For Want of a Cup: The Rise of Tea in England and the Impact of Water Quality on Economic Development *

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Abstract

While it is now well accepted that access to clean water plays an important role in public health and economic development, there is less historical evidence for the role that clean water played in the development of the now-rich world. I investigate this question by exploiting a natural experiment on the effects of water quality on mortality—the advent of tea consumption in 18th century England. The custom of tea drinking spread rapidly throughout England, even among lower classes, and resulted in an unintentional increase in consumption of boiled water which reduced mortality rates. This hypothesis is supported by results from two identification strategies indicating that areas with lower initial water quality had larger declines in mortality rates after tea drinking became widespread and in years following larger volumes of tea imports. These results are robust to the inclusion of additional controls for income and access to trade. Finally, I use cause-specific death data to show that higher volumes of tea imports were associated with fewer deaths from water-borne diseases, while the same is not true for non-water-borne diseases. This supports the idea that the mechanism behind the tea-mortality relationship was in fact boiled water.

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1 Introduction

The importance of access to clean water for economic development has recently received considerable attention among researchers and policy makers alike. While United Nations leaders declared victory in meeting the Millennium Development Goal of expanding access to safe drinking water, more than 700 million people still lack access to an improved drinking water source (WHO and UNICEF 2014). The fact that the majority of these people live in the developing world has stimulated substantial research in developing countries to estimate the impact of water interventions on health, mortality, and quality of life (Kremer et al. 2011, Galiani et al. 2005, Devoto et al. 2012). Although these studies highlight the role that access to clean water can play in economic development today, evaluating the importance of clean water to the development of the now-rich world can help illuminate the long-run impacts of clean water for economic development. This paper adds to both the historical and development literature by exploiting a natural experiment into the effects of water quality on mortality that occurred prior to the understanding that water contamination could compromise health, namely, the advent of tea consumption in 18th century England. Since brewing tea would have required boiling water, and boiling water is now recognized as a method of water purification, the rise of tea consumption in 18th century England would have resulted in an accidental improvement in the relatively poor quality of water available during the Industrial Revolution. To what extent can this explain the drop in mortality rates seen over this important period in economic development?

While there are now several historical studies of the relationship between water quality and mortality, they have largely focused on the U.S. experience, and in particular, the impacts of public health interventions targeted at improving drinking water sources and sewage systems in the late 19th and early 20th centuries (Alsan and Goldin 2015; Beach et al. 2014; Ferrie and Troesken 2008; Cutler and Miller 2005; Troesken 2004). By this time period, as with the water impact studies that take place in developing countries today, clean water and sanitation are widely understood to have a direct impact on health, thus raising the possibility that treatment estimates may suffer from endogeneity bias and be confounded with correlated effects (Currie et al. 2013). Although current development projects employing randomized controlled trials may avoid selection bias, an important policy question concerns how to ensure that the population adopts the intervention after the experimenters are gone, particularly if it represents a change in custom imposed from without. In contrast, the entirety of the period examined in this paper occurs prior to the widespread acceptance of the germ theory of disease and prior to major public health interventions. Thus, it also constitutes an important distinction from the historical and development literatures, as it concerns a change in culture and custom that occurred without any concerted policy intervention. While the link between increased tea consumption, population, and growth has been hypothesized by some historians (MacFarlane 1997; Mair and Hoh 2009; Standage 2006), to my knowledge this is the first paper to provide quantitative evidence on this relationship.

I put forth two identification strategies to estimate the causal relationship between tea consumption and mortality rates in England. The first is a difference-in-differences style model that compares the period before and after the widespread adoption of tea in England across areas that vary in their initial levels of water quality. Proxies for initial water quality come from geographical features of local communities as well as initial population density measures, and it is their interaction with variation in tea adoption over time that represents the independent variable of interest. Importantly, this allows for me to control for parish and year fixed effects separately and thus net out time-invariant differences across parishes as well as changes over time that are common to all parishes from the estimated impact of tea on mortality. This is similar to the approach used by Nunn and Qian (2011), who exploit regional variation in the suitability of land for potato cultivation to estimate the impact of the introduction of the potato on population.

The second identification strategy modifies this strategy to exploit actual tea import data at the national level interacted with the water quality measures. Here, I investigate whether positive shocks to tea imports resulted in larger declines in mortality rates in areas where water quality was initially worse. As expected, both sets of results suggest that tea was associated with larger declines in mortality rates in areas that had worse water quality to begin with. These results are robust to controlling for wages and interacted variables capturing distance to market and alternative imports, thus suggesting the results are not driven by economic factors such as rising incomes and access to trade. I provide further support for the boiled water mechanism with analyses of cause-specific death data that show increased tea imports resulted in fewer contemporaneous deaths from water-borne diseases, but no similar decline in contemporaneous deaths from non-water-borne diseases. Additional analyses linking tea imports with infant and early childhood mortality rates suggest that young children did not benefit from tea shocks, which is as expected if they were not major consumers of tea. All together, the totality of the results points to the importance of tea, and in particular the boiling of water, in reducing mortality rates across England during this important period in economic development.

The remainder of this paper is organized as follows. Section 2 provides some background on the historical context surrounding the introduction of tea to England. Section 3 presents the empirical strategy including the two identification strategies described above. Section 4 describes the data used in the analysis. Section 5 presents the results, robustness checks, and empirical support for the mechanism using cause-specific death and early childhood mortality data. Section 6 concludes.

2 Historical Background

Tea was first imported to England from China in 1689 (Mair and Hoh, 2009) and like most newly imported goods, at the outset, tea was regarded as a luxury good enjoyed by the elite. By the end of the 18th century, however, a consumer revolution was taking place in which broad social groups were able to purchase newly available goods, such as tea (Allen 2009, p.49-50). As such, historical evidence indicates that even the humblest peasant drank tea twice a day (MacFarlane p.144-48). The rapid and wide acceptance of tea throughout the population was likely due to the distinct properties of tea that made it accessible to all social classes. In particular, only a few leaves are necessary to make a decent pot and tea leaves can be reused, such that boiling water can be poured over already-used tea leaves (MacFarlane and MacFarlane 2003), thus decoupling the link between income and tea consumption. While this production process would have produced weaker tea, it also suggests that the main health improvement associated with tea would be related to the properties of boiled water, as opposed to any particular property of the tea leaf itself.

Why then did tea emerge as the English national beverage? One important factor is the prominent role of the English East India Company (EIC) which had a long-running monopoly over trade with the Far East until 1834. Through its dominance in international markets, the EIC was able to bring so much tea into England that it was able to push other beverages such as coffee, out of the market (Mair and Hoh 2009, p.176). Another cultural feature that helped solidify England as a nation of tea drinkers was the advent of tea houses, where, unlike all-male coffee houses, women could purchase their own tea. This ensured that tea would become a more accessible beverage, available to a wider population, and thus solidify its dominance as the country's national beverage. Tea gardens, which could be enjoyed by men, women, and families together, also enshrined tea as a cultural custom, as did the worker's tea break (Mair and Hoh 2009 p.186, MacFarlane and MacFarlane p.80-94).

The relative cost of tea, further diminished by the ability to reuse tea leaves, was also an important feature in establishing tea's dominance over alternative beverages. For instance, the consumption of alcoholic beverages, such as ale and beer, had a long history in England prior to the introduction of tea. Although these beverages would also have represented improvements over plain water, they were costly in comparison, in part due to the high costs of inputs involved in producing them, as well as the malt tax which further raised consumption costs. Thus, while "small beer" was at one point the usual beverage in England, by 1680, the malt tax had risen so considerably that it became necessary to find an alternative beverage (MacFarlane, p.151; Clark 1998, ch.1). While there are no widespread data on beverage consumption to document this trend, to the extent that some individuals were substituting tea for beer as opposed to water, it is important to note that this would only mean that the estimates here could be interpreted as lower bounds on the true impact of water quality on health outcomes. Like beer, other beverages that may have provided an improvement in water quality, such as coffee, chocolate, wine, and whiskey, would also have been less suitable as a national beverage due to the high costs of inputs involved in production and unpleasant side effects from large-scale consumption (MacFarlane and MacFarlane, p.283). Raw milk, on the other hand, would have been contaminated with bacteria until pasteurization began around 1890 (MacFarlane 125-26). In contrast, tea was a relatively cheap, accessible, and safe beverage that was mild enough to be drunk throughout the day by the entire population (MacFarlane and MacFarlane p.31-39).

At the time that tea was sweeping across England, the methods for disposing human waste in England were still very primitive. Far too few privies existed and householders were known to accumulate their excrement and dispose of them in streets and rivers (MacFarlane 1997, p176). This made cities, with rising population densities, particularly dangerous, and may explain why urban men were substantially shorter than rural men over this period of rapid urbanization (Steckel 2005). At this time, however, the critical importance of properly separating human excrement from drinking water sources was not understood and thus typhoid and later cholera outbreaks were common. This may have been in part due to the fact that the germ theory of disease was in its very infancy and unknown to more than a handful of people worldwide. Prevailing views on the causes of mortality crises focused on miasmas, clouds of noxious gases that moved indiscriminately across the population spreading illness and death. It was not until the 1840s that William Budd (MacFarlane p.110) and John Snow (Johnson 2006, p. 74) argued that typhoid and cholera were spread through contaminated water, and their hypotheses continued to be hotly debated until John Snow's pioneering epidemiological study of the London cholera outbreak of 1854 publicly demonstrated the link between water and disease (Johnson 2006). This discovery fueled the public health movement that emphasized the need to separate drinking water sources and sewage infrastructure. Nevertheless, public interventions were poorly funded and it was not until the late 19th and early 20th centuries, well beyond the period studied here, that significant improvements were made in public sanitation and environmental health (Harris et al. 2010). Thus, the fact that people were ignorant of the dangers of contaminated water during the rise of tea consumption, coupled with evidence that people were not motivated to drink tea for its health benefits (MacFarlane 1997, p.149) and actually debated the merits of tea-drinking, (Mair and Hoh p.178-80), all suggest that tea drinking was likely to be independent of the types of unobserved variables that might present a challenge for identification.

While some might be concerned that estimating the relationship between tea and mortality over this period is actually driven by rising wages, there is considerable evidence to suggest that although English wages were high relative to other countries, they rose very little over the course of the Industrial Revolution (Allen, 2009, p.41-42). Others have also suggested that however much real wages rose over this period, living standards did not rise (Mokyr 1993). What then can explain the dramatic drop in mortality seen over this period that has continued to be the subject of considerable historical debate (Johnson 1993)? While some have argued that it stemmed from nutritional improvements which allowed for a reduced incidence of infectious disease (McKeown 1983; Fogel 1989), still others have disputed this hypothesis (Schofield 1984; Lee 1981), and others have argued that nutrition actually declined over at least part of this period (MacFarlane 1997, ch.21). The decline of beer in the late 17th century owing to the high malt tax would certainly have meant a decline in nutritional quality of beverages, as tea is less nutritionally useful than beer. Thus the paradox of why England experienced a decline in mortality over this period without an increase in wages, living standards, or nutrition can be explained in part by the widespread adoption of tea as the national beverage and the commensurate increased consumption of boiled water (MacFarlane 1997, p. 150).

While this paper represents the first quantitative examination of this hypothesis, it should be noted that several historians have suggested that the custom of tea drinking was instrumental in curbing deaths from water-borne diseases and thus sowing the seeds for economic growth. MacFarlane (1997) draws comparisons between the experiences of England and Japan in this respect, concluding that "tea caused boiled water to be used, which caused dysentery to be minimized" (MacFarlane 1997, p.379). Mair and Hoh (2009, p.198) write that without "boiled beverages such as tea, the crowding together in immense cities...would have unleashed devastating epidemics." Similarly, Standage (2006, p.201) writes that the popularity of tea "allowed the workforce to be more densely packed in their living quarters around factories in the industrial cities. . . without risk of disease." This view is echoed by Johnson (2006, p. 95), who writes that "largely freed from waterborne disease agents, the tea-drinking population began to swell in number, ultimately supplying a larger labor pool to the emerging factory towns...."

3 Empirical Methods

3.1 First Identification Strategy

To measure the effect of tea drinking on mortality rates in England, I begin by comparing mortality across areas that varied in initial water quality before and after tea consumption became popular. This is estimated via the following regression model:

$$Deaths_{it} = a_1 + \gamma_1 WaterQuality_i \times PostTea_t + X_{it}\beta_1 + \mu_i + \delta_t + \varepsilon_{it} \ , \tag{1}$$

where the dependent variable is the natural log of the number of deaths in parish i in year t. The independent variable of interest, $WaterQuality_i \times PostTea_t$, is an interaction term between the initial water quality in parish i and a dummy variable indicating the period is after tea drinking was widespread among the broader population of England. As discussed above, although tea first came to England just prior to 1700, very little tea consumption was occurring very early in the period and thus could not have had an appreciable effect on death rates at that time. Instead, I date the widespread adoption of tea to the Tea and Window Act of 1784 which reduced the tea tax from 119 to 12.5 percent at one stroke (Mair and Hoh, p.187-88). This is further supported by Figure 1 which shows national tea imports over time, smoothed to a 3-year moving average in order to highlight breaks in trend. As can be seen from the figure, 1785 appears to be a clear dividing line in the time series of imports, with a substantial rise in tea imports occurring thereafter. In light of this, I define $PostTea_t$ to be an indicator for years 1785 or later. In subsequent specifications, I also introduce lead indicators for the periods immediately preceding 1785 interacted with water quality measures to show that the results are robust to concerns regarding pre-existing trends prior to 1785.

All regressions include parish fixed effects (μ_i) which control for all time-invariant factors at the parish level such as geographical features of the parishes themselves. Importantly, this will absorb any correlation between parish elevation and parish deaths that is fixed over time, and thus mitigate concerns that the coefficient of interest is driven by factors purely related to elevation. At the same time, year fixed effects (δ_t) are included in all specifications to control for time-varying factors that are common to all parishes, such as the national-level changes in income associated with the Industrial Revolution, as well as any national events such as wars. X_{it} includes controls for other parish characteristics that vary over time, such as population measures which will be discussed below, and later wages as well. Standard errors are clustered at the parish level. Equation (1) is estimated on the years 1700-1839 to more closely surround the rise of widespread tea adoption in England.

3.2 Second Identification Strategy

To provide further evidence of the impact that tea consumption had on mortality rates, I utilize actual tea import data to compare the impact of national tea imports on mortality rates in areas that varied in their level of initial water quality:

$$Deaths_{it} = a_2 + \gamma_2 WaterQuality_i \times Tea\,\mathrm{Im}ports_{t-1} + X_{it}\beta_2 + \mu_i + \delta_t + \varepsilon_{it}\ , \qquad (2)$$

where the independent variable of interest, $WaterQuality_i \times Tea\,\mathrm{Im}ports_{t-1}$, is the interaction term between initial water quality in parish i and national-level tea imports in year t-1. The use of lagged tea imports reflects the fact that tea imports arriving in London may not have reached the final consumer until the following year. All remaining variables are as specified above, where again year fixed effects and parish fixed effects provide important means of controlling for unobservables that otherwise might bias the coefficient of interest.

The raw relationship between tea imports and mortality rates is documented in Figure

2 which shows per capita tea imports and the English crude death rate over the period in which tea import data are available. Apart from the overall rise in tea imports that is clearly correlated with the drop in mortality rates over the period as a whole, there is also substantial variation in the tea series to be exploited by the identification strategy used here. In particular, it is expected that a substantial portion of the volatility in tea imports is driven by supply-side determinants such as weather shocks in China, thus producing exogenous variation in the supply of tea to England. As a robustness check to ensure that the estimated effects are not simply driven by changes in income or economic factors, subsequent specifications control for wages as well as interacted variables measuring access to trade and other imported goods. This adds weight to the causal interpretation for the special role that tea played in decreasing mortality.

3.3 Support for the Mechanism via Cause-Specific Deaths and Early Childhood Mortality

To further bolster the evidence that the mechanism behind these results was the improvement in water quality, I also use cause-specific death data over this time period available in Marshall (1832) to show that higher tea imports curbed deaths from water-borne diseases such as dysentery, commonly described as flux or bloody flux (Wrigley and Schofield 1981). At the same time, falsification tests show that shocks to tea imports did not significantly affect contemporaneous deaths from air-borne diseases such as tuberculosis and smallpox. Unfortunately, cause-specific death data are only available for London prior to the middle of the19th century, and thus the identification strategy here relies on linking variation in tea imports with variation in cause-specific deaths:

$$CAUSE\_Specific\_Deaths_{it} = a_3 + \gamma_3 Tea\,\mathrm{Im}ports_t + \theta_3 t + \phi_3 t^2 + \varepsilon_{it}\ , \tag{3}$$

where current year's tea imports are included in the specification due to the fact that London would have been the main port of entry and also the site of the mortality measurements in this specification. A linear and quadratic time trend are also included as controls. This is similar to the approach used by Galiani et al. (2005), with the obvious drawback that cause-specific mortality rates are not available across parishes, thus eliminating the possibility of a difference-in-differences strategy here.

As an extension, I also use data on infant and child mortality from London available in Marshall (1832) to run a similar specification to investigate whether infant and early childhood deaths can be linked to variation in tea consumption. In the context of childhood deaths, however, it is important to note that although infants and children may have been less likely to consume tea, they are also thought to be more sensitive to water-borne diseases, and thus they may have indirectly benefited from a lower incidence of these diseases among the tea-drinking population (MacFarlane 1997). Regardless, we should expect that the magnitude of the impact of tea on infants and young children should at the very least be more muted, if not statistically insignificant.

4 Data Sources

4.1 Mortality Data

The mortality rates and parish characteristics used in the analysis are constructed from Schofield and Wrigley's (2003) collection of records on burials, baptisms, and marriages for 404 English parishes over the years 1538-1849. To limit the focus to the years in which tea was introduced, this paper focuses on the sample starting in 1700. While Wrigley and Schofield (1981) use these data to recover population estimates for England as a whole, they do not provide population estimates for the parishes individually. Since it is important to scale deaths by the relative size of the parishes, I follow Wachter (1998) in constructing the following measure of parish population based on a weighted average of past measures of parish-specific burials, baptisms, and marriages:

$$\begin{aligned} Population_{it} &= 0.4 \times \frac{smooth(Baptisms_{\overline{it-20}})}{0.03} + 0.4 \times \frac{smooth(Burials_{\overline{it-20}})}{0.025} + \\ &\quad +0.2 \times \frac{smooth(Marriages_{\overline{it-20}})}{0.008} , \end{aligned} \tag{4}$$

where $Population_{it}$ is the constructed measure of population for parish i in year t and smooth($x_{\overline{it-20}}$) is the average of x over the *past* 20 years. As there may be some concern over the use of this constructed measure and the degree of measurement error it may include, I report specifications with the natural log of $Population_{it}$ on the right-hand side, as opposed to scaling the dependent variable by the constructed population measure. For comparison, I also present results with the measure of births ($Baptisms_{it}$) and marriages ($Marriages_{it}$)

on the right-hand side instead of the constructed population measure.[1]

4.2 Water Quality Measures

The water quality measures used in the analysis are based on the average elevation within a parish, as well as initial population density in the parish at a point in time prior to the rise of tea consumption.[2] It is believed that parish elevation should be positively correlated with water quality because parishes at higher elevation would have been less likely to be subjected to water contamination from surrounding areas. The measures of the average elevation (in meters) in the parish are constructed from Shuttle Radar Topography images (Jarvis, et al. 2008) based on historical parish boundaries (Southall and Burton 2004). A map of parish locations is provided in Figure 3, which shows that parishes are dispersed throughout England. Further analysis indicates that relatively high elevation parishes are not geographically concentrated either.

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[1] An earlier version of this paper also presented estimates using the control for marriages alone and found substantially similar results.

[2] An earlier version of this paper also used average slope as a water quality proxy, under the hypothesis that water would have been less likely to pool in steeper parishes. Since running water is generally higher quality than standing water, this would mean that steeper parishes would have had better water quality than parishes that were relatively flat. The entirety of the historical results, including robustness checks, is statistically significant and consistent with this hypothesis. However, subsequent analysis of the correlation between slope and fecal coliform levels in present-day Africa and India yields a statistically insignificant relationship between average slope and fecal coliform levels. While this may reflect the fact that the relationship between slope and fecal coliform in present-day India and Africa is not similar to that in 18th century England, I omit those specifications from the main results due to insufficient support for the use of slope as a water quality proxy.

The other proxy for water quality is population density, but here the correlation is thought to be negative as a denser parish would have posed greater challenges for disposing of human waste and thus provided greater sources for contamination. This is particularly true for this period prior to the widespread acceptance of the germ theory of disease and the public health movement that began later in the 19th century (Johnson 2006). To avoid inherent correlation between the dependent variable and the constructed measure of population density, I construct a measure of initial population density in 1700 using the calculation in equation (4) divided by parish area. While the use of a lagged measure of population density may result in a reduction in statistical precision, the argument here is that there are likely to be structural reasons determining population density that are likely to be fixed over time, and thus captured by this measure.

While it is not possible to test the hypothesized correlations between the water quality proxies and explicit water quality levels in the 18th century, I provide empirical support for these measures from present-day settings that arguably most closely approximate the period under study. To do this, I focus on Africa and India, as these are recognized as two areas with some of the worst access to sanitation facilities (WHO and UNICEF 2014, p.17), and thus present the greatest chance for water contamination. For these areas, I obtain data on fecal coliform levels from the United Nations Global Environment Management System Water Programme which include latitude and longitude coordinates at select water quality sites sampled over time. I then construct 3 kilometer buffer zones around these sites to reflect the average distance traveled to collect water in the developing world (Ure 2011). Appendix Figure 1 shows a map of the buffer zones surrounding these water quality sites. These buffer zones are then matched with Shuttle Radar Topography images (USGS 2015) for the relevant areas and population density data from 1990 Gridded Population of the World Version 3 (GPWv3): Population Density Grids (CIESIN and CIAT 2005). This exercise produces a data set with fecal coliform levels and associated elevation and population density data for 87 water quality sites in Africa and India over time.

Appendix Table 1 shows that, even after including country and year fixed effects, the relationship between fecal coliform levels and elevation is especially robust: locations at higher elevation are exposed to lower levels of fecal coliform. There is less support for the population density measure, owing in particular to large standard errors. This weaker relationship may stem from the fact that in the present day, when water quality is understood to be an important determinant of public health, officials are more likely to improve water sources in higher density areas. Regardless, the sign of the coefficient suggests that higher density areas have higher levels of fecal coliform and is thus consistent with the hypothesis that water quality and population density are inversely related.

4.3 Tea Imports

The data on national-level tea imports come from the East India Company records available from Bowen (2007) and cover the years 1761-1834. Unfortunately, the data on tea are not available at the parish level, thus requiring the more subtle empirical strategy discussed above. Figure 1 shows a dramatic rise in tea imports from China over the years 1761-1834, going from around 5 tons at the beginning of the period to over 30 tons at the end.[3] At the national level, there is a clear negative correlation between tea imports and mortality

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[3] In response to increased competition, the East India Company began to shift production and exportation of tea to India, but not until the late 1830s (Mair and Hoh, p.212-13).

rates (Wrigley and Schofield 1981, p.531-534), illustrated in Figure 2. Over this period, mortality rates fell from around 29 to 24 deaths per 1,000 people. At the same time, there appears to be substantial year-to-year variation in tea imports and mortality rates which will prove useful in the second identification strategy used here.

4.4 Descriptive statistics

Table 1 presents descriptive statistics for the data sources used in the analysis. Panel A includes means and standard deviations for the two measures of water quality used here: parish elevation and parish population density in 1700. Table 1, Panel B describes the demographic data that vary over time which are used in the first identification strategy over the years 1700-1839. Finally, Table 1, Panel C describes the data on tea imports for the years 1761-1834 which are used in the second identification strategy outlined above.

The descriptive statistics might better illustrate the spirit of the identification strategy in graphical form. To this end, Figures 4 and 5 graph death rates against tea imports for the three measures of water quality used in the analysis. Figure 3 graphs the death rates against tea imports distinguished by whether the parishes were in high elevation (better water quality) versus low elevation (worse water quality) areas. The fitted line for the low water quality areas appears to be steeper than that for high water quality areas, suggesting that increased tea consumption had a bigger impact on lowering mortality rates in areas where water quality was worse. In Figure 5, where population density in 1700 is used as the measure of water quality, worse water quality (higher population density) again appears to be linked with a bigger decline in death rates relative to areas with better water quality (lower population density), and thus produces a steeper fitted line for higher density parishes.

5 Results

5.1 First Identification Strategy

5.1.1 Main Results

Tables 2 and 3 presents the main results using the first identification strategy relying on the interaction between parish water quality measures and an indicator for the post-tea-drinking era which coincided with the dramatic drop in the tea tariff in 1785 (equation 1). Table 2 focuses on the elevation measure while Table 3 shows the results using initial population density. Both tables present results with the constructed population measure as well as the alternative specification where births and marriages are used as controls. Across both tables, the coefficients of interest on the interaction between the post-1785 indicator and the water quality variables all have the anticipated signs. The coefficient on the interaction term between elevation and post-tea indicator in Table 2 is positive, suggesting that a lower elevation (worse water quality) is associated with a bigger decline in deaths after tea drinking became widespread. The magnitude of the coefficient under both sets of controls (columns 1 and 2) ranges from 0.019 to 0.050. This suggests that after tea became widespread, parishes with 10 percent lower water quality saw a drop in deaths on the order of 0.2 to 0.5 percent.

To provide further interpretation of this magnitude, I use this estimate to determine how much of the decline in mortality over this period can be attributed to the adoption of tea. This approach is analogous to that used by Nunn and Qian (2011). I first construct a counterfactual estimate of parish-level deaths by multiplying the estimated coefficient of interest and the water quality measure for each parish and add that to the dependent variable observed at the end of the period ($\ln deaths_{i,1839} + \widehat{\beta} \ln elevation_i$). I then average this estimate over all parishes to construct a nation-wide estimate of the counterfactual $\ln deaths$ that would have occurred at the end of the period had tea not been introduced. Comparing this with the actual change in average $\ln deaths$ observed over this period indicates that the ratio of actual to counterfactual deaths was approximately 88 percent, indicating that tea was responsible for about 12 percent of the change in mortality observed over this period, according to the estimate in column (1) of Table 2.

Although the coefficients on the interaction between initial population density and the post-tea indicator (columns 1 and 2 of Table 3) are not statistically significant in these specifications, their signs are nevertheless consistent with the above interpretation. That is, since population density is negatively correlated with water quality, these estimates also suggest that worse water quality (higher initial population density) is associated with a drop in mortality after tea drinking became widespread.

5.1.2 Robustness

One common feature of difference-in-differences strategies is the parallel trends assumption that requires that the treated and control groups would have maintained parallel trends in the absence of treatment. While this assumption is ultimately untestable, a common method of bolstering the case for this assumption is to show that there were no pre-existing trends prior to treatment. Thus, to demonstrate the robustness of the first identification strategy, columns 3 and 4 of Tables 2 and 3 present the analogous results from equation (1) after including two pre-trend indicators interacted with the respective water quality measures. These include lead variables for the post-1760 era as well as the post-1770 era.

In Table 2, where elevation is the proxy for water quality, all coefficients on lead indicators interacted with water quality are statistically insignificant, indicating that the impact of tea on mortality is concentrated in the expected period. There is also little change in the magnitude of the coefficient of interest, ranging from 0.023 to 0.034. In Table 3, where population density is the water quality measure, the coefficients on the lead periods are statistically insignificant with the exceptions of the interactions with the 1760 indicator. The latter estimates, however, are in the opposite direction of the coefficient of interest, suggesting that the estimated impact of tea is not driven by a pre-existing trend. At the same time, it should be noted that the coefficient of interest based on population density in Table 3 is statistically significant with the anticipated sign. Parishes that had a ten percent higher initial population density experienced a decline in deaths between 0.17 and 0.25 percent after tea drinking became widespread. Overall, this evidence mitigates concerns over whether pre-existing changes in mortality rates are driving the effects of interest and supports the notion that areas with worse water quality had greater declines in mortality after tea drinking became widespread in 1785.

5.2 Second Identification Strategy

5.2.1 Main Results

Table 4 present the main results using the second identification strategy relying on actual shocks to tea imports (equation 2), with both measures of water quality and both population controls. The coefficients on the interaction terms between water quality and lagged tea imports suggest the same pattern that was observed in Figures 3 and 4. First, the interaction term between tea imports and elevation has a positive coefficient (columns 1 and 3) with a magnitude ranging from 0.011 to 0.013. This suggests that lower elevation parishes (with worse water quality) had relatively larger declines in mortality rates when England experienced a positive shock to tea imports. In particular, the magnitudes suggest that for a parish with a one standard deviation lower elevation (worse water quality), a 10 percent increase in tea imports would have implied a 0.1 percent drop in deaths (10*0.011*0.907), based on the estimate in column (1). Note that this is similar to the magnitude observed in the first identification strategy.

The results using the population density measure (columns 2 and 3 of Table 4) produce negative coefficient estimates of interest, but a similar pattern of results since population density is negatively correlated with water quality. The similarity of coefficient estimates in the range of -0.006 to -0.010 is also reassuring. The fact that the coefficients of interest are statistically significant at the 1 percent level (elevation measure) or 5 percent level (population density measure) also lends credence to the results. Moreover, these results validate those from the first identification strategy and again indicate that tea reduced mortality rates more in areas with worse initial water quality.

5.2.2 Robustness

One concern with these interpretations is whether the coefficients of interest are picking up correlations between the independent variables of interest and some unobserved variables that are actually driving the results. While the complexity of the identification strategy relying on the interaction between the water quality measures and the tea imports, as well as the inclusion of year and parish fixed effects may mitigate some of these concerns, additional controls may lend further support for the interpretation. Arguably, the primary concern is that the interaction term may be correlated with changes in income. While there are few comprehensive sources of data that vary across parishes over time during this period in history, I turn to economic historians that have constructed their own data sets to bridge the gap. In particular, I use regional wage data by quinquennia available in Clark (2000). While these are described as daily farm wages, it is likely that competitive pressures would have worked to equilibrate wages across sectors and thus represent a reasonable proxy for income.

The results from the second identification strategy (equation 2) after controlling for wages can be found in Table 5, for both measures of water quality as well as both population-level controls. Somewhat paradoxically, the coefficient on wages is positive suggesting areas with higher growth rates experienced greater mortality. This likely indicates that local economic growth was also correlated with factors detrimental to human health and is thus also serving as a further control for those factors. Nevertheless, the primary interest is in exploring the impact on the coefficients of interest and here we see that they are very close in magnitude to the results from Table 4, and are all still statistically significant at the 5 percent level. Table 6 goes on to include the wage measures as controls in the estimation of equation (1), again for both measures of water quality as well as both population-level controls. Again similar results are obtained, compared with the results without controlling for wages from Tables 2 and 3, columns 1 and 2. Overall, these results mitigate concerns that the results are driven purely by region-specific variation in economic growth.

To further address concerns that the measures of water quality are actually picking up some underlying wealth distributions or proximity to trade routes that are actually driving the correlation with mortality rates, I include additional parish-level controls interacted with variables that vary over time. These include parish characteristics such as the distance to the nearest market town in 1700 (in km) and a variable indicating that the parish is within 10 km of the coast, interacted with tea imports. A related concern is that the tea import data might be reflecting changes in income over time across parishes and these changes had a differential impact on mortality across different types of parishes. To address this, I make use of the East India Company's records on other (miscellaneous) imports and interact them with the measures of water quality.

Table 7 reports the results from these regressions. While the coefficient on the distance to market town interaction term is statistically significant across all specifications, almost all of the interaction terms using miscellaneous imports or the indicator for proximity to the coast are not. More importantly, Table 7 shows that the inclusion of these additional controls does not substantially affect the pattern of results. Coefficient estimates on the interaction term between elevation and tea are in a very similar range as was observed in Table 4 (0.009 to 0.012), and statistically significant at the 5 and 1 percent levels, respectively. While the population density measure is no longer statistically significant, it is still negative in sign, suggesting that parishes with higher initial population density, and correspondingly worse water quality, saw a bigger decrease in mortality when there were larger tea imports.

5.3 Support for the Mechanism via Cause-Specific Deaths and Early Childhood Mortality

To provide further support that these estimates are driven by increased consumption of boiled water, as opposed to any properties of the tea itself, Table 8 shows the results from equation (3). Here, I investigate whether variation in tea imports can explain variation in cause-specific mortality rates and infant and child mortality rates in London specifically. Columns (1) and (2) show that higher tea volumes are associated with lower deaths from flux and bloody flux, two diseases most clearly identified with dysentery and diarrhea specifically.[4] First, it should be noted that the average number of deaths due to both flux and bloody flux look small, particularly in comparison with those due to smallpox and consumption (tuberculosis). This is likely due to the difficulty in classifying cause of death during this period of time prior to modern medicine. In particular, it is likely that diarrheal diseases were misclassified, owing to symptoms such as fevers and abdominal pains that may have been confused with other diseases. Thus, although deaths due to intestinal infections are found to account for 8 percent of all deaths around the mid-19th century, it is reasonable to presume that actual rates were higher (Wrigley and Schofield 1981, p. 659). Thus, while we can conclude from columns (1) and (2) of Table 8 that higher tea volumes are associated with fewer deaths from flux and bloody flux (coefficient estimates -0.282 and -0.561, respectively), we should be more cautious in interpreting the relative impact implied by these estimates.

Nevertheless, we can compare the sign and absolute magnitude of these results with those

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[4] A separate diagnosis for bloody flux appears in the middle of this period, explaining the smaller sample size in column (2).

suggested by falsification tests where contemporaneous non-water-borne related deaths are used as dependent variables (columns 3 and 4 of Table 8). The choice of consumption and smallpox are used in light of the greater likelihood that these diseases would not have been confused with dysentery, in particular smallpox which was "clearly recognizable" (Wrigley and Schofield 1981, p.688). Columns (3) and (4) show that the coefficients on smallpox and consumption are positive in sign and statistically insignificant, with much larger magnitudes (1.735 and 2.791, respectively), in part owing to the much larger number of deaths due to these diseases over this period. This suggests that while tea drinking was associated with a decline in water-borne diseases, no similar decline in non-water-borne diseases was observed. This adds credence to the hypothesis that the mechanism by which tea reduced mortality was through the boiling of water.

As mentioned above, it is less clear whether tea should have had a noticeable impact on the mortality rates of infants and children, since children are more susceptible to water-borne diseases and may have benefited indirectly from a lower incidence of these diseases among the tea-drinking population. At the very least, however, we should expect that the impact would likely have been less important than for adults. As shown in Table 8, the evidence here does not point to any statistically significant relationship between tea imports and either infant (under 2 years old) or child (2 to 5 years old) deaths. Estimates are also small in magnitude (-6.74 and 2.138, respectively) relative to the large average number of deaths per year for these age groups (7189 and 2038, respectively). This may reflect the possibility that infants and children were less likely to drink tea, implying they did not see as much benefit to increases in tea volumes.

6 Conclusion

Overall, evidence presented in this paper suggests that the rise of tea consumption in 18th century England had an important impact on the drop in mortality rates observed during this important period in economic development. Two identification strategies, relying on the argument that areas that had worse initial water quality levels should have experienced larger declines in mortality rates, produce estimates that support this view and are further bolstered by several robustness checks that rule out the possibility that this relationship is purely driven by rising incomes or access to trade. Additional evidence using cause of death and early childhood mortality data also support the interpretation and are consistent with the hypothesized mechanism, namely, the increased consumption in boiled water required to make tea. The fact that these results are supported by two identification strategies using different sources of variation as well as two proxies for water quality also add credence to the results. While the magnitudes of the estimates can be interpreted to suggest that tea was responsible for about 12 percent of the decline in death rates observed over this period, it is important to note that this is almost certainly underestimated because tea would have reduced mortality rates in parishes with relatively good water quality over this period as well.

Although the broader impact of tea consumption on mortality rates at the dawn of the Industrial Revolution has been hypothesized by some historians noted above, to my knowledge this paper provides the first quantitative evidence on this relationship. Consequently, the empirical relationship uncovered here makes a significant contribution to the literature on the origins of the Industrial Revolution as well as the field of economic development which has recently seen a surge in attention devoted to improvements in water quality in currently developing countries. While that literature has primarily focused on evaluations of policy interventions and randomized trials, this paper is an important exception. Here, I present a case in which water quality was improved without design or concerted intervention, but instead through a change in culture and custom that ultimately looks to have proven critical for long-run economic development.

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Table 1: Descriptive Statistics

Panel A: Parish Characteristics	Mean	Std Dev	Median	N
Parish on coast or within 10 km of coast	0.267	0.443	0	404
Distance to Nearest Market Town in 1700 (km)	4.433	3.534	4	404
Area (acres)	5750.579	5348.921	4237	394
Population Density in 1700 (Pop_Constructed_1700/Area)	1.916	19.367	0.144	394
Parish elevation (meters)	83.502	60.246	76.6166	402
ln(elevation)	4.112	0.907	4.33881	402

Panel B: Parish-year characteristics, 1700-1839	Mean	Std Dev	Median	N
Deaths (burials)	31.438	43.998	20	52516
ln(Deaths)	2.963	0.993	2.996	52516
Births (baptisms)	41.029	60.276	27	52637
ln(Births)	3.253	0.958	3.296	52637
Marriages	11.558	20.553	7	50662
ln(Marriages)	1.911	0.997	1.946	50662
Population (Constructed Measure)	1247.764	1648.759	839.614	52849
ln(Population, Constructed)	6.735	0.852	6.733	52849

Panel C: Annual Imports, 1761-1834	Mean	Std Dev	Median	N
Tea Imports, millions of pounds, lagged	18.005	11.778	17.324	74
ln(Tea), lagged	2.590	0.878	2.851	74

Table 2: The Impact of Tea Adoption on Mortality using Elevation Measure

	(1) ln(Deaths)	(2) ln(Deaths)	(3) ln(Deaths)	(4) ln(Deaths)
PostTea*ln(Elevation)	0.0194***	0.0502***	0.0227***	0.0339***
	(0.00696)	(0.0120)	(0.00774)	(0.00988)
Post1770*ln(Elevation)			0.00370	0.00961
			(0.0117)	(0.00975)
Post1760*ln(Elevation)			-0.00901	0.0121
			(0.0128)	(0.0113)
ln(Population)	0.807***		0.808***	
	(0.0440)		(0.0444)	
ln(Births)		0.287***		0.287***
		(0.0176)		(0.0175)
ln(Marriages)		0.0639***		0.0635***
		(0.00622)		(0.00622)
Parish FEs	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES
Observations	52,223	49,965	52,223	49,965

Robust standard errors clustered at parish level in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 3: The Impact of Tea Adoption on Mortality using Initial Population Density Measure

	(1) ln(Deaths)	(2) ln(Deaths)	(3) ln(Deaths)	(4) ln(Deaths)
PostTea*ln(PopDensity_1700)	-0.00730	-0.0138	-0.0165***	-0.0248***
	(0.00608)	(0.0127)	(0.00575)	(0.00910)
Post1770*ln(PopDensity_1700)			-0.000172	0.00242
			(0.00633)	(0.00602)
Post1760*ln(PopDensity_1700)			0.0132**	0.0129*
			(0.00599)	(0.00704)
ln(Population)	0.817***		0.818***	
	(0.0451)		(0.0451)	
ln(Births)		0.285***		0.286***
		(0.0182)		(0.0182)
ln(Marriages)		0.0654***		0.0653***
		(0.00655)		(0.00653)
Parish FEs	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES
Observations	51,163	48,926	51,163	48,926

Robust standard errors clustered at parish level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4: The Impact of Tea Imports on Mortality

	(1) ln(Deaths)	(2) ln(Deaths)	(3) ln(Deaths)	(4) ln(Deaths)
ln(Tea)*ln(Elevation)	0.0107***		0.0130***	
	(0.00327)		(0.00438)	
ln(Tea)*ln(PopDensity_1700)		-0.00601**		-0.0104**
		(0.00246)		(0.00404)
ln(Population)	0.720***	0.722***		
	(0.0537)	(0.0543)		
ln(Births)			0.233***	0.230***
			(0.0166)	(0.0168)
ln(Marriages)			0.0439***	0.0443***
			(0.00674)	(0.00690)
Population Control	Constructed	Constructed	Births&Marriages	Births&Marriages
Parish FEs	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES
Observations	26,745	26,199	25,986	25,446

Robust standard errors clustered at parish level in parentheses below point estimates

*** p<0.01, ** p<0.05, * p<0.1

Table 5: The Impact of Tea Imports on Mortality, Controlling for Wages

	(1) ln(Deaths)	(2) ln(Deaths)	(3) ln(Deaths)	(4) ln(Deaths)
ln(Tea)*ln(Elevation)	0.00882***		0.00936**	
	(0.00326)		(0.00417)	
ln(Tea)*ln(PopDensity_1700)		-0.00545**		-0.00918**
		(0.00236)		(0.00369)
ln(wage)	0.174***	0.169***	0.331***	0.331***
	(0.0497)	(0.0495)	(0.0658)	(0.0671)
Population Control	Constructed	Constructed	Births&Marriages	Births&Marriages
Parish FEs	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES
Observations	26,745	26,199	25,986	25,446

Robust standard errors, clustered at parish level, in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 6: The Impact of Tea Adoption on Mortality, Controlling for Wages

	(1) ln(Deaths)	(2) ln(Deaths)	(3) ln(Deaths)	(4) ln(Deaths)
PostTea*ln(Elevation)	0.0166**		0.0436***	
	(0.00700)		(0.0117)	
PostTea*ln(PopDensity_1700)		-0.00566		-0.00988
		(0.00572)		(0.0117)
ln(wage)	0.160***	0.165***	0.304***	0.329***
	(0.0380)	(0.0375)	(0.0610)	(0.0631)
Population Control	Constructed	Constructed	Births&Marriages	Births&Marriages
Parish FEs	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES
Observations	51,874	50,814	49,629	48,590

Robust standard errors, clustered at parish level, in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 7: The Impact of Tea Imports on Mortality with Additional Controls

	(1) ln(Deaths)	(2) ln(Deaths)	(3) ln(Deaths)	(4) ln(Deaths)
ln(Tea)*ln(Elevation)	0.00908**		0.0122***	
	(0.00425)		(0.00455)	
ln(MiscImports)*ln(Elevation)	0.00496		0.00737	
	(0.00660)		(0.00609)	
ln(Tea)*ln(PopDensity_1700)		-0.000801		-0.00299
		(0.00256)		(0.00319)
ln(MiscImports)*ln(PopDensity_1700)		-0.00719		-0.00987*
		(0.00458)		(0.00568)
ln(Tea)*NearCoast	-0.000552	-0.00701	0.00789	-0.00190
	(0.00717)	(0.00686)	(0.00981)	(0.00941)
ln(Tea)*DistanceToMarket	0.00269***	0.00181*	0.00399***	0.00275**
	(0.000842)	(0.000947)	(0.00122)	(0.00135)
Population Control	Constructed	Constructed	Births&Marriages	Births&Marriages
Parish FEs	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES
Observations	26,745	26,199	25,986	25,446

estimates

*** p<0.01, ** p<0.05, * p<0.1

Table 8: The Impact of Tea Imports on Cause-Specific Deaths, Infant, and Child Mortality in London

Dependent Variable: Deaths due to…

	(1)	(2)	(3)	(4)	(5)	(6)
	water-borne		non-water-borne			
	flux	bloody flux	smallpox	consumption	under 2 mortality	age 2-5 mortality
Tea (volume)	-0.282**	-0.561**	1.735	2.791	-6.473	2.138
	(0.133)	(0.264)	(6.914)	(7.473)	(8.612)	(4.391)
Observations	71	29	71	71	70	70
Mean of dep var	14.49	83.03	1487.73	3838.62	7188.50	2038.31

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Notes: Other control variables include a linear and quadratic time trend

Sources: Author's calculations based on mortality data from Marshall (1832) and tea import data from English East India Company records (Bowen 2007)

Figure 1: Smoothed annual tea imports (3 year moving average)

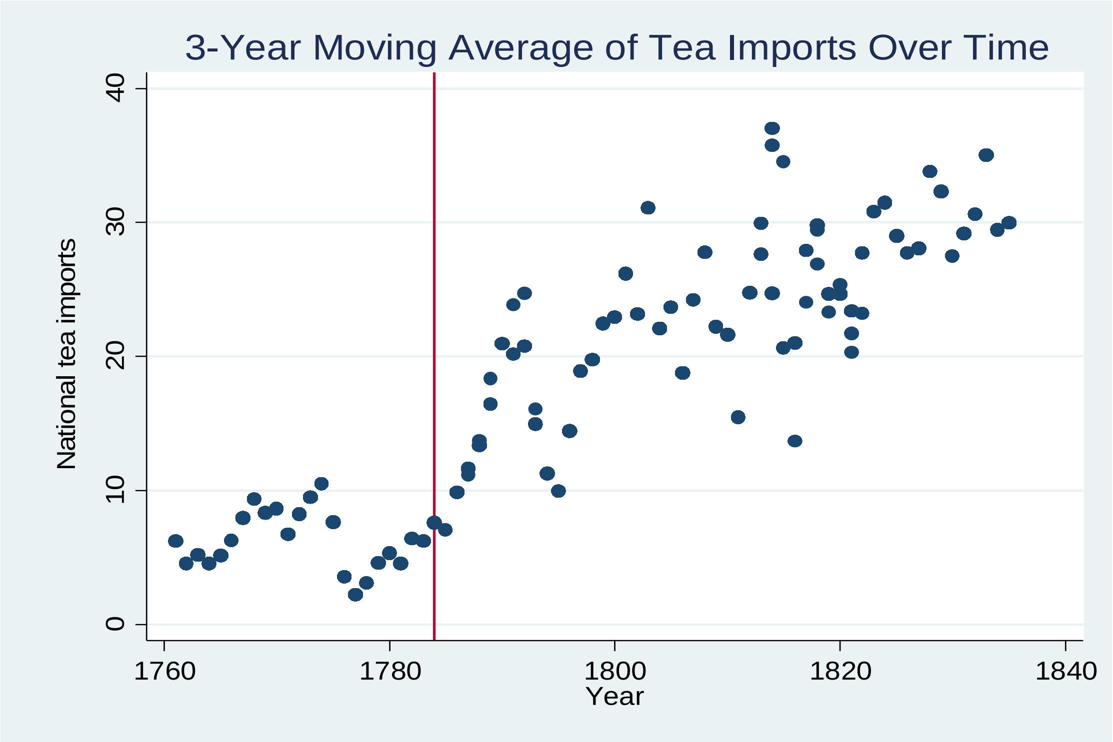
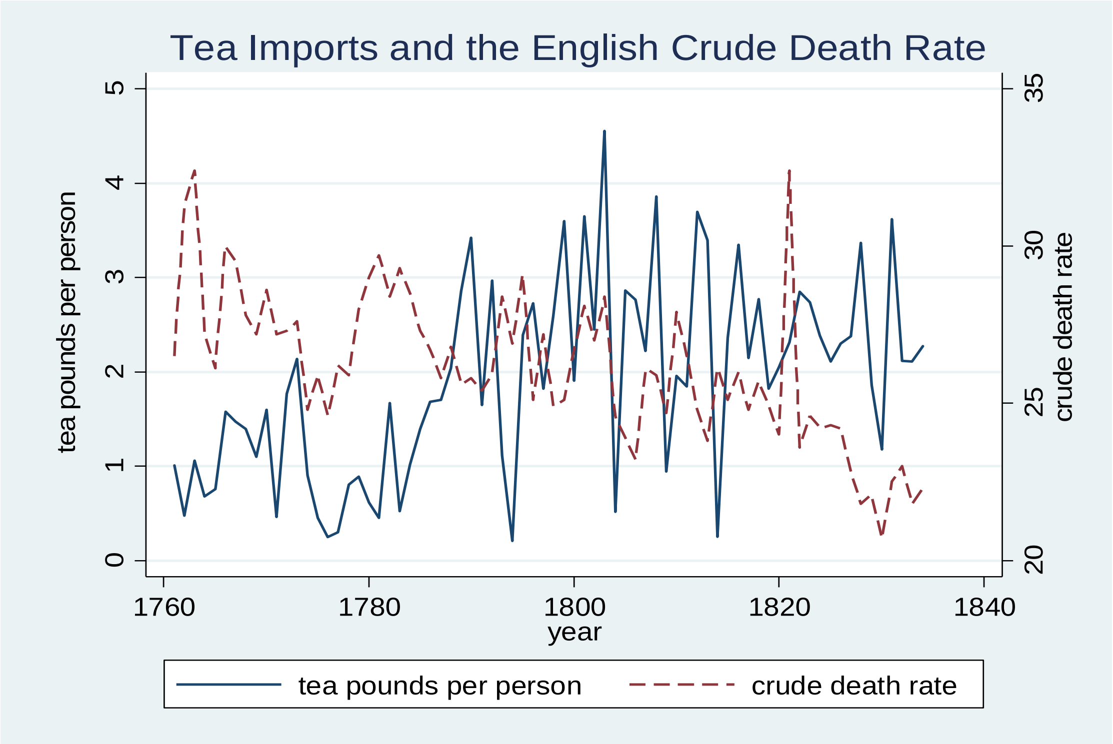


Figure 2: Tea Imports and the English Crude Death Rate



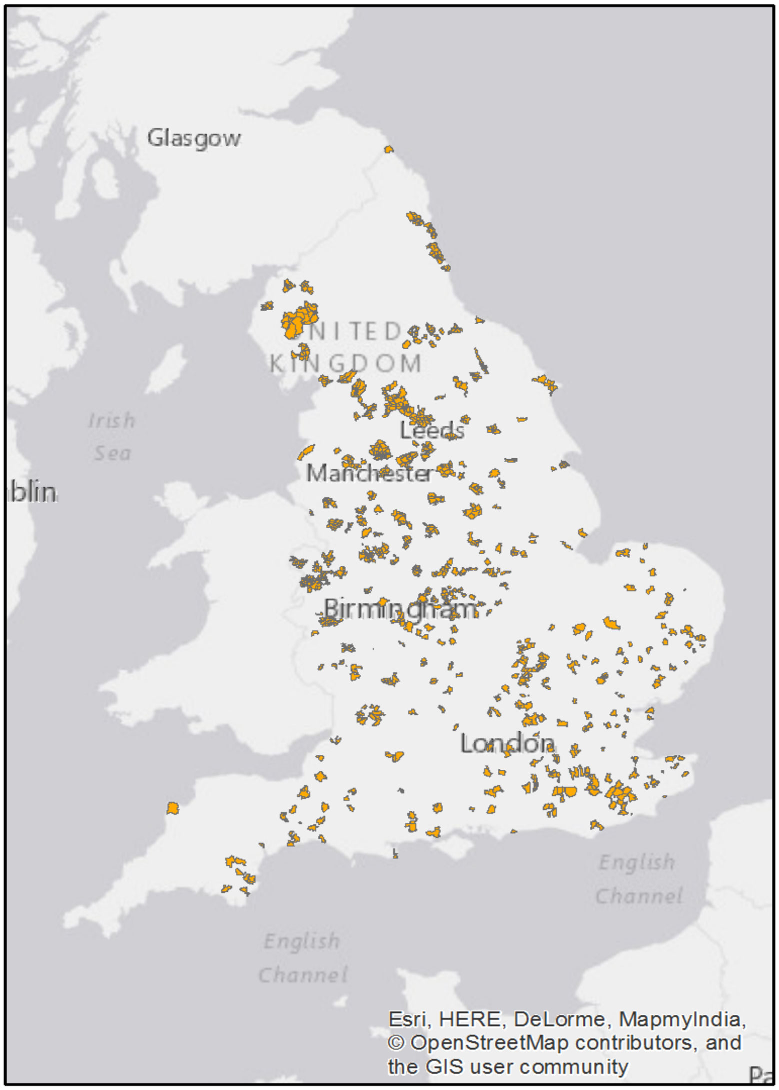


Figure 3: Parish Locations

Source: Southall, H.R. Burton, N. GIS of the Ancient Parishes of England and Wales, 1500-1850, UKDA study number: 4828.

Overlaid on ESRI Basemap of England

Figure 4: Average Parish Death Rates by Elevation and Lagged Tea Imports

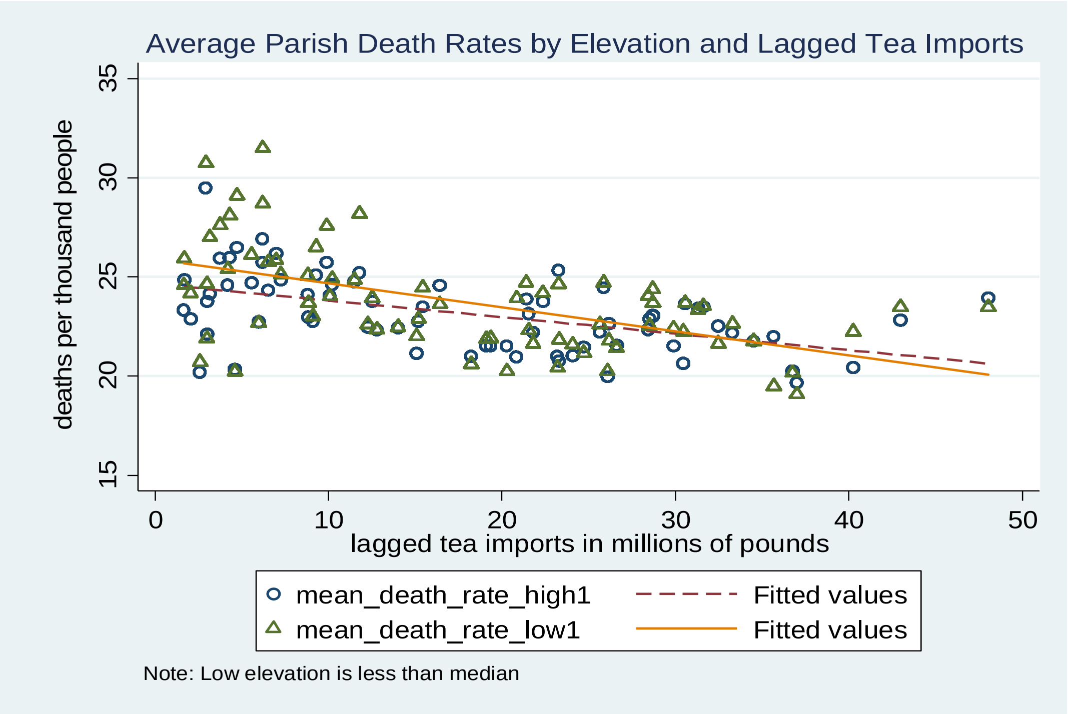
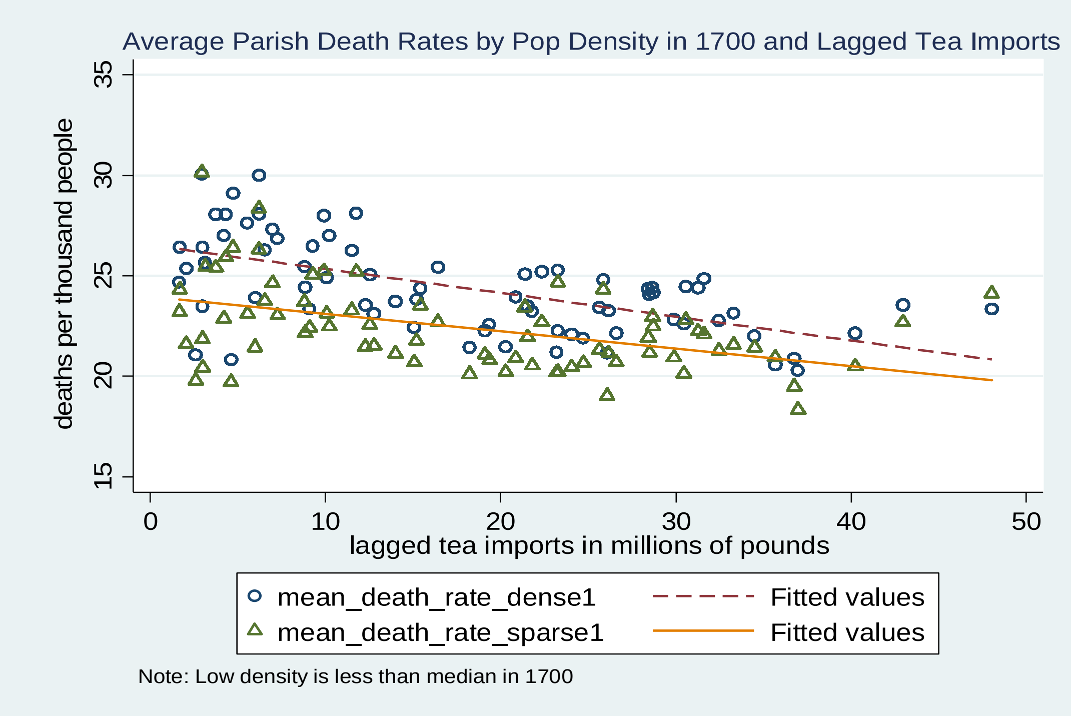
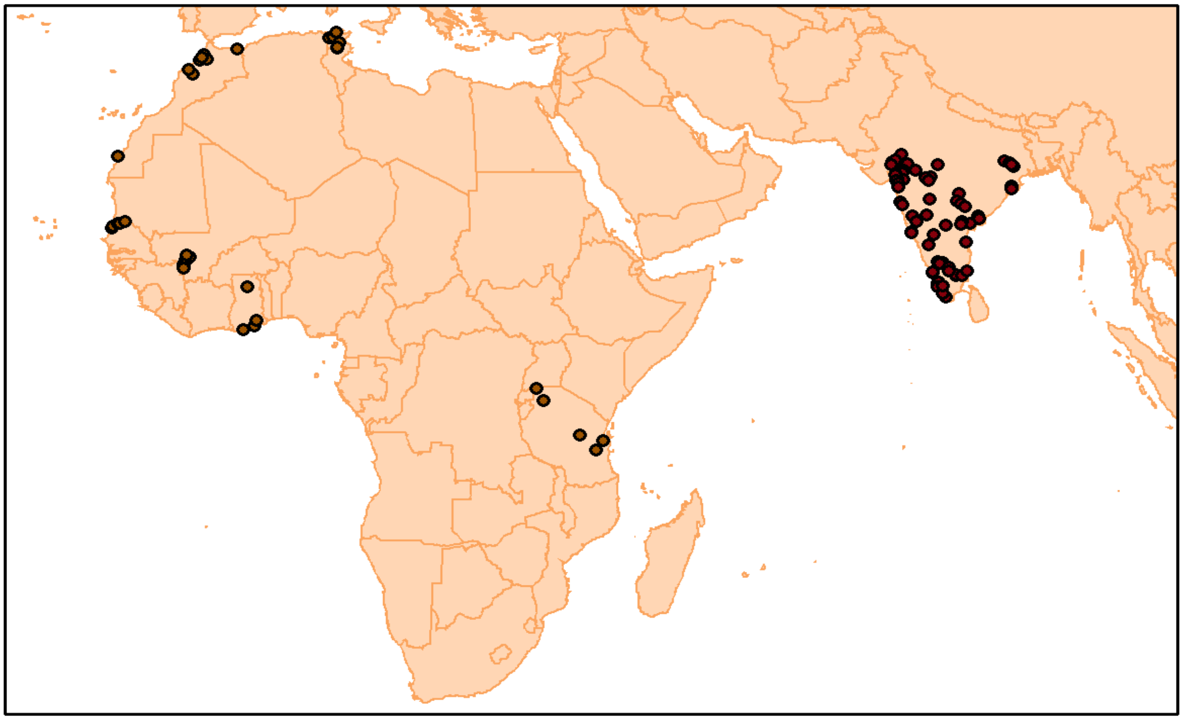


Figure 5: Average Parish Death Rates by Population Density in 1700 and Lagged Tea Imports





Appendix Figure 1: Locations of Water Quality Monitoring Sites in Africa and India

Source: United Nations Global Environment Management System Water Programme Overlaid over ESRI Generalized World Countries Map.

Appendix Table 1: Supporting Evidence for Water Quality Measures

	(1) ln(FecalColiform)	(2) ln(FecalColiform)
ln(Elevation)	-0.345**	
	(0.171)	
ln(PopulationDensity)		0.446
		(0.395)
Country FEs	YES	YES
Year FEs	YES	YES
Observations	1,008	1,008

Robust standard errors, clustered at 87 station sites in parentheses

*** p<0.01, ** p<0.05, * p<0.1