + \psi_i t + \epsilon_{it} \end{aligned} \tag{4}$$

where $Rain_t$ represents the sum of the Palmer Drought Severity Index for London during the main barley-growing months of February through May in year t. Since overly wet barley growing seasons are bad for barley production, large positive values of the PDSI will lead to a decreased crop yield, and thus limited beer availability. Because our rain data are for London, the sample is limited to the parishes which surround the London metropolitan area.[11] Consequently, we use only the number of water sources as a measure of water quality in this specification because there is substantially less variation in elevation across these parishes. The three interaction terms, $Rain_t * LowSources$, $Rain_t * GleySoil$, and $Rain * GleySoil * LowSources$, measure whether rainier seasons are more impactful to summer deaths in areas with few nearby water sources and in areas with gley

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[11] These include the parishes of Buckinghamshire, Surrey, Berkshire, Essex, Herfordshire, Kent, Middlesex, Bedfordshire, Cambridgeshire, Huntingdonshire, Hampshire, Norfolk, Oxfordshire, Suffolk and Sussex.

soil, where barley production is most common. If rainy barley growing seasons lead people to consume less beer and thus more unsafe drinking water, we would expect all three coefficients to be positive. The remaining variables in equation (4) are the same as specified in our previous models. Results from this specification are reported in Table 3.

The first three columns of Table 3 build up to the full model in equation (4) by progressively adding interaction terms. In column (1), the interaction term measuring the effect of rainier barley growing seasons on parishes with few nearby water sources is positive and statistically significant. Column (2) replaces the $Rain*Sources$ interaction with $Rain*GleySoil$ and demonstrates that rainy barley-growing seasons lead to more summer deaths in areas more suitable for growing barley. Column (3) includes both interaction terms, and they each remain positive and statistically significant at the 10% significance level.

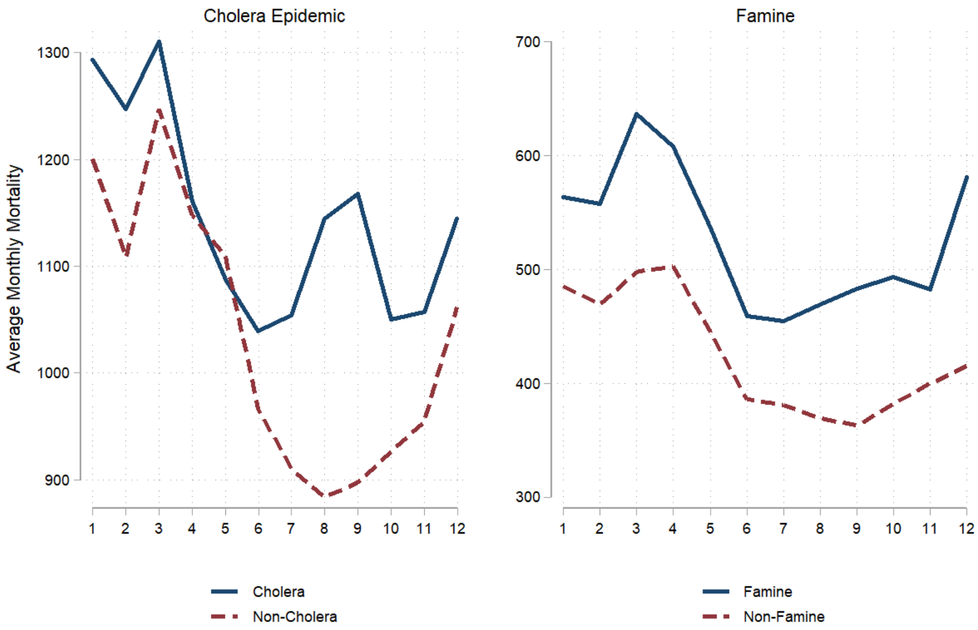
Column (4) adds a triple-interaction term, $Rain * Gley * Sources$, which measures the effect of rainy barley-growing seasons on parishes with gley soil and few nearby water sources. When this is included, the two previous interaction terms lose statistical significance and are close to zero, but the triple-difference is positive and statistically significant at the 5% level, suggesting that parishes with lower water quality and gley soil are particularly vulnerable to beer scarcity driven by a low barley yield. Column 5 replaces the log of summer deaths on the left-hand side with the ratio between summer and winter deaths and the effect is still positive and statistically significant. Appendix Table 10 recreates this table correcting for potential spatial autocorrelation and the results are once again similar.

5. Conclusion

Through several identification strategies, this paper provides the first quantitative evidence on the importance of beer to human health during the Industrial Revolution in England. As demonstrated here, the relative scarcity of beer–whether driven by a tax hike or a poor crop yield due to excessive rainfall– contributed to rising deaths in England. The estimates showing disparate impacts across areas which varied in their inherent water quality, using two different proxies for water quality, also suggest that the root cause of the variation in mortality associated with beer was indeed driven by water quality as opposed to some other explanation. The additional evidence leveraging variation in parish reliance on beer due to its relative abundance as driven by variation in soil suitability, also points to the primacy of beer in explaining the patterns observed. Moreover, the seasonal pattern of deaths suggest these mortality events were not driven by starvation, but by waterborne diseases which had larger impacts when beer was relatively scarce.

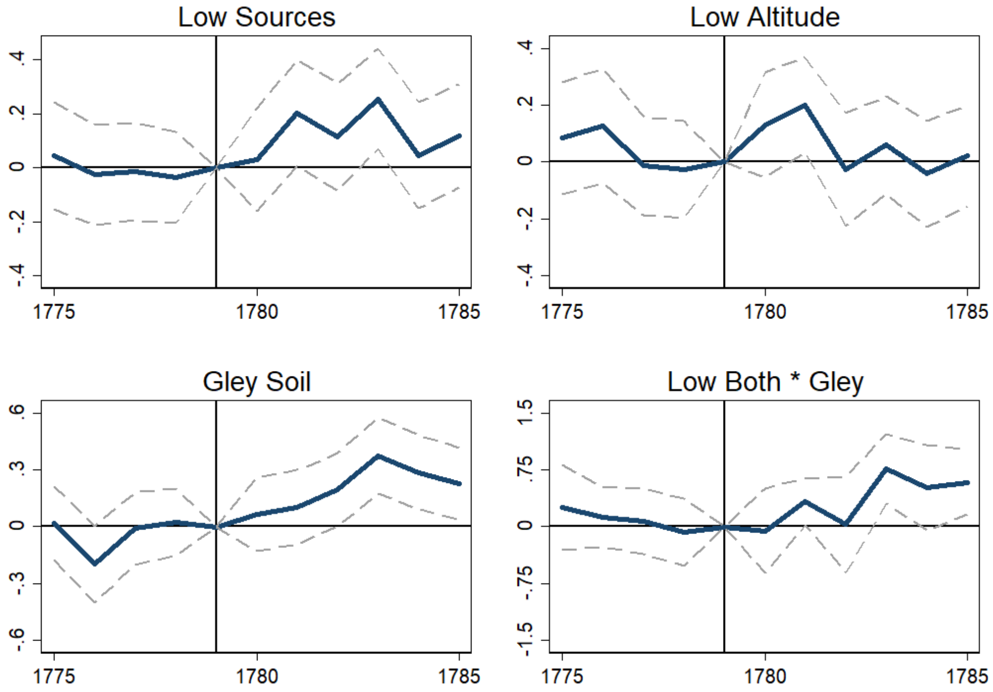
While this research highlights the importance of alternative beverages to human history, it also underscores the importance of access to clean water for human health and economic development today. In areas of the world where widespread adoption of water improvement technologies remain out of reach, much can still be learned from this historical experience.

Figure 1 — Comparing Monthly Mortality in England Around Crises Caused by Waterborne Illness versus Famine



Note: This figure displays monthly average mortality (average number of deaths) during and around two crises in English history. The left graph displays monthly average mortality before and during the 1831-32 cholera outbreak. The solid line displays monthly average mortality during the outbreak, while the dashed line displays monthly average mortality in the 30 years leading up to it (1800-1830). The graph on the right shows monthly average mortality around the pan-European famine of the 1580s and 1590s. 1580-1584, 1588-1589, and 1599-1600 were the famine years, and monthly average mortality in these years is indicated by the solid line. Monthly average mortality in non-famine years (1585-1586, 1590-1598) is indicated by the dashed line.

Figure 2 — Event-Study Estimates of the Effect of the 1780 Malt Tax Increase on Summertime Mortality in Parishes with Few Water Sources, Low Elevation, and Gley Soil



Note: This figure displays event-study estimates comparing the log of summer deaths in parishes that are more exposed to the malt tax increase. The top left graph displays estimates for parishes with few nearby water sources, the top right graph displays estimates for parishes with low elevation, the bottom left graph displays estimates for parishes which have gley soil, and the bottom right displays estimates for parishes with low water sources, low elevation and gley soil. Standard errors are clustered at the parish level.

Table 1 — The Effect of the 1780 Malt Tax Increase on Summertime Mortality in Parishes with Varying Levels of Inherent Water Quality

	(1) Smr Dths	(2) Smr Dths	(3) Smr Dths	(4) Ratio	(5) Ratio	(6) Ratio
Low Sources * Post	0.163^{***}		0.125^{*}	0.259^{**}		0.240^{**}
	(0.0590)		(0.0647)	(0.103)		(0.115)
High Sources * Post		-0.149^{***}	-0.0971^{*}		-0.149^{*}	-0.0496
		(0.0519)	(0.0571)		(0.0839)	(0.0950)
Difference			0.222			.2896
P-value			.001			.009
Low Elevation * Post	0.124^{*}		0.0879	0.220^{*}		0.233^{*}
	(0.0629)		(0.0660)	(0.116)		(0.119)
High Elevation * Post		-0.136^{**}	-0.108^{*}		-0.0345	0.0392
		(0.0580)	(0.0608)		(0.107)	(0.109)
Difference			0.196			.194
P-value			.010			.174
Low * Low * Post	0.249^{**}		0.229^{**}	0.491^{***}		0.475^{***}
	(0.112)		(0.113)	(0.180)		(0.181)
High * High * Post		-0.289^{***}	-0.273^{***}		-0.271^{**}	-0.237^{*}
		(0.0741)	(0.0743)		(0.121)	(0.121)
Difference			0.502			.712
P-value			.000			.001
Observations	7448	7448	7448	7991	7991	7991

Note: This table compares outcomes before and after the 1780 increase in the malt tax for parishes above the 75th percentile and below the 25th percentile in water quality (high and low water quality, respectively), relative to parishes in the 25th-75th percentile range of water quality. The top panel uses the number of available water sources as the measure of water quality, the middle panel uses the elevation of the parish, while the bottom panel estimates the model on the intersection of the two measures of water quality. The first two columns use the log of summer deaths as the dependent variable and estimate the coefficient on high and low water quality parishes separately, before including them in the same regression (column 3). Also in column 3, the difference between the high and low water quality coefficients is calculated and a p-value on the equality of the coefficients is displayed. Columns 4-6 replicates columns 1-3 replacing the log of summer deaths with the ratio between summer and winter deaths as the dependent variable. In every specification, controls are included for parish population, regional wages, tea imports, parish and year fixed effects as well as a parish linear time trend. In columns 1-3, the log of winter deaths is also included. Standard errors are clustered at the parish level. $^{*}\ p < 0.10$, $^{**}\ p < 0.05$, $^{***}\ p < .01$

Table 2 — The Effect of the 1780 Malt Tax Increase on Summertime Mortality in Parishes with Gley Soil

	(1) Smr Dths	(2) Smr Dths	(3) Smr Dths	(4) Ratio
Post - Gley Soil	0.182^{***}	0.178^{***}	0.174^{***}	0.142
	(0.0594)	(0.0599)	(0.0612)	(0.106)
Log Population		-0.935^{***}	-1.110^{***}	0.224
		(0.305)	(0.336)	(0.475)
Log Wage		0.274	0.323	0.521
		(0.238)	(0.243)	(0.362)
Tea Imports x Gley Soil		-0.00291	0.00682	0.0156
		(0.0236)	(0.0241)	(0.0393)
Ln Winter Deaths			0.0490^{***}	
			(0.0149)	
Observations	7775	7753	7448	7991

Note: This table compares outcomes before and after the 1780 increase in the malt tax for parishes with gley soil, which is ideal for growing barley, to all other parishes. Column 1 includes parish and year fixed effects as well as a parish linear time trend. Column 2 adds controls for population, regional wages and tea imports. Column 3 includes the log of winter deaths to control for factors which impact mortality year round. Column 4 does not include the log of winter deaths as a control, but instead replaces the log of summer deaths with the ratio between summer and winter deaths as the dependent variable. Standard errors are clustered at the parish level. * $p < 0.10$, ** $p < 0.05$, *** $p < .01$

Table 3 — The Effect of Rainy Barley Growing Seasons on Summertime Mortality in Parishes with Few Water Sources and Gley Soil - 1726-1830

	(1) Smr Dths	(2) Smr Dths	(3) Smr Dths	(4) Smr Dths	(5) Ratio
Rain x LoWaterQual	0.00330^{**}		0.00288^{*}	0.0000660	-0.000488
	(0.00161)		(0.00160)	(0.00174)	(0.00239)
Rain x Gley		0.00372^{*}	0.00328^{*}	-0.00121	-0.00499
		(0.00195)	(0.00192)	(0.00279)	(0.00396)
Rain x Gley x LoWaterQual				0.00922^{**}	0.0128^{**}
				(0.00368)	(0.00511)
Observations	10315	10315	10315	10315	11125

Note: This table displays estimates of the effect of rainy barley growing seasons on different types of parishes which are more or less vulnerable to shocks in beer availability. Column 1 measures the impact on parishes with few nearby water sources, while column 2 estimates the impact on parishes with gley soil, which would otherwise be able to produce large quantities of barley. Column 3 includes both singular interactions, while column 4 includes the singular interactions and the joint interaction measuring the effect of rainy barley growing seasons on parishes with few water sources and gley soil. Column 5 includes the joint interaction and replaces the log of summer deaths on the left hand side with the ratio between summer and winter deaths. In every specification, controls are included for parish population, regional wages, tea imports, parish and year fixed effects as well as a parish linear time trend. Except in column 5 where the log of winter deaths in that parish is the denominator of the dependent variable, the log of winter deaths is also included to control for factors which impact mortality year round. Standard errors are clustered at the parish level. $^{*}\ p < 0.10$, $^{**}\ p < 0.05$, $^{***}\ p < .01$.

References

Accum, Friedrich Christian (1820). *A treatise on adulterations of food, and culinary poisons: Exhibiting the fraudulent sophistications of bread, beer, wine, spiritous liquors, tea, coffee ... and methods of detecting them.* Longman, Hurst.

Alfani, Guido and Cormac Ó Gráda (2018). "The timing and causes of famines in Europe." In: *Nature Sustainability* 1, pp. 283–288.

Ali-Shtayeh, M. S. et al. (1989). "Prevalence and seasonal fluctuations of intestinal parasitic infections in the Nablus area, West Bank of Jordan". In: *Annals of Tropical Medicine & Parasitology* 83.1, pp. 67–72.

Alsan, Marcella and Claudia Goldin (2019). "Watersheds in Child Mortality: The Role of Effective Water and Sewerage Infrastructure, 1880–1920". In: *Journal of Political Economy* 127.2, pp. 586–638.

Anderson, D. Mark, Kerwin Kofi Charles, Michael McKelligott, et al. (May 2022). *Safeguarding Consumers Through Minimum Quality Standards: Milk Inspections and Urban Mortality, 1880-1910.* Working Paper 30063. National Bureau of Economic Research.

Anderson, D. Mark, Kerwin Kofi Charles, and Daniel I. Rees (Apr. 2022). "Reexamining the Contribution of Public Health Efforts to the Decline in Urban Mortality". In: *American Economic Journal: Applied Economics* 14.2, pp. 126–57.

Antman, Francisca M. (Nov. 2023). "For Want of a Cup: The Rise of Tea in England and the Impact of Water Quality on Mortality". In: *The Review of Economics and Statistics* 105.6, pp. 1352–1365. ISSN: 0034-6535.

Ashraf, Nava et al. (2021). "Water, Health and Wealth: The Impact of Piped Water Outages on Disease Prevalence and Financial Transactions in Zambia". In: *Economica* 88.351, pp. 755–781.

Assembly, UN General (2015). *Transforming our world : the 2030 Agenda for Sustainable Development.* Tech. rep.

Bamforth, Charles W. (2004). *Beer: Health and nutrition.* Blackwell Science.

Beach, Brian et al. (2016). "Typhoid Fever, Water Quality, and Human Capital Formation". In: *The Journal of Economic History* 76.1, pp. 41–75.

Bellido-Blasco, Juan B. et al. (2002). "The Protective Effect of Alcoholic Beverages on the Occurrence of a Salmonella Food-Borne Outbreak". In: *Epidemiology* 13.2, pp. 228–230. ISSN: 10443983.

Brenner, Hermann et al. (May 1999). "Alcohol consumption and Helicobacter pylori infection: Results from the German National Health and Nutrition survey". English (US). In: *Epidemiology* 10.3, pp. 214–218. ISSN: 1044-3983.

Briffa, K. R., G. van der Schrier, and P. D. Jones (2009). "Wet and dry summers in Europe since 1750: evidence of increasing drought". In: *International Journal of Climatology* 29.13, pp. 1894–1905.

Burrell, Sean and Geoffrey Gill (Oct. 2005). "The Liverpool Cholera Epidemic of 1832 and Anatomical Dissection—Medical Mistrust and Civil Unrest". In: *Journal of the History of Medicine and Allied Sciences* 60.4, pp. 478–498. ISSN: 0022-5045.

Burton, N., J. Westwood, and P. Carter (2004). "GIS of the Ancient Parishes of England and Wales, 1500-1850 [computer Öle]". In: *UK Data Archive [distributor].*

Chan, Christina H., Ashleigh R. Tuite, and David N. Fisman (Aug. 2013). "Historical Epidemiology of the Second Cholera Pandemic: Relevance to Present Day Disease Dynamics". In: *PLOS ONE* 8.8, pp. 1–8.

Chen, Chian-Ching, Chuan-Yao Lin, and Kow-Tong Chen (2019). "Epidemiologic features of shigellosis and associated climatic factors in Taiwan". In: *Medicine* 98.

Clark, Christine (1998). *The British Malting Industry Since 1830.* London: The Hambledon Press.

Clark, Gregory (2001). "Farm Wages and Living Standards in the Industrial Revolution: England, 1670-1869". In: *The Economic History Review* 54.3, pp. 477–505. ISSN: 00130117, 14680289.

Colella, Fabrizio et al. (2019). "Inference with Arbitrary Clustering". In: *IZA Discussion Paper 12584.*

Cutler, David and Grant Miller (Feb. 2005). "The role of public health improvements in health advances: The twentieth-century United States". In: *Demography* 42.1, pp. 1–22. ISSN: 0070-3370.

Cutler, David M. and Grant Miller (Apr. 2022). "Reexamining the Contribution of Public Health Efforts to the Decline in Urban Mortality: Comment". In: *American Economic Journal: Applied Economics* 14.2, pp. 158–65.

Desenclos, Jean-Claude A. et al. (1992). "The Protective Effect of Alcohol on the Occurrence of Epidemic Oyster-Borne Hepatitis A". In: *Epidemiology* 3.4, pp. 371–374. ISSN: 10443983.

Devoto, Florencia et al. (May 2012). “Happiness on Tap: Piped Water Adoption in Urban Morocco”. In: *American Economic Journal: Economic Policy* 4.4, pp. 68–99.

Eber, MR et al. (2011). “Seasonal and Temperature-Associated Increases in Gram-Negative Bacterial Bloodstream Infections among Hospitalized Patients.” In: *PLoS ONE* 6.9.

Ferrie, Joseph P. and Werner Troesken (2008). “Water and Chicago’s mortality transition, 1850–1925”. In: *Explorations in Economic History* 45.1, pp. 1–16. ISSN: 0014-4983.

Freeman, J.T., D.J. Anderson, and D.J. Sexton (2009). “Seasonal peaks in Escherichia coli infections: possible explanations and implications”. In: *Clinical Microbiology and Infection* 15.10, pp. 951–953. ISSN: 1198-743X.

Galiani, Sebastian, Paul Gertler, and Ernesto Schargrodsky (2005). “Water for Life: The Impact of the Privatization of Water Services on Child Mortality”. In: *Journal of Political Economy* 113.1, pp. 83–120. ISSN: 00223808, 1537534X.

Glaeser, Edward L. (2012). *Triumph of the city: How our greatest invention makes us richer, smarter, Greener, healthier, and happier.* Penguin Books.

Hartwell, Ronald Max (Spring 1981). “Taxation in England during the Industrial Revolution”. In: *Cato Journal* 1.1, pp. 129–153.

Al-Hasan, M.N. et al. (2009). “Seasonal variation in Escherichia coli bloodstream infection: a population-based study”. In: *Clinical Microbiology and Infection* 15.10, pp. 947–950. ISSN: 1198-743X.

Homan, Michael M. (2004). “Beer and Its Drinkers: An Ancient Near Eastern Love Story”. In: *Near Eastern Archaeology* 67.2, pp. 84–95.

Jarvis, A. et al. (2008). “Hole-filled seamless SRTM data V4”. In: *International Centre for Tropical Agriculture (CIAT).*

Johnson, Steven (2006). *The ghost map: The story of London’s most terrifying epidemic.* Riverhead.

Komisarow, Sarah (2017). “Public health regulation and mortality: Evidence from early 20th century milk laws”. In: *Journal of Health Economics* 56, pp. 126–144. ISSN: 0167-6296.

Kremer, Michael et al. (Feb. 2011). “Spring Cleaning: Rural Water Impacts, Valuation, and Property Rights Institutions*”. In: *The Quarterly Journal of Economics* 126.1, pp. 145–205. ISSN: 0033-5533.

Lee, H.S., T.T. Ha Hoang, and P. et al. Pham-Duc (2017). “Seasonal and geographical distribution of bacillary dysentery (shigellosis) and associated climate risk factors in Kon Tum Province in Vietnam from 1999 to 2013.” In: *Infect Dis Poverty* 113.

Liu, Li et al. (2018). “Fermented beverage and food storage in 13,000y-old stone mortars at Raqefet Cave, Israel: Investigating Natufian ritual feasting”. In: *Journal of Archaeological Science: Reports* 21, pp. 783–793. ISSN: 2352-409X.

Mathias, Peter (1959). *The Brewing Industry in England 1700-1830.* London: Cambridge University Press.

McNicoll, Geoffrey (2018). “Guido Alfani and Cormac Ó Gráda (eds.) Famine in European History Cambridge: Cambridge University Press, 2017. xi + 325 p. $89.99; $29.99 (pbk.).” In: *Population and Development Review* 44.1, pp. 182–183.

Naous, Amal. et al. (2013). “Intestinal amebiasis: A concerning cause of acute gastroenteritis among hospitalized Lebanese children”. In: *North American Journal of Medical Sciences* 5.12, pp. 689–698.

Nye, John V. C. (Oct. 2011). “624 Brewing Nation: War, Taxes, and the Growth of the British Beer Industry in the Eighteenth and Nineteenth Centuries”. In: *The Economics of Beer.* Oxford University Press. ISBN: 9780199693801.

— (2007). *War, Wine, and Taxes.* Princeton University Press.

Paulette, Tate (2021). “Inebriation and the early state: Beer and the politics of affect in Mesopotamia”. In: *Journal of Anthropological Archaeology* 63, p. 101330. ISSN: 0278-4165.

Richet, H. (2012). “Seasonality in Gram-negative and healthcare-associated infections.” In: *Clin Microbiol Infect.* 934.

Saad, N.J. et al. (2018). “Seasonal dynamics of typhoid and paratyphoid fever.” In: *Scientific Reports* 8.6870.

Samuel, Delwen (1996). “Archaeology of Ancient Egyptian Beer”. In: *Journal of the American Society of Brewing Chemists* 54.1, pp. 3–12.

Schwab, F, P Gastmeier, and E Meyer (2014). “The Warmer the Weather, the More Gram-Negative Bacteria - Impact of Temperature on Clinical Isolates in Intensive Care Units.” In: *PLoS ONE* 9.3.

Sheth, Neela K., T R Wisniewski, and Timothy R. Franson (1988). "Survival of enteric pathogens in common beverages: an in vitro study." In: *The American journal of gastroenterology* 83 6, pp. 658–60.

Snow, John (1855). "On the Mode and Communication of Cholera". In: *John Churchill.*

Southall, H.R. and N. Burton (2004). "GIS of the Ancient Parishes of England and Wales, 1500-1850." In: *UKDA study number: 4828.*

Standage, Tom (2006). *History of the world in six glasses.* Anchor Canada.

Strachan, N. J. C. et al. (2013). "Identifying the seasonal origins of human campylobacteriosis". In: *Epidemiology and Infection* 141.6, pp. 1267–1275.

Tangtrongsup, Sahatchai et al. (2020). "Seasonal distributions and other risk factors for Giardia duodenalis and Cryptosporidium spp. infections in dogs and cats in Chiang Mai, Thailand". In: *Preventive Veterinary Medicine* 174, p. 104820. ISSN: 0167-5877.

Troesken, Werner (2004). *Water, race, and disease.* MIT Press.

Wachter, Kenneth (1998). "Levels of Demographic Randomness: Evidence from the Wrigley and Schofield Parish Series". In:

Ward, Michael P (2002). "Seasonality of canine leptospirosis in the United States and Canada and its association with rainfall". In: *Preventive Veterinary Medicine* 56.3, pp. 203–213. ISSN: 0167-5877.

Wrigley, E.A and R.S Schofield (2003). *Parish Register Aggregate Analyses, 1662-1811; 404 Data.* Colchester, Essex: UK Data Archive.

Yun, J., M. Greiner, and C. et al. Höller (2016). "Association between the ambient temperature and the occurrence of human Salmonella and Campylobacter infections." In: *Sci Rep* 6.

Zinn, Caleb et al. (2018). "How are water treatment technologies used in developing countries and which are the most effective? An implication to improve global health". In: *Journal of Public Health and Emergency* 2.0. ISSN: 2520-0054.

A. Online Appendix (Not for Publication)

Table 1 — Summary Statistics for Parishes with Low, Medium, and High Numbers of Nearby Water Sources - 1779

	Low Sources	Medium Sources	High Sources	p-value
Summer/Winter Deaths	1.06	1.09	0.98	0.68
Altitude	81.25	81.05	90.59	0.40
Distance to Market	4.52	4.57	4.01	0.41
Log of Population	6.55	6.75	7.13	0.00
Burials	23.7	32.6	48.5	0.00
Summer Burials	5.4	7.4	9.8	0.00
Area	4,773	5,348	7,740	0.00
Landlocked	0.47	0.45	0.55	0.26
Observations	124	176	100	

Note: This table displays summary statistics for parishes with low, medium and high numbers of nearby water sources in 1779, the year before the malt tax was increased in 1780. Parishes with four or fewer nearby water sources are deemed to have low sources, parishes with between five and 18 nearby water sources are deemed to have medium sources, while parishes with 19 or more nearby sources are deemed to have high sources.

Table 2 — The Effect of the 1780 Malt Tax Increase on Wintertime Mortality in Parishes with a Varying Numbers of Nearby Water Sources (Falsification Exercise)

	(1) Winter Deaths	(2) Winter Deaths	(3) Winter Deaths
Low Sources * Post	0.0263		-0.00719
	(0.0546)		(0.0593)
High Sources * Post		-0.0840	-0.0870
		(0.0521)	(0.0565)
Difference			.080
P-value			.212
Observations	7991	7991	7991

Note: This table compares the natural log of winter deaths before and after the 1780 increase in the malt tax for parishes above the 75th percentile and below the 25th percentile in water quality, relative to parishes in the 25th-75th percentile range of water quality. The first two columns estimate the coefficient on high and low water quality parishes separately, before including them in the same regression in column 3. Also in column 3, the difference between the high and low water quality coefficients is calculated and a p-value on the equality of the coefficients is estimated. In every specification, controls are included for parish population, regional wages, tea imports, parish and year fixed effects as well as a parish linear time trend. Standard errors are clustered at the parish level. * $p < 0.10$, ** $p < 0.05$, *** $p < .01$.

Table 3 — The Effect of the 1780 Malt Tax Increase on Wintertime Mortality in Parishes with Varying Elevation (Falsification Exercise)

	(1) Winter Deaths	(2) Winter Deaths	(3) Winter Deaths
Low Elevation * Post	-0.0422		-0.0548
	(0.0536)		(0.0577)
High Elevation * Post		-0.0211	-0.0385
		(0.0548)	(0.0588)
Difference			.016
P-value			.803
Observations	7991	7991	7991

Note: This table compares the natural log of winter deaths before and after the 1780 increase in the malt tax for parishes above the 75th percentile and below the 25th percentile in elevation, relative to parishes in the 25th-75th percentile range of water quality. The first two columns estimate the coefficient on high and low water quality parishes separately, before including them in the same regression in column 3. Also in column 3, the difference between the high and low water quality coefficients is calculated and a p-value on the equality of the coefficients is estimated. In every specification, controls are included for parish population, regional wages, tea imports, parish and year fixed effects as well as a parish linear time trend. Standard errors are clustered at the parish level. * $p < 0.10$, ** $p < 0.05$, *** $p < .01$

Table 4 — The Effect of the 1780 Malt Tax Increase on Wintertime Mortality in Parishes with Varying Water Quality (Falsification Exercise)

	(1) Winter Deaths	(2) Winter Deaths	(3) Winter Deaths
Low * Low * Post	-0.147*		-0.151*
	(0.0890)		(0.0894)
High * High * Post		-0.0591	-0.0697
		(0.0649)	(0.0654)
Difference			.081
P-value			.43
Observations	7991	7991	7991

Note: This table compares the natural log of winter deaths before and after the 1780 increase in the malt tax for parishes above the 75th percentile and below the 25th percentile in both water sources and elevation, relative to parishes in the 25th-75th percentile range of water quality. The first two columns estimate the coefficient on high and low water quality parishes separately, before including them in the same regression in column 3. Also in column 3, the difference between the high and low water quality coefficients is calculated and a p-value on the equality of the coefficients is estimated. In every specification, controls are included for parish population, regional wages, tea imports, parish and year fixed effects as well as a parish linear time trend. Standard errors are clustered at the parish level. * $p < 0.10$, ** $p < 0.05$, *** $p < .01$

Table 5 — The Effect of the 1780 Malt Tax Increase on Summertime Mortality in Parishes with Varying Levels of Inherent Water Quality. Estimated with various standard errors to test for robustness to spatial autocorrelation.

	(1) Smr Dths	(2) Smr Dths	(3) Smr Dths	(4) Smr Dths	(5) Smr Dths	(6) Smr Dths
Low Sources * Post	0.163**		0.125*	0.125*	0.125**	0.125*
	(0.0670)		(0.0692)	(0.0647)	(0.0527)	(0.0643)
High Sources * Post		-0.149**	-0.0971	-0.0971	-0.0971	-0.0971**
		(0.0657)	(0.0655)	(0.0616)	(0.0672)	(0.0380)
Difference			.222	.222	.222	.222
P-value			.0070	.0013	.0006	.0008
Low Alt. * Post	0.123		0.0930	0.0930	0.0930*	0.0930
	(0.0757)		(0.0739)	(0.0685)	(0.143)	(0.0598)
High Alt. * Post		-0.122***	-0.0931***	-0.0931	-0.0931	-0.0931
		(0.0403)	(0.0312)	(0.0575)	(0.127)	(0.0622)
Difference			.186	.186	.186	.186
P-value			.0264	.0642	.0226	.0042
Low * Low * Post	0.249**		0.229**	0.229**	0.229***	0.229**
	(0.0998)		(0.101)	(0.103)	(0.0769)	(0.0957)
High * High * Post		-0.289***	-0.273***	-0.273***	-0.273***	-0.273***
		(0.0835)	(0.0837)	(0.0684)	(0.0822)	(0.0850)
Difference			.502	.502	.502	.502
P-value			.0001	.0000	.0000	.0000
Standard Error	acreg(50)	acreg(50)	acreg(50)	acreg(80)	acreg(20)	Bootstrap
Observations	7448	7448	7448	7448	7448	7448

Note: This table compares outcomes before and after the 1780 increase in the malt tax for parishes above the 75th percentile and below the 25th percentile in water quality (high and low water quality, respectively), relative to parishes in the 25th-75th percentile range of water quality. The top panel uses the number of available water sources as the measure of water quality, the middle panel uses the elevation of the parish, while the bottom panel estimates the model on the intersection of the two measures of water quality. The first two columns use the log of summer deaths as the dependent variable and estimate the coefficient on high and low water quality parishes separately, before including them in the same regression (column 3). Columns 1-3 allow for an arbitrary correlation between parishes within 50 kilometers of one another. Column 4 repeats the regression from column 3 allowing for correlation in parishes within 80 kilometers, while column 5 allows for correlations in parishes within 20 kilometers. Finally, column 6 bootstraps the standard errors with 500 replications. * $p < 0.10$, ** $p < 0.05$, *** $p < .01$

Table 6 — Testing Robustness of the Effect of the 1780 Malt Tax Increase on Summer Deaths in Parishes with Varying Water Quality - Number of Deaths as Dependent Variable

	(1) Summer Deaths	(2) Summer Deaths	(3) Summer Deaths
Low Sources * Post	0.716^{**}		0.520
	(0.351)		(0.360)
High Sources * Post		-0.733	-0.514
		(0.454)	(0.477)
Difference			1.033
P-value			.0404
Low Alt. * Post	0.429		0.0748
	(0.395)		(0.409)
High Alt. * Post		-1.142^{***}	-1.118^{**}
		(0.437)	(0.455)
Difference			1.193
P-value			.0226
Low * Low * Post	0.963^{*}		0.797
	(0.497)		(0.498)
High * High * Post		-2.525^{***}	-2.468^{***}
		(0.932)	(0.934)
Difference			3.265
P-value			.0017
Observations	8,424	8,424	8,424

Note: This table compares outcomes before and after the 1780 increase in the malt tax for parishes above the 75th percentile and below the 25th percentile in water quality (high and low water quality, respectively), relative to parishes in the 25th-75th percentile range of water quality. The top panel uses the number of available water sources as the measure of water quality, the middle panel uses the elevation of the parish, while the bottom panel estimates the model on the intersection of the two measures of water quality. The first two columns use the number of summer deaths as the dependent variable and estimate the coefficient on high and low water quality parishes separately, before including them in the same regression (column 3). Also in column 3, the difference between the high and low water quality coefficients is calculated and a p-value on the equality of the coefficients is displayed. In every specification, controls are included for parish population, regional wages, tea imports, the number of winter deaths, parish and year fixed effects as well as a parish linear time trend. Standard errors are clustered at the parish level. * $p < 0.10$, ** $p < 0.05$, *** $p < .01$

Table 7 — The Effect of the 1780 Malt Tax Increase on Wintertime Mortality in Parishes with Gley Soil (Falsification Exercise)

	(1) Winter Deaths	(2) Winter Deaths	(3) Winter Deaths	(4) Winter Deaths
Post - Gley Soil	0.0560	0.0518	0.0533	0.0549
	(0.0572)	(0.0572)	(0.0574)	(0.0597)
Log Population	-1.567***	-1.553***	-1.556***	-1.787***
	(0.336)	(0.336)	(0.336)	(0.327)
Log Wage		0.324	0.320	0.369*
		(0.216)	(0.217)	(0.222)
Tea Imports x Gley Soil			-0.00885	-0.0167
			(0.0224)	(0.0235)
Summer Deaths				0.0426***
				(0.0134)
Observations	7991	7991	7991	7448

Note: This table compares the natural log of winter mortality before and after the 1780 increase in the malt tax for parishes with gley soil, which is ideal for growing barley, to all other parishes. In the first column population is controlled for, while the second column adds regional wages, the third column includes a control for tea imports and the fourth column adds a control for the number of summer deaths. In every specification, parish and year fixed effects as well as a parish linear time trend are included as controls. Standard errors are clustered at the parish level.
* $p < 0.10$, ** $p < 0.05$, *** $p < .01$

Table 8 — The Effect of the 1780 Malt Tax Increase on Summertime Mortality in Parishes with and without Gley Soil. Estimated with various standard errors to test for robustness to spatial autocorrelation.

	(1) Smr Dths	(2) Smr Dths	(3) Smr Dths	(4) Smr Dths	(5) Smr Dths	(6) Smr Dths
Post - Gley Soil	0.182^{*}	0.178^{*}	0.174^{*}	0.174^{**}	0.174^{**}	0.174^{***}
	(0.0955)	(0.0935)	(0.0928)	(0.0786)	(0.0766)	(0.0560)
Log Population		-0.935^{***}	-1.110^{***}	-1.110^{***}	-1.110^{***}	-1.110^{***}
		(0.225)	(0.266)	(0.218)	(0.279)	(0.327)
Log Wage		0.274	0.323	0.323	0.323	0.323
		(0.285)	(0.288)	(0.290)	(0.258)	(0.232)
Log Winter Deaths			0.0490^{***}	0.0490^{***}	0.0490^{***}	0.0490^{***}
			(0.0151)	(0.0118)	(0.0131)	(0.0139)
Standard Error	acreg(50)	acreg(50)	acreg(50)	acreg(80)	acreg(20)	Bootstrap
Observations	7754	7753	7448	7448	7448	7448

Note: This table compares outcomes before and after the 1780 increase in the malt tax for parishes with gley soil compared to all other parishes. Column 1 includes parish and year fixed effects as well as a parish linear time trend. Column 2 adds controls for population, regional wages and tea imports. Column 3 includes the log of winter deaths to control for factors which impact deaths year round. Columns 1-3 allow for an arbitrary correlation in the residuals of parishes within 50 kilometers. Column 4 repeats the specification from column 3 with the distance cutoff changed to 80 kilometers, while column 5 uses a distance cutoff of 20 kilometers. Finally, column 6 bootstraps the standard errors with 500 replications. * $p < 0.10$, ** $p < 0.05$, *** $p < .01$

Table 9 — Testing Robustness of the Effect of the 1780 Malt Tax Increase on Summer Deaths in Parishes with Gley Soil - Number of Summer Deaths as Dependent Variable

	(1) Summer Deaths	(2) Summer Deaths	(3) Summer Deaths	(4) Ratio
Post - Gley Soil	0.891^{**}	0.824^{**}	0.799^{**}	0.142
	(0.364)	(0.364)	(0.368)	(0.108)
Log Population		-5.634^{**}	-4.689^{**}	0.224
		(2.219)	(2.017)	(0.488)
Log Wage		2.877	2.499	0.521
		(1.775)	(1.736)	(0.372)
Tea Imports x Gley Soil		0.0872	0.0999	0.0156
		(0.134)	(0.133)	(0.0404)
Winter Deaths			0.0997^{***}	
			(0.0213)	
Observations	8446	8424	8424	7991

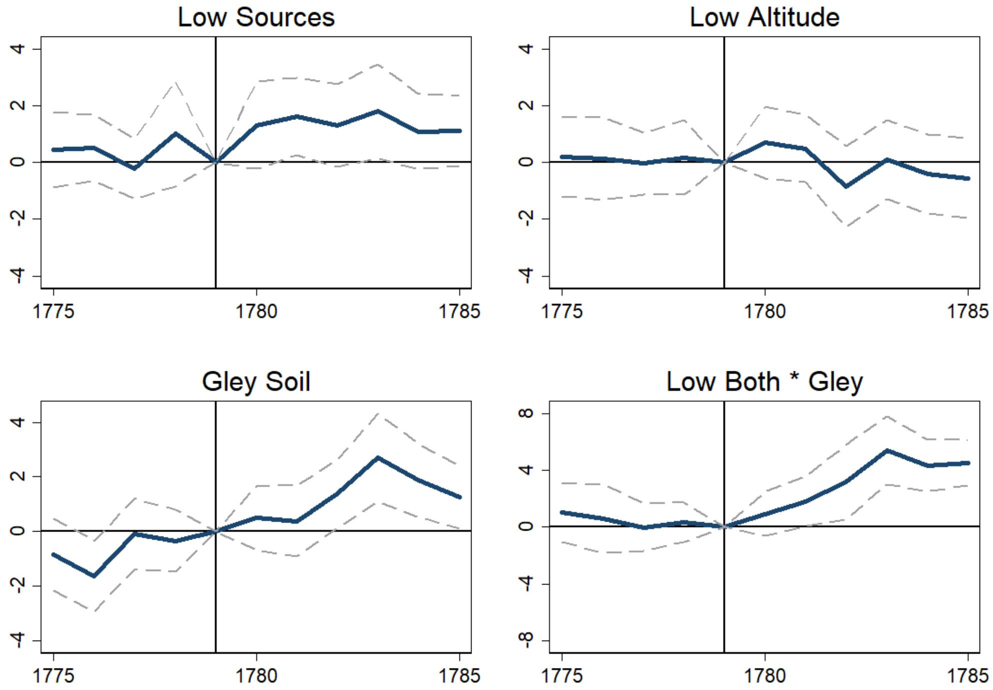
Note: This table compares outcomes before and after the 1780 increase in the malt tax for parishes with gley soil compared to all other counties. Column 1 includes parish and year fixed effects as well as a parish linear time trend. Column 2 adds controls for population, regional wages and tea imports. Column 3 includes the log of winter deaths to control for factors which impact mortality year round, while column 4 replaces the log of summer deaths with the ratio between summer and winter deaths as the dependent variable and drops winter deaths as a control since it is included on the left-hand side. Standard errors are clustered at the parish level. * $p < 0.10$, ** $p < 0.05$, *** $p < .01$

Table 10 — The Effect of Rainy Barley Growing Seasons on Summertime Mortality in Parishes with Few Water Sources and Gley Soil - 1726-1830. Estimated with various standard errors to test for robustness to spatial autocorrelation.

	(1) Smr Dths	(2) Smr Dths	(3) Smr Dths	(4) Smr Dths	(5) Smr Dths	(6) Smr Dths
Rain x Sources	0.00330^{***}		0.0000660	0.0000660	0.0000660	0.0000660
	(0.000967)		(0.00159)	(0.00140)	(.)	(0.00184)
Rain x Gley		0.00372^{**}	-0.00121	-0.00121	-0.00121	-0.00121
		(0.00186)	(0.00176)	(0.00189)	(0.00145)	(0.00276)
Rain x Gley x Sources			0.00922^{***}	0.00922^{***}	0.00922^{***}	0.00922^{**}
			(0.00302)	(0.00300)	(0.00248)	(0.00377)
Standard Error	acreg(50)	acreg(50)	acreg(50)	acreg(20)	acreg(80)	Bootstrap
Observations	10315	10315	10315	10315	10315	10315

Note: This table displays estimates of the effect of rainy barley growing seasons on different types of parishes which are more or less vulnerable to shocks in beer availability. Columns 1 through 3 replicate the main specifications from Table 3 in the paper, allowing for an arbitrary correlation in the standard errors of parishes within 50 kilometers of one another. Column 4 repeats column 3, allowing for correlations between parishes within 20 kilometers, while column 5 allows for correlations between parishes within 80 kilometers of one another. Finally, column 6 bootstraps the standard errors with 500 replications. * $p < 0.10$, ** $p < 0.05$, *** $p < .01$.

Figure 1 — Testing Robustness of Event-Study Estimates of the Effect of the 1780 Malt Tax Increase on Summertime Mortality in Parishes with Lower Water Quality and Gley Soil - Number of Summer Deaths as Dependent Variable



Note: This figure displays event-study estimates comparing the number of summer deaths in parishes that are more exposed to the malt tax increase. The top left graph displays estimates for parishes with few nearby water sources, the top right graph displays estimates for parishes with low elevation, the bottom left graph displays estimates for parishes which have gley soil, and the bottom right displays estimates for parishes with low water sources, low elevation and gley soil. Standard errors are clustered at the parish level.