For Want of a Cup: The Rise of Tea in England and the Impact of Water Quality on Mortality [*]

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Abstract

This paper explores the impact of water quality on mortality by exploiting a natural experiment—the rise of tea consumption in 18th century England. This resulted in an unintentional increase in consumption of boiled water, thereby reducing mortality rates. The methodology uses two identification strategies tying areas with lower initial water quality to larger declines in mortality rates after tea drinking became widespread and following larger volumes of tea imports. Results are robust to the inclusion of controls for income and access to trade. The hypothesis is further bolstered by suggestive evidence from cause-specific deaths and early childhood mortality.

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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 inspired 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, Ashraf et al. 2017). 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 impacts of clean water on mortality, and thus long-run economic development. This paper adds to both the historical and development literatures 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 widespread adoption of tea drinking which began 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 aimed 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 by external authorities. In contrast, the entirety of the period examined in this paper occurs prior to the widespread acceptance of the germ theory of disease and before major public health interventions.

Another important distinction that sets this paper apart is that it concerns a change in culture and custom that occurred without any concerted policy efforts and associated expense. As such, this paper has unique lessons for current public health policymakers who might choose to focus on infrastructure that might be cost-effective in the long-run, but which may face numerous barriers to implementation along the way. Simple, less-costly technologies may be readily available and lessons on expanding the adoption of important health practices today may be drawn from this episode in history. The fact that the changes examined in this paper were ultimately brought about by international trade also connect this paper to the wider literature on innovations and technologies facilitated by the diffusion of goods and ideas across borders (Buera and Oberfield 2020), and highlight the potential health consequences of shifts in trade and consumption patterns (Nunn and Qian 2011).

Although 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. To estimate it, 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. As water quality would not have been measured during this time period when the importance of water quality was not understood, I offer two proxies for initial water quality based on geographical features of local communities and use both to independently estimate the impacts of water quality on mortality. These measures of water quality are the elevation and the number of running water sources in an area, as given by the main rivers near that location. It is their interaction with tea adoption over time that represents the key independent variable of interest. Importantly, this allows 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 aforementioned geographical proxies for water quality. Here, I investigate whether positive shocks to tea imports resulted in larger declines in mortality rates in areas where water quality was initially worse. For robustness, I again use the two measures of water quality noted above to estimate the impact of water quality on mortality and find similar results. 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 or access to trade.[1] Overall, the results from both identification strategies, using both measures of water quality, and controlling for other time-varying factors at the local level, as well as including parish and year fixed effects and parish-specific time trends, suggest that tea was associated with larger declines in mortality rates in areas that had worse water quality to begin with. 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 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. At the same time, robustness checks rule out alternative mechanisms such as any correlated trends in the prevalence of smallpox or efforts to eradicate it. Thus, 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

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[1] While a positive relationship between income and health is typically presumed today, the historical correlation is not so obvious. For example, incomes may have been higher in urban locations, but these areas may also have carried additional health risks relative to rural areas, such as those linked with higher population density and pollution. The empirical strategy will attempt to address these differences through the use of fixed effects and other control variables.

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 and offers suggestive support for the mechanism using cause-specific death and early childhood mortality data. Section 3 presents the empirical strategy including the two identification strategies described above. Section 4 describes the historical and geographic data sources brought together for purposes of this analysis. Section 5 presents the results of both empirical strategies and robustness checks. Section 6 concludes.

2 Historical Background

2.1 The Rise of Tea in 18th Century England

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). This transition was facilitated by the Tea and Windows Act of 1784 which reduced the tea tax from 119 to 12.5 percent at one stroke (Mair and Hoh 2009), an event that will be used to mark the advent of tea adoption in the first identification strategy below. Indeed, by the end of the century, historical evidence indicates that even the humblest peasant drank tea twice a day (MacFarlane 1997).

The rapid and widespread 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). 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 drink, 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, MacFarlane and MacFarlane 2003).

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 1997; Clark 1998). While there are no widespread data on beverage consumption to document this trend, the extent to which some individuals were substituting tea for beer as opposed to water would only mean that the estimates here can 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 2003). Raw milk, on the other hand, would have been contaminated with bacteria until pasteurization began around 1890 (MacFarlane 1997). 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 2003).

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). 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 1997) and John Snow 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) and actually debated the merits of tea-drinking, (Mair and Hoh 2009), all suggest that tea drinking was likely to be independent of the types of unobserved variables that might present a challenge for identification.

Nevertheless, some may point out other challenges for identification in the current study, such as the major geopolitical events that transpired during this historical period, including British military conflicts as well as the French Revolution and Napoleonic Wars which commenced in the late 18th century. The other major economic event is of course the Industrial Revolution which was also advancing in this time period and which might represent both a cause and effect of the improved health brought about by the advent of tea consumption. Thus, some may be concerned that together these significant events might have impacted mortality rates in England and disrupted international trade (Juhász 2018) in such a way as to drive the results seen here. To address these challenges, the empirical strategy offers multiples sources of identifying variation, using both timing of the drop in the tea tariff and tea shipments, as well as two sources of water quality measures.[2] With regard to the latter, some might be concerned that proximity to streams may be correlated with water power determining industrial strength (Crafts and Wolf 2014), thus elevation is offered as an alternative, and controls for market access and real wages are subsequently incorporated into the analysis. Note also that if a higher number of water sources were simply a proxy for higher income, we would expect to see the opposite results to those shown here in which areas with lower water quality actually see the greatest health benefits with the introduction of tea.[3] Finally, it is important to note that any demographic, political, and socioeconomic changes that were common across parishes in a given year or within parishes across time would be accounted for by regression fixed effects at the year and parish levels. Moreover, the identification strategy leveraging interactions between variation in parish water quality measures and proxies for tea consumption suggest that alternative explanations stemming solely from other events in this time period are not likely to fully explain the pattern of results below.

While some might be concerned that the relationship between tea and mortality over this

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[2] An additional robustness check limits the sample period to observations prior to 1800 which would also address concerns over confounding events in the early 19th century, such as the Napoleonic Wars (Juhász 2018).

[3] This discussion presumes that the regression model has adequately controlled for other factors associated with income that might also affect health, such as those related to the urbanicity of the parish environment, through the use of parish fixed effects, parish-specific time trends, and other control variables.

period is actually driven by rising wages, it should also be noted that there is considerable evidence to suggest that although English wages were high relative to other countries, they rose very little over this period (Allen 2009). 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 (Stevenson 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). 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 rates 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).

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...."

2.2 Suggestive Evidence of a Link between Tea and Mortality

Aggregate statistics at the national level provide suggestive evidence to support these claims and are provided in the Online Appendix. Figure 1 of the Online Appendix matches data on English tea imports from China and the English crude death rate over the 1761-1834 period, distinguished by the 1785 drop in the tea tariff discussed above. Online Appendix Figure 1A documents a dramatic increase in tea imports per person from around 1 pound per person at the beginning of this period to almost 3 pounds per person by the end. The jump in imports around 1785 is clearly evident by comparing the linear projection over the pre- and post-adoption periods. Over the same period, the English crude death rate fell from around 28 to 23 deaths per 1,000 people, a decline that appears to have accelerated after 1785 (Online Appendix Figure 1B). Thus, the national picture over this critical period in the development of England, prior to the documented link between water and disease, is marked by a dramatic rise in tea consumption and drop in mortality rates.

To further bolster the evidence that the mechanism behind these relationships was the improvement in water quality brought about by water boiled for tea, I 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). 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. Thus, the simple relationship between tea and water-borne diseases is graphed in Online Appendix Figure 2A, which shows a scatterplot of ln London deaths from flux and ln tea pounds per person. The linear regression linking the two shows a negative, statistically significant relationship (coefficient estimate -.354, standard error .144), thus supporting the link between tea and water-borne diseases. 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 (consumption) in Online Appendix Figure 2B (coefficient estimate .007, standard error .016).

As an extension, I also use data on infant and early childhood mortality (deaths under age 2 and deaths between ages 2 and 5, respectively) from London available in Marshall (1832) to explore whether infant and early childhood deaths can be linked to variation in tea consumption.[4] In the context of childhood deaths, however, it is important to note that although infants and young children would have been less likely to consume tea, infants especially would be more sensitive to water-borne diseases in the environment, and thus may have indirectly benefited from a lower incidence of these diseases among the tea-drinking population (MacFarlane 1997). However, one might expect that the impact of tea drinking

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[4] While these graphs are only meant to be suggestive of correlations in the unadulterated summary statistics, both the Augmented Dickey-Fuller and Philips-Perron tests suggest we can reject the null of non-stationary series at the 5% level in all cases.

may have been more muted for these young groups, who were not likely to be avid tea drinkers. Indeed, the simple linear regression of ln infant deaths on ln tea imports in Online Appendix Figure 2C shows a negative relationship that is statistically significant, but with a coefficient that is smaller in magnitude (-.107, standard error .025). At the same time, Online Appendix Figure 2D shows that we cannot rule out the hypothesis that tea had no effect on mortality for young children ages 2 to 5 (coefficient estimate -.038, standard error .043).

These patterns are consistent with the notion that the special relationship between tea and mortality did not run through some other economic or demographic explanation that would have benefited everyone equally in the population, but instead benefited consumers of boiled water for tea in particular. Thus, data from London provide suggestive support for the link between the rise of tea and the drop in mortality, as well as the causal mechanism through boiled water. The remainder of the paper links exogenous sources of variation and proxies for water quality at a sub-national level to establish a causal link between tea and mortality.

3 Empirical Methods

3.1 First Identification Strategy

To measure the effect of tea drinking on mortality rates in England, I begin by dividing the sample into high and low water quality areas, based on geographical features to be discussed in Section 4. For simplicity, I divide the sample based on whether the parish was in the top or bottom fifty percent of the distribution of these features, and subsequently compare mortality across areas that varied in initial water quality before and after tea consumption became popular.[5] This is estimated via the following regression model:

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\begin{aligned}
Deaths_{it} = & \sum_{k=-5,k\neq 0}^{5} \pi_k (LoWaterQuality_i \times TimePd_{kt}) + \\
& + \sum_{k=-5,k\neq 0}^{5} \gamma_k (HiWaterQuality_i \times TimePd_{kt}) + X_{it}\beta + \mu_i + \delta_t + \psi_i t + \varepsilon_{it} \ , \quad (1)
\end{aligned}
$$

where the dependent variable is the natural log of the number of deaths in parish i in year t.[6] The independent variables of interest, $(LoWaterQuality_i \times TimePd_{kt})$ and $(HiWaterQuality_i \times TimePd_{kt})$ measure the interaction between the initial water quality in parish i and a dummy variable indicating the time period, where the time periods have been divided into five ten-year periods before and after the widespread adoption of tea as a national beverage ($k = 0$). Thus, the period immediately prior to the drop in the tea levy has been omitted as the reference category ($k = 0$). 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 Windows Act of 1784 which reduced the tea tax from 119 to 12.5 percent at one stroke (Mair and Hoh 2009). This is further supported by Online Appendix Figure 1A which shows national tea imports

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[5] An earlier version of this paper reported qualitatively similar results using an interaction model where a continuous measure of the water quality measure was used, as opposed to an indicator for above or below median water quality. This was replaced with the model used here that allows for a straight-forward graphical representation of results over time.

[6] Using the natural log of the dependent variable simplifies the interpretation and reduces the influence of outliers, but as will be shown below, does not qualitatively affect the results.

rising over time and a substantial rise in tea imports occurring after 1785. As five 10-year intervals are included in the specification to check for the existence of any pre-existing trends in mortality rates across parishes, the sample used in this analysis ranges from 1725 to 1834.

All regressions include parish fixed effects (μ_i) which control for all time-invariant factors at the parish level such as persistent geographical features of the parishes themselves. Importantly, this will absorb any correlation between parish water quality and parish deaths that is fixed over time, and thus mitigate concerns that the coefficient of interest is driven by factors purely correlated with the water quality measures. 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 events common to all parishes such as wars or other wide-spread conflicts such as the French Revolution and Napoleonic Wars.[7] X_{it} includes controls for other parish characteristics that vary over time, such as the population measures discussed below. Finally, a parish-specific time trend, ($\psi_i t$) is included to account for any other smooth changes in economic, demographic, or health-related changes at the parish-level.[8] As some may argue that the inclusion of such a control may also absorb some of the actual impact of tea, the resulting estimates can thus be thought of as conservative estimates of

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[7] There are 404 parishes and each parish is observed repeatedly before and after the Tea and Windows Act.

[8] The inclusion of parish-specific time trends may also stem concerns over data quality related to the rise of nonconformity and associated under-registration of vital events in the ecclesiastical records which Schofield and Hinde (2020) argue took place gradually over time, but potentially at different rates across parishes. Nevertheless, difference-in-differences results comparing low and high water quality areas are substantially similar without the parish-specific time trends and can be found in the Online Appendix.

the impact of tea on mortality. Standard errors are clustered at the parish level.[9]

3.2 Second Identification Strategy

To provide further evidence of the impact of tea consumption 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:

$$\begin{aligned} Deaths_{it} &= \theta_1(LoWaterQuality_i \times TeaImp_{t-1}) + \theta_2(HiWaterQuality_i \times TeaImp_{t-1}) + \\ &\quad + X_{it}\beta + \mu_i + \delta_t + \psi_i t + \varepsilon_{it} \ , \qquad (2) \end{aligned}$$

where the independent variables of interest, *LoWaterQaulity* $\times$ *TeaImp*$_{t-1}$ and *HiWaterQaulity* $\times$ *TeaImp*$_{t-1}$, represent the interaction terms between indicators for low and high initial water quality, respectively, 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.[10] All remaining variables are as

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[9] To address spatial correlation concerns raised in Kelly (2019), I have checked for autocorrelation in regression residuals of all four of the main regression models in the paper using the spatwmat command in Stata to create a weighting matrix measuring the inverse of the distance between each pair of parishes in the data set. I set the bandsize to the maximum Euclidean distance and then calculated Moran's I for the residuals from each of the regressions, averaged within parishes, using the spatgsa command in Stata with the Moran option. The p values from this test range from 0.37 to 0.44 across the four main regression models, suggesting that we can safely fail to reject the null of zero spatial autocorrelation of the residuals at conventional levels.

[10] Since tea is relatively lightweight and durable over a short period of time, it is reasonable to expect that it would have reached the end user in this time frame, and thus that geographical distribution and consumption of tea would have occurred within that year. At the very least, the analysis would require

specified above, where again year fixed effects, parish fixed effects, and parish-specific time trends provide important means of controlling for unobservables that otherwise might bias the coefficient of interest.[11] Since tea import data are only available for the years 1761-1834, the analysis sample for purposes of estimating Equation (2) is limited to those years.

As discussed above, the raw relationship between tea imports and mortality rates is documented in Online Appendix Figure 1 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 or transportation delays on the high seas, 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

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that any differences in rates of diffusion across time or parishes are captured by the regression fixed effects, parish-specific time trends, or by the subsequent control variables such as market access included in the specifications below. In particular, note that these elements would address any variation in transportation costs across parishes over time, such as those associated with waterways or elevation, which might otherwise confound the coefficient of interest.

[11] As discussed below the prior specification, standard errors are clustered at the parish level and residuals show no evidence of spatial autocorrelation. Difference-in-differences results comparing low and high water quality areas are also very similar without the parish-specific time trends and can be found in the Online Appendix.

goods. This adds weight to the causal interpretation for the special role that tea played in decreasing mortality.

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 from the mid-16th to mid-19th centuries. Going this far back in time, it should be noted that these series are not without complications.[12] Wrigley and Schofield (1981) address data quality issues such as their representativeness for England as a whole and correct the data series for a rise in nonconformity that would result in fewer vital events being recorded with the church as one moves forward in time. Nonetheless, concerns have also been raised about the adjustment factors themselves (Lindert 1983) and our relatively limited knowledge of internal migration across these parishes over time may raise related concerns. In response to all of these points, it should be noted that any fixed differences in data quality across parishes or across time would be captured by the regression fixed effects just as any smooth demographic changes across parishes over time, whether occurring naturally in the parishes themselves, or in the correction factors incorporated by the authors of the data set, are likely to be subsumed in the parish-specific time trend. Schofield and Hinde (2020) argue that despite data quality issues with the parish records, they can still

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[12] Also noteworthy is the fact that studies are increasingly using population data over similar time periods or even further back in history (e.g. Beach and Hanlon 2018; Nunn and Qian 2011).

be used to analyze relatively short-run fluctuations across parishes, which could describe the identification strategy linking shocks to tea imports with excess mortality across parishes. Moreover, as the subject of this paper focuses squarely on the link between mortality, tea, and water quality, and exploits several different sources of variation including elevation, water sources, and trade data in the analysis, it is unlikely that data quality issues alone are sufficient to explain away all of the pieces of evidence presented here.

As tea import data are only available between 1761-1834, the sample used in the second empirical strategy is focused on those years. However, to establish that there were no pre-existing trends in mortality rates prior to the advent of tea consumption, the sample used in the first empirical strategy is expanded to include the years 1725-1834.[13] While Wrigley and Schofield (1981) use the collection of parish records 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:

$$\begin{aligned} Population_{it} &= 0.4 \times \frac{smooth(Baptisms_{\overline{it-20}})}{0.03} + 0.4 \times \frac{smooth(Burials_{\overline{it-20}})}{0.025} + \\ &\quad +0.2 \times \frac{smooth(Marriages_{\overline{it-20}})}{0.008}, \end{aligned} \tag{3}$$

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

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[13] Earlier versions of this paper used mortality data beginning in 1700 in the first identification stratgey with qualitatively similar results.

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 robustness, 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, and find that they are very similar to those using the constructed parish-level population measure.[14]

4.2 Water Quality Measures

The primary water quality measure used in the analysis is the number of water sources within 3 km of the parish, as 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).[15] It is expected that parishes with a higher number of rivers proximate to the parish would have benefited from greater availability of running water, and thus would have benefited from relatively cleaner water compared with those parishes which were limited to only a few sources and thus suffered from a greater likelihood of contamination. This would be consistent with historical accounts

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[14] The use of the alternative population controls and controlling for them on the right-hand side also addresses concerns that population may be mismeasured due to migration between parishes, and thus may lead to a skewed perception of the death rate if relying solely on one measure. An earlier version of this paper also presented estimates using a control for marriages alone as a proxy for the population and found substantially similar results.

[15] Main rivers are typically larger rivers and streams, designated by the UK Environment Agency to manage flood risk. The 3 km distance reflects the average distance traveled to collect water in the developing world (Ure 2011).

documenting the link between the availability of water and public health as well as the challenges of obtaining sufficient water for the population (Pyke 1966; Buer 1926; MacFarlane 1997). While the analysis will attempt to control for the extent to which commerce and economic opportunities vary across parishes, some may still be concerned about omitted variable bias due to a positive correlation between water power and industrial strength (Crafts and Wolf 2014) for example, which may drive higher incomes.[16] However, note that any such correlations would run counter to the anticipated results, i.e., these would generate a bias against finding that low water quality parishes, as measured by number of water sources, would have generated health improvements after tea was introduced and when tea imports were relatively high. A map of parish locations by the number of water sources is provided in Online Appendix Figure 3A, which shows that parishes with more and fewer rivers are dispersed throughout England.

An alternative water quality proxy, the average elevation within a parish, is also offered to show that the relationship between tea and mortality is robust to alternative measures of water quality.[17] Elevation is believed to be positively correlated with water quality

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[16] Of course, higher incomes, particularly those tied to industrial strength, may also have been associated with greater health risks during this period, such as those driven by pollution and higher population density in urban centers. This discussion presumes that the regression model has adequately controlled for such factors through the use of parish fixed effects, parish-specific time trends, and other control variables.

[17] Earlier versions of this paper used additional water quality proxies for robustness. Specifically, initial population density was used as an alternative measure of water quality, relying on the argument that population density would have been inversely correlated with water quality due to contamination from human waste. Using this measure produced results that were qualitatively similar to those presented here, however, as population density, even when measured at the beginning of the period, may be argued to be endogenous, this version now focuses on arguably more exogenous sources of variation in water quality stemming from

because parishes at higher elevation would have been less likely to be subjected to water contamination from surrounding areas. Additional suggestive evidence of the link between water quality and elevation is offered by Wrigley and Schofield (1981, Appendix 10). There, they analyze the seasonal pattern of local mortality crises across parishes over time and find peaks during the late summer and early fall months, known to be the classic season of epidemic diarrheal infections, such as dysentery. Moreover, they show that higher altitude was negatively related to local mortality crises, thus establishing the link between waterborne diseases and elevation which I exploit here. The specific measures of the average elevation (in meters) in the parish used in the analysis are constructed from Shuttle Radar Topography images (Jarvis et al. 2008) based on historical parish boundaries (Burton et. al. 2004; Southall and Burton 2004). A map of parish locations by elevation is provided in Online Appendix Figure 3B, which shows that high and low elevation parishes are also spread throughout England.

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geographic differences across parishes. An earlier version of this paper also used average slope as an alternative water quality proxy, under the hypothesis that water would have been less likely to pool in steeper parishes and thus steeper parishes would have had better water quality than parishes that were relatively flat. Results were consistent with this hypothesis, however, as slope and elevation are closely related, including both arguably does not add much to the analysis. In ancillary studies using modern-day data on fecal coliform, slope, and elevation, in developing countries, an earlier version of this paper also found greater support for the use of elevation as a measure of water quality versus slope, but these results are not included here, as the modern-day setting, in which populations are well aware of the importance of water quality, may not translate well to the historical setting. Thus, the focus on elevation and the number of running water sources used in the current paper.

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 nuanced empirical strategy discussed above. Online Appendix Figure 1A shows a dramatic rise in tea imports from China over the years 1761-1834, going from around 1 pound per person at the beginning of this period to almost 3 pounds per person by the end.[18] At the national level, there is a clear negative correlation between tea imports and mortality rates (available in Wrigley and Schofield 1981), which is illustrated in Online Appendix Figure 1. Over this period, mortality rates fell from around 28 to about 23 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 of the Online Appendix 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: number of water sources (main rivers) and parish elevation. As seen in the table, the number of water sources available to parishes was generally high and varied considerably across parishes (mean 15, standard deviation 26). The average elevation (meters) in contrast, is relatively low, with less variability (mean 83, standard deviation 60).

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[18] 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 2009). Consequently, this measure should be regarded as a close approximation to the national imports of tea.

Thus, the extent to which the results are supported by these two alternative measures of water quality can be seen as robust evidence of a relationship between tea and mortality. Online Appendix Table 1, Panel B describes the demographic data that vary over time which are used in the first identification strategy over the years 1725-1834. The average deaths per parish over the entire period is about 33 and the constructed measure of population is about 1344. Finally, Online Appendix 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, showing lagged tea imports of about 17.8 million pounds per year over this period.

Table 2 of the Online Appendix provides a standard difference-in-differences view of the spirit of the first identification strategy with summary statistics. There we see that, without accounting for any population controls or time trends, the difference-in-differences estimate averaging over the pre-and post- tea periods already suggests that there was a bigger decline in the natural log of mortality in areas with lower water quality relative to areas with higher water quality.[19] This effect is strong and statistically significant at the 1% level regardless of whether the specification uses ln(deaths) at the parish level (Panel A) or number of deaths in the parish (Panel B), and whether the water quality proxy is based on the number of water sources or the parish elevation. Thus, the decline in mortality over time appears to be clearly linked with the water quality measures, and suggests a steep fall in low versus

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[19] More specifically, Table 2 of the Online Appendix shows that deaths are rising in both high and low water quality parishes over this period, but they are rising more in high water quality areas. As we know the national crude death rate falls over this period (Online Appendix Figure 1B), the rise in mortality seen in Online Appendix Table 2 likely reflects increases in population across parishes which are not accounted for in the table, but will be controlled for in the regression analysis below.

high water quality areas after the dramatic drop in the tea tax. Adding controls for parish population and other economic variables and time trends, as part of the regression analysis below, will help yield a more precise estimate of this robust relationship. Showing a lack of pre-existing trends and exploiting variation in actual tea imports will also help bolster the causal interpretation for the suggestive results discussed here.

5 Results

5.1 First Identification Strategy

The main results of the first identification strategy relying on the interaction between parish water quality measures and an event study of the pre- and post-tea drinking era are presented graphically. Specifically, the coefficients of interest for low and high water quality parishes (π_k and γ_k, respectively) from equation (1) are overlaid for ease of comparison in Figure 1, Panel A, which uses the number of parish water sources as the measure of water quality. As discussed above, the post-tea drinking period follows the dramatic drop in the tea tariff in 1785 as part of the Tea and Windows Act. In Panel A of Figure 1, the constructed population measure is used as a control and, for robustness, births and marriages are used as the population controls in Panel B. In Panels A1 and B1, graphing just the estimates for low and high water quality interacted with the time period indicators, we see that the coefficient estimates for both low and high water quality parishes hover around zero prior to the advent of tea consumption in 1785. More importantly, the difference between low and high water quality parishes ($\pi_k - \gamma_k$) prior to 1785 (graphed in Panels A2 and B2) suggests no pre-existing difference, with confidence intervals that generally include zero. This provides support for the parallel trends assumption underlying the identification strategy that requires the treated and comparison groups to 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, and the results from Figure 1 suggest that this was in fact the case with the event at the heart of the first empirical strategy.

After the drop in the tea tax, however, Figure 1 Panel A1 shows that high and low water quality parishes follow different trends, with mortality rates in higher water quality parishes dropping slightly, but mortality in lower water quality parishes dropping much more. This is consistent with the hypothesis that boiling water for tea constituted an improvement in water quality that disproportionately affected low water quality areas. That is to say, higher water quality areas, especially measured as they are here by the arbitrary above-median-number of water sources distinction, may have experienced positive health benefits and commensurate lower levels of mortality as a result of tea drinking, but lower water quality areas benefited more, as demonstrated by an even bigger drop in mortality rates after the advent of tea drinking. All estimates are also statistically significant at the 1% level, suggesting the high degree of confidence in these results.

The strong link between the rise of tea consumption and declines in mortality rates becomes especially clear in the graphs on the right of Figure 1, which graph the difference in the coefficient estimates between low and high water quality parishes ($\pi_k - \gamma_k$), using the constructed population control (Panel A2) as well as the births and marriages control (Panel B2). There, it is abundantly clear that the difference between low and high water quality parishes hovers close to zero in the pre-1785 period and moves distinctly below zero in the post-1785 period. It is also noteworthy that the difference across low and high water quality parishes grows over time in the post-1785 period, which would be consistent with an increased diffusion of the cultural practice of tea drinking and thus boiling water. With regard to the magnitudes of the impact of tea drinking on mortality, the estimates suggest that areas with worse water quality saw yearly mortality rates drops by about 18% by the end of the period, relative to parishes with better water quality (Panel A2). Put differently, tea drinking was responsible for a drop in mortality rates of roughly 25% by the end of the period in low water quality areas, while they dropped by a more modest 7% in better water quality parishes (Panel A1). Panel B of Figure 1 estimates the same relationships as Figure 1, Panel A, but controls for births and marriages instead of the constructed population measure. Thus, it can be regarded as a robustness check on the use of the latter as a control. As can be seen from the figure, there is little difference between the estimates across the two panels, and thus the resulting difference-in-differences estimate of the impact of tea on mortality (about 19% in Panel B2) is very close to that obtained with the constructed population measure from above.

Figure 2 repeats the analysis using the average parish elevation as the measure of water quality to show that the relationship between tea and mortality is robust to alternative measures of water quality. Again, the coefficient of interest for low and high water quality parishes (π_k and γ_k) show similar patterns, and again suggest a decline in mortality for high and low water quality parishes, but a steeper decline after the drop in the tea tax in parishes with relatively worse water quality, regardless of whether the constructed population measure or births and marriages are used as controls (Panel A or B). These estimates are negative and generally statistically significant in both high and low water quality parishes in the post-tea tax period. The estimates in low and high water quality parishes also move very closely together in the pre- period, only to diverge in post- period. This is more readily apparent when the difference is graphed in Figures 2A2 and 2B2 where we can see that the confidence interval on the difference in coefficient estimates ($\pi_k - \gamma_k$) includes zero in the pre- period and goes below zero in the post- period. Nevertheless, while the estimates in Panels A1 and B1 show statistically significant impacts on mortality in both high and low-water quality parishes after 1785, the difference in these estimates (Panels A2 and B2) are always negative in the post-period, but only statistically significant in the two decades following the drop in the tea tax. Thus, these estimates are strongly supportive of the tea-mortality relationship described above, but the use of elevation as a water quality proxy appears to yield more imprecise estimates than those in Figure 1, which may be due to its relative strength as a water quality proxy.[20] Nevertheless, the evidence from Figures 1 and 2 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 saw greater declines in mortality after tea drinking became widespread in 1785.

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[20] In additional results not reported here, I have limited the sample to the bottom 25% of parishes as measured by both number of water sources and elevation and compared these to the top 25% of parishes on the same measure. As expected, estimates form this more extreme comparison in what one might expect are the tails of the distribution of water quality, yields negative estimates of the impact of tea on mortality that are higher in magnitude than those seen here, but the estimates are also noisier, and thus not presented here.

5.2 Second Identification Strategy

Table 1 present the main results using the second identification strategy leveraging variation in actual tea imports (equation 2), and linking them with both measures of water quality (columns 1 and 2) and both sets of population controls (Panels A and B). The coefficients on the interaction terms between water quality and lagged tea imports suggest the same pattern that was observed in Figures 1 and 2. Namely, in periods following larger imports of tea, parishes with high and low water quality levels both saw a reduction in mortality rates, but parishes with worse water quality saw a bigger decline. Moreover, the estimates from Table 1 suggest that these estimated impacts are strong and statistically significant at the 1% level, regardless of whether the parish's number of water sources or elevation is used as the measure of water quality.

Specifically, when using the number of water sources as the measure of water quality, coefficient estimates (standard errors) are -.173 (.022) in low water quality areas and -.159 (.021) in high water quality areas (Panel A, column 2), suggesting that a given increase in tea volume would have about a 1.4% bigger decline in mortality rates in low water quality areas relative to high water quality areas. The estimates from Panel A are very similar if elevation is used as the water quality proxy, -.154 (.021) in low water quality areas and -.140 (.022), and produce the same difference-in-differences estimate, -.014 (.006). The difference-in-differences estimate of an increase in tea imports on mortality in low versus high water quality areas is also essentially unchanged if births and marriages are used as the population control instead of the constructed population measure in Panel B: -.014(.006) if the number of water sources is the water quality proxy and -.015(.006) if elevation is the water quality proxy.

5.3 Robustness and Threats to Identification

While the lack of pre-existing trends discussed above lends support to the first identification strategy, the major threat to identification that remains is the possibility that there was some non-tea intervention that reduced mortality more in parishes with lower water quality relative to those with higher water quality. The fact that the pattern is robust to two alternative water quality proxies (based on the number of water sources and elevation) should assuage some of these concerns. Additionally, the second identification strategy based on variation in tea imports should also mitigate doubts that there was some other important event or intervention that coincided with the drop in the tea tariff in 1785 that is actually driving the results from the first identification strategy.

Nevertheless, one alternative hypothesis for such an intervention might be the discovery and dissemination of the smallpox vaccine around the turn of the 19th century. To address this competing explanation, I experiment with two approaches.[21] The first approach estimates equation (2) after dropping all post-1800 observations, to focus on the sample prior to the smallpox intervention.[22] These are presented in Table 2, Panel A, which shows that the difference-in-differences estimate is slightly smaller in magnitude, but still negative for both measures of water quality, and statistically significant at the 5% level when elevation is used as the water quality proxy (coefficient estimate -.020, standard error .009). Alternatively,

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[21] Thanks to an anonymous referee for suggsting these two approaches.

[22] Note that this robustness check should also address concerns that the results are somehow driven by events in the early 19th century, such as the Napoleonic Wars (Juhász 2018).

Table 2, Panel B uses the full sample but controls explicitly for the smallpox deathrate, available for London from Creighton (1894).[23] As can be seen from the table, the coefficient on the London smallpox death rate is not statistically significant when either number of water sources or elevation is used as the water quality measure, and the difference-in-differences estimate of the impact of tea on mortality rates in low versus high water quality parishes is unchanged from the main results (coefficient estimate -.014, standard error .006). Thus, we can conclude that the natural experiment measuring the impact of tea on mortality is not affected by variation in any smallpox intervention.

Another concern with the causal interpretation of this exercise 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 along with parish-specific time trends, mitigates 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.

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[23] The data are available in tabular form, and also include deaths from all causes in London, so that the control is ln (deaths due to small pox in London/all deaths in London) per year.

The results from the second identification strategy (equation 2) after controlling for wages can be found in Table 3, for both measures of water quality. For brevity, only the results with the constructed population measure are presented here. Somewhat paradoxically, the coefficient on wages is positive, but statistically insignificant, 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 from equation (2) and here we see that the coefficients are similar to those from Table 1, and are all still statistically significant at the 1 percent level. Whether number of water sources or elevation is used as the measure of water quality, the impact of a given increase in tea imports results in a larger decline in mortality in low water quality areas versus high water quality areas, and result in a difference-in-differences estimate of -.014 (.006) (columns 1 and 2).

To further address concerns that the measures of water quality might be 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 that these changes had a differential impact on mortality across different types of parishes. To rule this out, I make use of the East India Company's records on other (miscellaneous) imports, interact them with the measures of water quality, and control for this interaction.

Columns (3) and (4) of Table 3 report the results from these robustness regressions. None of the additional controls are statistically significant and all corresponding coefficients are close to zero. Moreover, the magnitudes of the coefficients of interest on the tea imports interacted with the water quality indicators fall slightly, but are still statistically significant at the 10% or 5% levels. More importantly, the inclusion of these additional controls does not substantially affect the pattern of results showing that a given increase in tea leads to a bigger drop in mortality in low water quality parishes versus higher water quality parishes. The difference in the impact of tea across the areas is very close to prior estimates, -.013 (.007) in column 3 and -.014 (.006) in column 4, and is statistically significant at the 5% level if the water quality is measured with number of water sources and statistically significant at the 10% level if water quality is measured with elevation.

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 global economic development. Two identification strategies, both relying on the argument that areas with worse water quality should experience greater health benefits from improved drinking water, but using different sources of underlying variation, produce estimates that support this view. They are also bolstered by the use of two alternative proxies for water quality, and several robustness checks that rule out the possibility that this relationship is purely driven by rising incomes, access to trade, or alternative interventions. 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 of boiled water required to make tea. The fact that the results remain relatively stable using different sources of variation as well as two proxies for water quality also adds credibility to the results. While the magnitudes of the estimates can be interpreted to suggest that a given increase in tea consumption reduced mortality by about 1.4% more in low water quality areas relative to high water quality areas over this period, it is important to note that this is certainly an underestimate of the impact of improvements in water quality on mortality because tea clearly 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, 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 the literature has primarily focused on evaluations of large-scale policy interventions and randomized controlled trials, this paper presents an important exception. In this case water quality was improved without design or costly concerted intervention, but instead through a change in culture and custom that ultimately looks to have proven critical for long-run economic development. As such, current public health policymakers may yet draw lessons from this episode in history as to the most cost-effective strategies for improving health in areas where changes to infrastructure or the adoption of new technologies might not be feasible.

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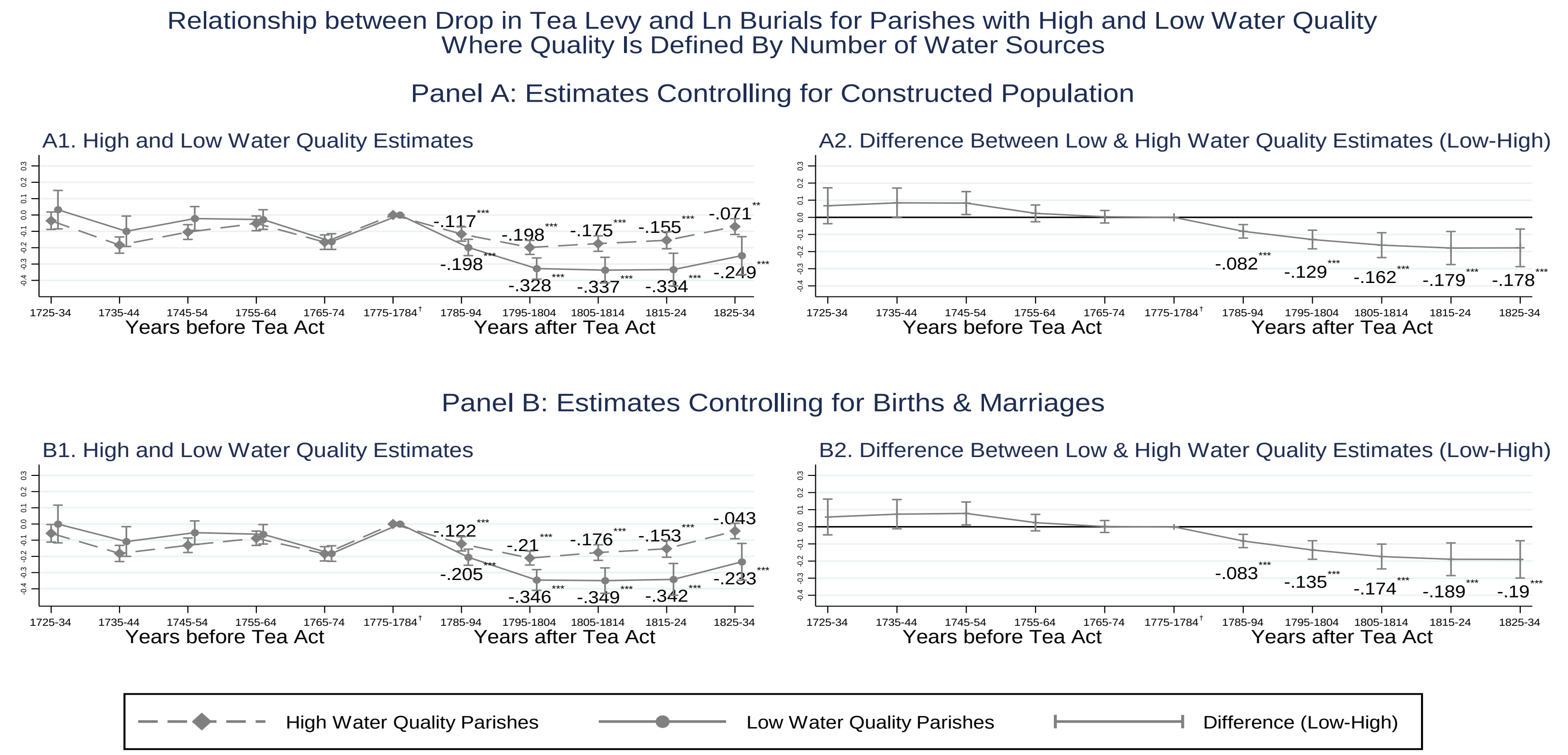
Figure 1



Relationship between Drop in Tea Levy and Ln Burials for Parishes with High and Low Water Quality
Where Quality Is Defined By Number of Water Sources

Panel A: Estimates Controlling for Constructed Population

A1. High and Low Water Quality Estimates

A2. Difference Between Low & High Water Quality Estimates (Low-High)

Panel B: Estimates Controlling for Births & Marriages

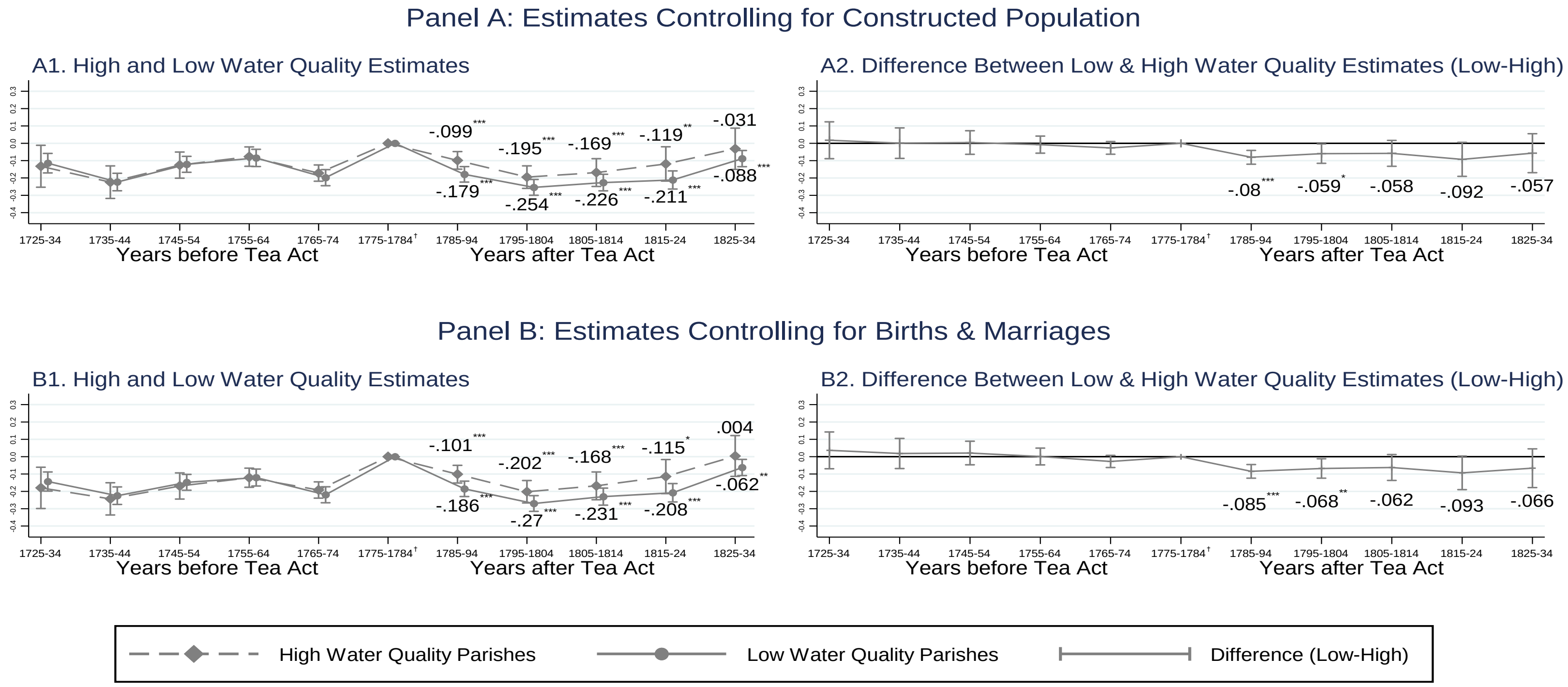
B1. High and Low Water Quality Estimates

B2. Difference Between Low & High Water Quality Estimates (Low-High)

†The reference category is the period immediately before the Tea and Windows Act
Sources: Schofield and Wrigley (2003) Population Data and UK Environment Agency Statutory Main River Map of England
All regressions include controls for parish and year fixed effects, and parish specific linear time trends.
90% confidence intervals are calculated from standard errors clustered at the parish level.

Figure 2

Relationship between Drop in Tea Levy and Ln Burials for Parishes with High and Low Water Quality Where Quality Is Defined By Elevation



†The reference category is the period immediately before the Tea and Windows Act
Source: Schofield and Wrigley (2003) Population Data and SRTM Data on 404 Parishes
All regressions include controls for parish and year fixed effects, and parish specific linear time trends.
90% confidence intervals are calculated from standard errors clustered at the parish level.

Table 1: Relationship between Tea Imports and Mortality for Parishes with High and Low Water Quality, 1761-1834

Panel A: Controlling for Constructed Population Measure

	(1)	(2)
	Water Quality Defined By	
	Elevation	No. Water Sources
	ln(Burials)	ln(Burials)
High Water Quality * Ln(Lag Tea Imports)	-0.140***	-0.159***
	(0.022)	(0.021)
Low Water Quality * Ln(Lag Tea Imports)	-0.154***	-0.173***
	(0.021)	(0.022)
Ln(Constructed Population)	0.213***	0.213***
	(0.064)	(0.064)
Diff. in Estimate (Low - High Water Quality)	-0.014**	-0.014**
	(0.006)	(0.006)
Observations	25,865	25,865
R-squared	0.887	0.887

Panel B: Controlling for Births and Marriages

	(1)	(2)
	Water Quality Defined By	
	Elevation	No. Water Sources
	ln(Burials)	ln(Burials)
High Water Quality * Ln(Lag Tea Imports)	-0.160***	-0.180***
	(0.020)	(0.019)
Low Water Quality * Ln(Lag Tea Imports)	-0.175***	-0.194***
	(0.019)	(0.020)
Ln(Births)	0.132***	0.132***
	(0.013)	(0.013)
Ln(Marriages)	0.018***	0.018***
	(0.006)	(0.006)
Diff. in Estimate (Low - High Water Quality)	-0.015**	-0.014**
	(0.006)	(0.006)
Observations	25,865	25,865
R-squared	0.888	0.888

All regressions include parish fixed effects, year fixed effects, and parish-specific linear time trends.

Robust standard errors in parentheses, clustered at parish level.

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

Table 2: Robustness to Smallpox Concerns

Panel A: Limiting Sample to 1761-1800

	(1)	(2)
	Water Quality Defined By	
	Elevation	No. Water Sources
	ln(Burials)	ln(Burials)
High Water Quality * Ln(Lag Tea Imports)	-0.069***	-0.086***
	(0.024)	(0.023)
Low Water Quality * Ln(Lag Tea Imports)	-0.089***	-0.097***
	(0.023)	(0.024)
Ln(Constructed Population)	-0.425***	-0.427***
	(0.099)	(0.099)
Diff. in Estimate (Low - High Water Quality)	-0.020**	-0.011
	(0.009)	(0.009)
Observations	15,230	15,230
R-squared	0.881	0.881

Panel B: Controlling for London Small Pox Death Rate

	(1)	(2)
	Water Quality Defined By	
	Elevation	No. Water Sources
	ln(Burials)	ln(Burials)
High Water Quality * Ln(Lag Tea Imports)	-0.240***	-0.258***
	(0.089)	(0.089)
Low Water Quality * Ln(Lag Tea Imports)	-0.254***	-0.272***
	(0.089)	(0.089)
Ln(Constructed Population)	0.213***	0.213***
	(0.064)	(0.064)
Ln(London Small Pox Death Rate)	-0.080	-0.079
	(0.077)	(0.077)
Diff. in Estimate (Low - High Water Quality)	-0.014**	-0.014**
	(0.006)	(0.006)
Observations	25,865	25,865
R-squared	0.887	0.887

All regressions include parish fixed effects, year fixed effects, and parish-specific linear time trends.

Note that in Panel B, London Small Pox Death Rate is London Deaths from Small Pox/ All London Deaths.

Robust standard errors in parentheses, clustered at parish level.

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

Table 3: Relationship between Tea Imports and Mortality for Parishes with High and Low Water Quality with Additional Controls, 1761-1834

	(1)	(2)	(3)	(4)
	Water Quality Defined By			
	Elevation	No. Water Sources	Elevation	No. Water Sources
	ln(Burials)	ln(Burials)	ln(Burials)	ln(Burials)
High Water Quality x Ln(Lag Tea Imports)	-0.160***	-0.179***	-0.109*	-0.117**
	(0.029)	(0.028)	(0.058)	(0.058)
Low Water Quality x Ln(Lag Tea Imports)	-0.174***	-0.192***	-0.122**	-0.132**
	(0.028)	(0.030)	(0.058)	(0.058)
Ln(Regional Wage)	0.075	0.075	0.079	0.074
	(0.071)	(0.071)	(0.072)	(0.071)
Ln(Constructed Population)	0.213***	0.212***	0.212***	0.211***
	(0.064)	(0.064)	(0.064)	(0.064)
NearCoast x Ln(Lag Tea Imports)			-0.002	-0.007
			(0.008)	(0.007)
DistanceToMarket x Ln(Lag Tea Imports)			0.001	0.001
			(0.001)	(0.001)
High Water Quality x Ln(Lag Misc. Imports)			-0.040	-0.056
			(0.044)	(0.044)
Low Water Quality x Ln(Lag Misc. Imports)			-0.054	-0.039
			(0.046)	(0.045)
Diff. in Estimate (Low - High Water Quality)	-0.014**	-0.014**	-0.013*	-0.014**
Interacted with Tea	(0.006)	(0.006)	(0.007)	(0.006)
Diff. in Estimate (Low - High Water Quality)			-0.014	0.017
Interacted with Misc. Imports			(0.013)	(0.013)
Observations	25,865	25,865	25,865	25,865
R-squared	0.887	0.887	0.887	0.887

All regressions include ln(constructed parish population), parish fixed effects, year fixed effects, and parish-specific linear time trends.

Robust standard errors in parentheses, clustered at parish level.

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

“For Want of a Cup:
The Rise of Tea in England and the Impact of Water Quality on Mortality”

Francisca M. Antman
University of Colorado Boulder

January 13, 2021

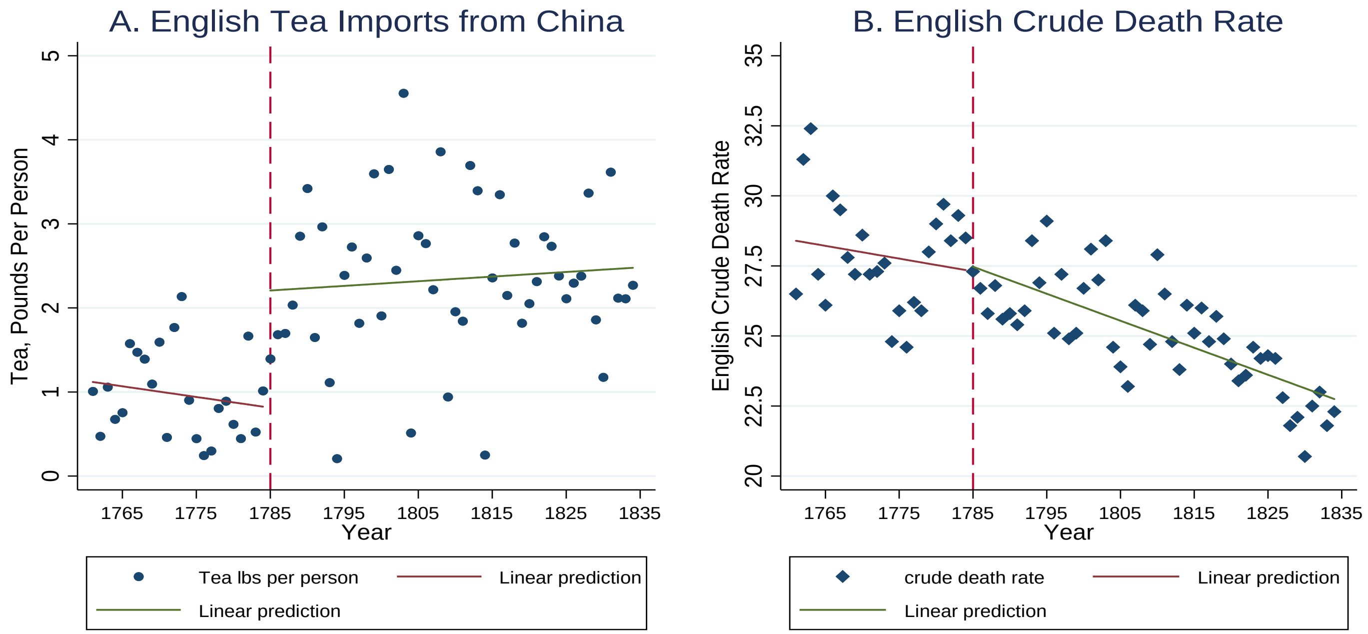
ONLINE APPENDIX

Part I: Supplemental Figures and Tables
Part II: Results without Parish-Specific Time Trends

ONLINE APPENDIX

Part I: Supplemental Figures and Tables

Figure 1: English Tea Imports from China and the English Crude Death Rate, 1761-1834

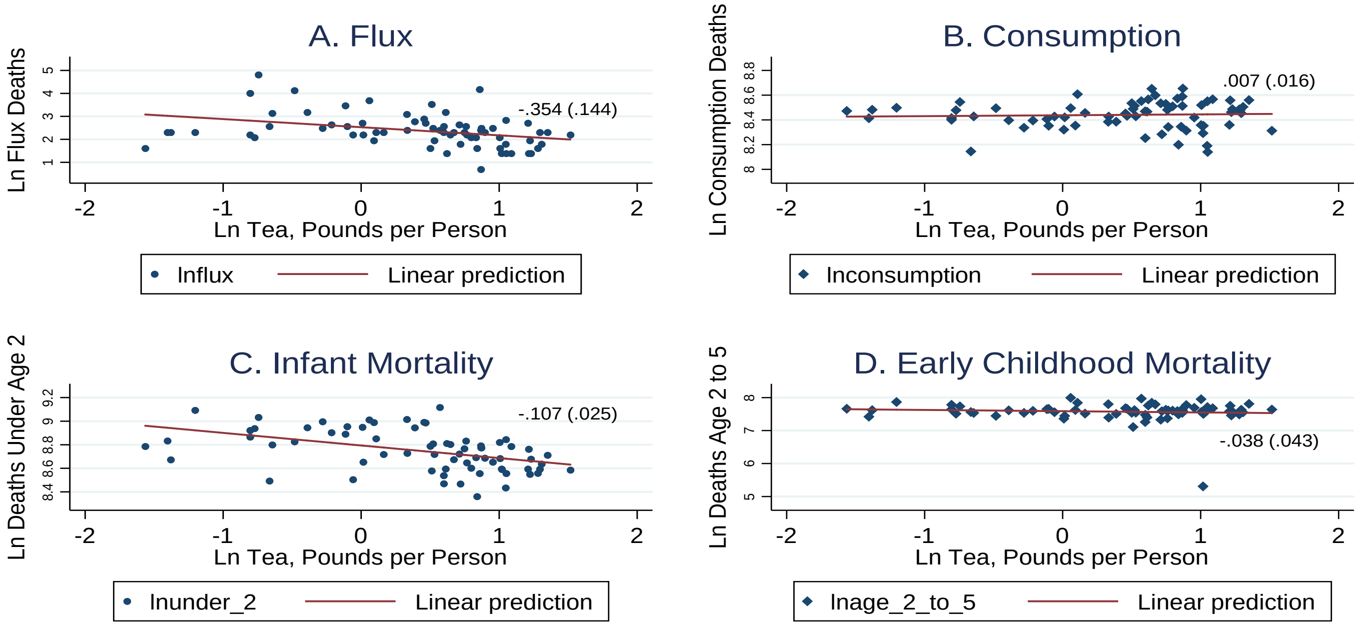


A. English Tea Imports from China

B. English Crude Death Rate

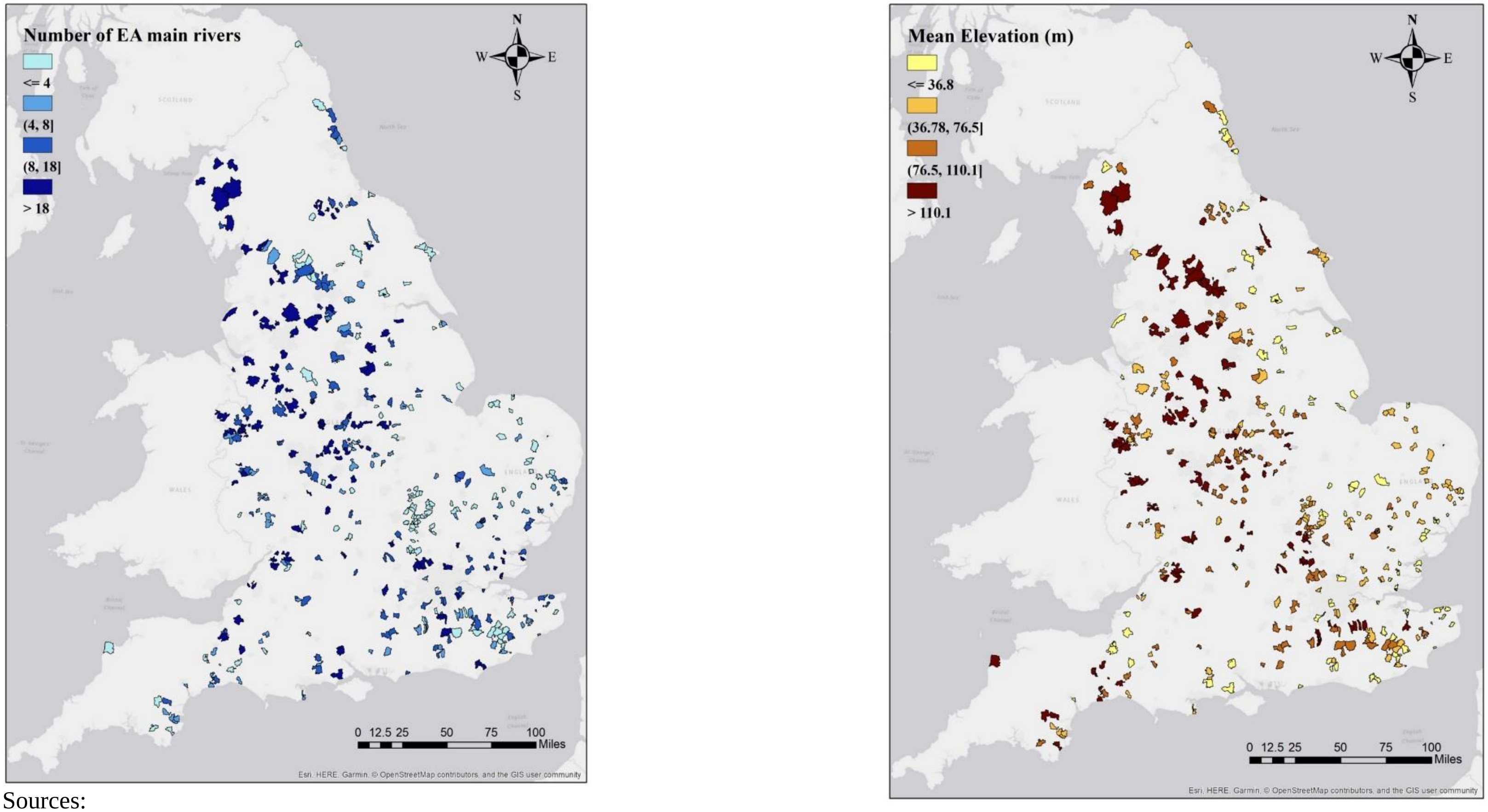
Linear prediction from regression on linear time trend.
Sources: East India Company Tea Imports from UKDataArchive SN5690 PI: H.V. Bowen.
Crude death rate from Wrigley and Schofield (1981).

Figure 2: London Cause of Death and Tea Imports, 1761-1834



Linear prediction from regression of Ln Specific Deaths on Ln Tea Import Volume/English Population.
Sources: East India Company Tea Imports from UKDataArchive SN5690 PI: H.V. Bowen.
English Population data from Wrigley and Schofield (1981). Cause of Death Data from Marshall (1832).
Coefficient and Robust Standard Error in Parentheses.

Figure 3: Parishes by Number of Water Sources and Elevation


A. Parishes Defined by Number of Water Sources (Main Rivers)

B. Parishes Defined by Elevation

Sources:

1. The 404 parishes come from GIS of the Ancient Parishes of England and Wales, 1500-1850, UKDA study number: 4828
2. The elevations are generated using NASA's 30-m SRTM (Shuttle Radar Topography Mission) data
3. The basemap is ESRI Basemap of England
4. EA main rivers is the Statutory Main River Map generated by Environment Agency, an open data source of UK government (https://data.gov.uk/)

Table 1: Descriptive Statistics

Panel A: Main Parish Characteristics	Mean	Std Dev	N
Parish Elevation (meters)	83.362	60.264	404
Number of Water Sources (Main Rivers)	15.035	26.244	404
Parish on coast or within 10 km of coast	0.267	0.443	404
Distance to Nearest Market Town in 1700 (km)	4.433	3.534	404

Panel B: Parish-year characteristics, 1725-1834	Mean	Std Dev	N
Deaths (burials)	33.412	46.126	39,943
ln(Deaths)	3.037	0.971	39,943
Births (baptisms)	44.730	62.562	39,943
ln(Births)	3.365	0.921	39,943
Marriages	12.281	21.414	39,943
ln(Marriages)	1.977	0.992	39,943
Population (Constructed Measure)	1344.832	1731.580	39,943
ln(Population, Constructed)	6.825	0.830	39,943

Panel C: Annual Imports, 1761-1834	Mean	Std Dev	N
Tea Imports, millions of pounds, lagged	17.823	11.755	73
ln(Tea), lagged	2.578	0.878	73

Notes: East India Company tea imports from UK Data Archive SN5690 PI: H.V. Bowen.

Number of water sources are calculated from Environment Agency Statutory Main River Map of England

Data on parish characteristics and mortality rates come from Schofield and Wrigley (2003).

Elevation data come from NASA's 30-m SRTM (Shuttle Radar Topography Mission)

Table 2: Means of Deaths and LnDeaths by Water Quality Level of Parishes, Before and After 1785

	Low Water Quality Parishes			High Water Quality Parishes			DD
	Pre-1785	Post-1785	DT	Pre-1785	Post-1785	DC	(DT-DC)
Panel A: Ln Burials as Outcome							
Ln Burials	2.778	2.848	0.069***	3.215	3.396	0.181***	-0.111***
N water sources measure of water quality	[0.891]	[0.893]	(0.012)	[0.956]	[1.030]	(0.015)	(0.019)
	12,086	8,939	21,025	10,954	7,964	18,918	39,943
Ln Burials	2.938	3.030	0.092***	3.034	3.182	0.148***	-0.056***
Elevation measure of water quality	[0.959]	[0.987]	(0.014)	[0.934]	[1.003]	(0.014)	(0.020)
	11,454	8,438	19,892	11,586	8,465	20,051	39,943
Panel B: Burials as Outcome							
Burials	23.462	25.881	2.419***	37.857	50.852	12.994***	-10.575***
N water sources measure of water quality	[25.037]	[37.854]	(0.434)	[40.026]	[73.233]	(0.831)	(0.911)
	12,086	8,939	21,025	10,954	7,964	18,918	39,943
Burials	28.898	33.340	4.442***	31.698	41.939	10.241***	-5.798***
Elevation measure of water quality	[30.758]	[44.437]	(0.533)	[36.499]	[69.742]	(0.760)	(0.929)
	11,454	8,438	19,892	11,586	8,465	20,051	39,943

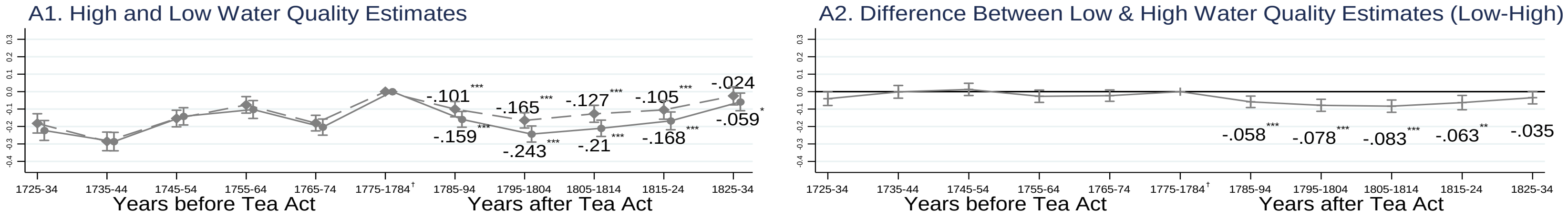
Notes: Standard deviations are in brackets and standard errors are in parentheses. * $p<0.1$; ** $p<0.05$; *** $p<0.01$. The number of observations is listed in the third row corresponding to each outcome.

ONLINE APPENDIX

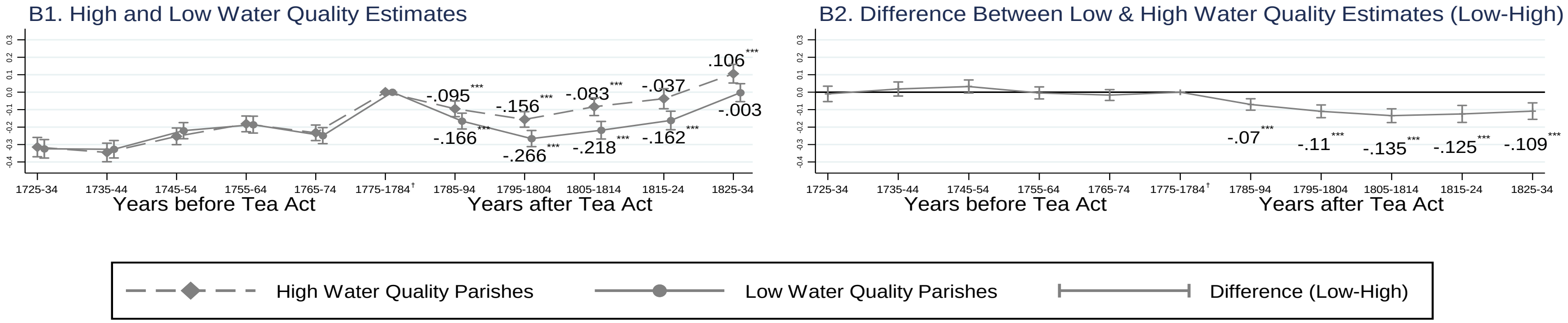
Part II: Results without Parish-Specific Time Trends

Figure A1: Relationship between Drop in Tea Levy and Ln Burials for High and Low Water Quality Parishes
Where Quality Is Defined By Number of Water Sources, Without Parish-Specific Time Trends

Panel A: Estimates Controlling for Constructed Population



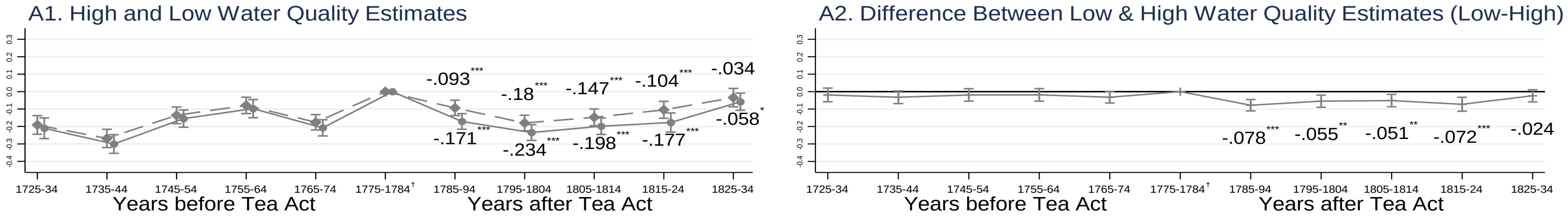
Panel B: Estimates Controlling for Births & Marriages



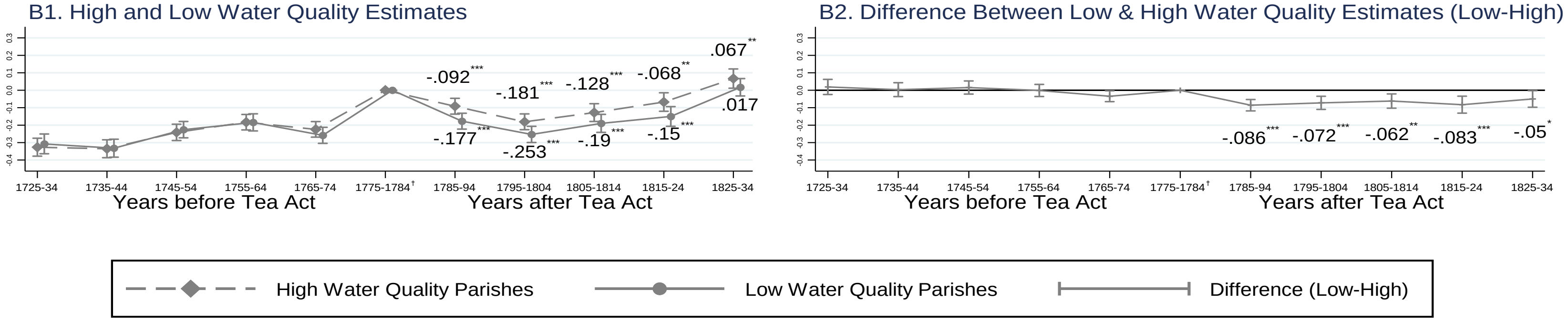
[†]The reference category is the period immediately before the Tea and Windows Act
Sources: Schofield and Wrigley (2003) Population Data and UK Environment Agency Statutory Main River Map of England
All regressions include controls for parish and year fixed effects.
90% confidence intervals are calculated from standard errors clustered at the parish level.

Figure A2: Relationship between Drop in Tea Levy and Ln Burials for Parishes with High and Low Water Quality Where Quality Is Defined By Elevation, Without Parish-Specific Time Trends

Panel A: Estimates Controlling for Constructed Population



Panel B: Estimates Controlling for Births & Marriages



†The reference category is the period immediately before the Tea and Windows Act
Source: Schofield and Wrigley (2003) Population Data and SRTM Data on 404 Parishes
All regressions include controls for parish and year fixed effects.
90% confidence intervals are calculated from standard errors clustered at the parish level.

Table A1: Relationship between Tea Imports and Mortality for Parishes with High and Low Water Quality, 1761-1834, Without Parish-Specific Time Trends

Panel A: Controlling for Constructed Population Measure

	(1)	(2)
	Water Quality Defined By	
	Elevation	No. Water Sources
	ln(Burials)	ln(Burials)
High Water Quality * Ln(Lag Tea Imports)	-0.032	-0.026
	(0.022)	(0.022)
Low Water Quality * Ln(Lag Tea Imports)	-0.051**	-0.049**
	(0.023)	(0.022)
Ln(Constructed Population)	0.743***	0.732***
	(0.040)	(0.040)
Diff. in Estimate (Low - High Water Quality)	-0.020***	-0.023***
	(0.006)	(0.006)
Observations	25,865	25,865
R-squared	0.881	0.881

Panel B: Controlling for Births and Marriages

	(1)	(2)
	Water Quality Defined By	
	Elevation	No. Water Sources
	ln(Burials)	ln(Burials)
High Water Quality * Ln(Lag Tea Imports)	0.097***	0.110***
	(0.022)	(0.022)
Low Water Quality * Ln(Lag Tea Imports)	0.073***	0.066***
	(0.021)	(0.021)
Ln(Births)	0.229***	0.224***
	(0.017)	(0.017)
Ln(Marriages)	0.043***	0.042***
	(0.007)	(0.007)
Diff. in Estimate (Low - High Water Quality)	-0.024***	-0.044***
	(0.009)	(0.009)
Observations	25,865	25,865
R-squared	0.878	0.878

All regressions include parish fixed effects and year fixed effects.

Robust standard errors in parentheses, clustered at parish level.

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

Table A2: Robustness to Smallpox Concerns, Without Parish-Specific Time Trends

Panel A: Limiting Sample to 1761-1800

	(1)	(2)
	Water Quality Defined By	
	Elevation	No. Water Sources
	ln(Burials)	ln(Burials)
High Water Quality * Ln(Lag Tea Imports)	-0.048**	-0.050***
	(0.019)	(0.019)
Low Water Quality * Ln(Lag Tea Imports)	-0.079***	-0.073***
	(0.020)	(0.020)
Ln(Constructed Population)	0.619***	0.610***
	(0.070)	(0.070)
Diff. in Estimate (Low - High Water Quality)	-0.031***	-0.023***
	(0.008)	(0.008)
Observations	15,230	15,230
R-squared	0.872	0.872

Panel B: Controlling for London Small Pox Death Rate

	(1)	(2)
	Water Quality Defined By	
	Elevation	No. Water Sources
	ln(Burials)	ln(Burials)
High Water Quality * Ln(Lag Tea Imports)	-0.130	-0.124
	(0.087)	(0.087)
Low Water Quality * Ln(Lag Tea Imports)	-0.149*	-0.147*
	(0.088)	(0.087)
Ln(Constructed Population)	0.743***	0.743***
	(0.040)	(0.040)
Ln(London Small Pox Death Rate)	-0.078	-0.078
	(0.076)	(0.076)
Diff. in Estimate (Low - High Water Quality)	-0.020***	-0.023***
	(0.006)	(0.006)
Observations	25,865	25,865
R-squared	0.881	0.881

All regressions include parish fixed effects and year fixed effects.

Note that in Panel B, London Small Pox Death Rate is London Deaths from Small Pox/ All London Deaths.

Robust standard errors in parentheses, clustered at parish level.

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

Table A3: Relationship between Tea Imports and Mortality for Parishes with High and Low Water Quality with Additional Controls, 1761-1834, Without Parish-Specific Time Trends

	(1)	(2)	(3)	(4)
		Water Quality Defined By		
	Elevation	No. Water Sources	Elevation	No. Water Sources
	ln(Burials)	ln(Burials)	ln(Burials)	ln(Burials)
High Water Quality x Ln(Lag Tea Imports)	-0.106***	-0.102***	-0.072	-0.064
	(0.027)	(0.027)	(0.056)	(0.056)
Low Water Quality x Ln(Lag Tea Imports)	-0.122***	-0.123***	-0.085	-0.087
	(0.028)	(0.028)	(0.056)	(0.056)
Ln(Regional Wage)	0.199***	0.206***	0.188***	0.193***
	(0.046)	(0.046)	(0.046)	(0.046)
Ln(Constructed Population)	0.733***	0.722***	0.731***	0.722***
	(0.039)	(0.039)	(0.039)	(0.039)
NearCoast x Ln(Lag Tea Imports)			-0.0002	-0.006
			(0.007)	(0.007)
DistanceToMarket x Ln(Lag Tea Imports)			0.003***	0.003***
			(0.001)	(0.001)
High Water Quality x Ln(Lag Misc. Imports)			-0.044	-0.049
			(0.043)	(0.044)
Low Water Quality x Ln(Lag Misc. Imports			-0.050	-0.045
			(0.045)	(0.044)
Diff. in Estimate (Low - High Water Quality)	-0.015**	-0.021***	-0.013*	-0.023***
Interacted with Tea	(0.006)	(0.006)	(0.007)	(0.006)
Diff. in Estimate (Low - High Water Quality)			-0.006	0.004
Interacted with Misc. Imports			(0.010)	(0.010)
Observations	25,865	25,865	25,865	25,865
R-squared	0.881	0.881	0.881	0.882

All regressions include ln(constructed parish population), parish fixed effects and year fixed effects.

Robust standard errors in parentheses, clustered at parish level.

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