NBER WORKING PAPER SERIES

ENERGY AND THE ENVIRONMENT IN ECONOMIC HISTORY

Karen Clay

Working Paper 31408
http://www.nber.org/papers/w31408

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
June 2023

I have not received any funding for this research and I do not have any relevant financial relationships. The views expressed herein are those of the author and do not necessarily reflect the views of the National Bureau of Economic Research.

Energy and the Environment in Economic History
Karen Clay
NBER Working Paper No. 31408
June 2023
JEL No. N50,N70,Q32,Q53

ABSTRACT

Both energy and the environment are inputs into production, influencing the economy and the overall welfare of the population. While the economy itself has been a central focus of economic history from its inception, energy and the environment have received more limited attention. On the energy side, the relative lack of attention reflects economic historians' focus on labor, capital, and technology. Two areas that have received attention are the effects of energy on the spatial location of economic activity and the importance of coal for the Industrial Revolution. On the environmental side, the relative lack of attention likely reflects the focus on the positive aspects of industrialization and the difficulty of finding data related to air, water, and land pollution. One environmental area that has received attention is water pollution from human waste, which had large mortality impacts, particularly in cities. This essay reviews long run trends in energy use and water and air pollution and then turns to the energy and environmental literatures in economic history. The conclusion offers some thoughts regarding opportunities for further research in energy and the environment.

Karen Clay
Heinz College
Carnegie Mellon University
5000 Forbes Avenue
Pittsburgh, PA 15213
and NBER
kclay@andrew.cmu.edu

Introduction

Both energy and the environment are inputs into production, influencing the economy and the overall welfare of the population. In a broader sense, they can also be conceived of as a subset of the broader set of natural resources. Energy comes from food, fodder, wood, coal, oil, natural gas, water, and more recently wind, solar, and nuclear. The environment includes clean air, water, and land, themselves natural resources.

While the economy itself has been a central focus of economic history from its inception, energy has received much more limited attention. Why has energy received limited attention? Part of this reflects economic history's focus on capital and labor inputs in the two major sectors – agriculture and manufacturing. On the labor side, scholars have examined slavery, human capital, and migration. On the capital side, scholars have examined machinery, firm organization, capital markets, and banking. Technology, because it allowed for increasing productivity of capital and labor, has also received considerable attention. Although energy has generally received less attention, there are some important exceptions. These include the literature on the spatial location of economic activity and the related literature on the Industrial Revolution. In the latter, the importance of coal has been a subject of intense debate.

Another way to think about why energy has received less attention in economic history is to look at what economists focused on energy study today. The literature has many interrelated strands. One strand is focused on reducing consumption of energy, energy efficiency, and decarbonization by changing the mix of energy consumption. Another strand examines the impacts of regulations, taxes, fees, and prices on energy use in aggregate, across different sectors of the economy, and on specific groups such as low income consumers. A third strand examines the operation of energy markets including markets for oil, natural gas, and electricity. A fourth strand examines the effects of energy shocks on local economic outcomes. As will be discussed further in later in this chapter, the fourth strand overlaps to a greater degree with the economic history literature than many of the other strands. Overall, the lack of research on these topics in economic history reflects both data limitations and the more limited regulation of energy in most countries before 1970.

Until recently, environmental externalities have also received limited attention in the literature. This likely reflects the focus on the positive aspects of industrialization and the lack of data. Interestingly, early work often focused on human externalities rather than industrial externalities. Dense human habitation created water pollution and led to the spread of disease. Cities, where the problem was most severe, had high mortality until the installation of water and sewer systems reduced exposure to pathogens. More recently, scholars have begun to study the effects of air pollution.

As with energy, it is useful to consider what environmental economists study today to understand why the environment has received less attention in economic history. The strands of the environmental literature focus on specific types of pollution including water, land, and air pollution. Outcomes of interest include health, education, productivity, housing prices, and crime. The strands of the literature on regulatory approaches to reducing pollution investigate command and control and market based solutions and the effectiveness of specific regulations. Like the literature on energy, the lack of research on the effects of pollution and its regulation reflects both data limitations and the more limited regulation of environmental externalities in most countries before 1970.

This chapter surveys cliometric papers on energy and the environment. The methodologies vary depending on the era in which the paper was written and the topic. Where possible, the chapter draws on papers that use causal empirical approaches such as difference-in-differences, instrumental variables and synthetic controls. To avoid overlap with the modern literatures on energy and the environment and limit the survey to economic history, papers are only included that study periods before 1970. By default, the geographic focus is on North America and Europe. Work on other regions has been limited by lack of data.

The chapter begins by reviewing long run trends in energy use and water and air pollution. The next two sections review the energy and environmental literatures. The final section offers some concluding thoughts regarding opportunities for further research in energy and the environment.

Background

Energy

Using data from Henriques and Borowiecki (2017), Fig. 1 documents the trends in energy use per capita in six countries from 1800 to 2010: Canada, France, Germany, Japan, United Kingdom, and the United States. Prior to 1800, in most parts of the world, energy consumption was low and relatively constant over time.(Kander et al., 2013). The main contributors to energy consumption were food, fodder, and wood. Energy consumption was low during the early part of the nineteenth century, rose in the late nineteenth century through 1970 with interruptions for wars, and then plateaued after 1970. Within these trends, the United States and Canada are notable for their high levels of energy consumption both in 1800 and in the latter part of the twentieth century. The United Kingdom was similar to the United States and Canada in the nineteenth century, primarily because of the use of coal for heating. It plateaued, however, and was similar to France, Germany, and Japan at the end of the twentieth century.

Fig. 2 shows how the mix of energy inputs shifted over time. For much of the nineteenth century wood was the dominant fuel source. The coal slowly grew in importance in the early nineteenth century and gathered speed over the remainder of the century. Coal became the dominant fuel source beginning around 1870. Oil gained importance over the twentieth century and was the most important fuel source from around 1970 onward.

Fig. 3 highlights changes in energy intensity per dollar of GDP since 1800. Two countries – the United States and Canada – started at high levels and show substantially declining intensity over the entire period. France, Germany, Japan, and the United Kingdom show flatter trends.

Energy produces heating and lighting services, which are of enormous importance for human welfare. In his seminal paper, Nordhaus (1996) discusses the dramatic overall decline in the cost of lighting in cents and in hours of work necessary to purchase 1,000 lumen-hours. Open fire required 58 hours of labor per 1,000 lumen hours. In 1800, tallow candles required 5.4 hours of labor; in 1900, carbon filament electric light required 0.22 hours of labor; in 1992, compact fluorescent light required just 0.0001 hours.

The prices of heating services measured in labor hours have also fallen. Fouquet (2011a) and Muller (2016) measure the cost of heating services in England and Vermont, respectively. The prices of heating services in hours of labor have declined at remarkably similar rates in the two areas from 1790 to 2010: -1.1% for Vermont and -0.9% for England. Declines in the costs of heating and lighting as measured in hours of work are almost entirely missed by use of traditional price indices, yet they had important implications for the quality of life.

Environment

Air pollution was a concern as early as the thirteenth century in London and in many locations around the world by the late nineteenth and early twentieth centuries. In the United States, which along with Great Britain was an early leader in legislation, efforts to combat pollution were largely local and generally ineffective. The U.S. Public Health Service measured air pollution in selected cities in the early 1930s (Clay, 2018). Despite the evidence this provided of high levels of pollution, little progress was made in the 1930s and 1940s. Severe episodes of pollution led to deaths in Donora in 1948 and London in 1952. The widespread availability of television, which brought the crises into the homes of viewers, created heightened concern. Shortly after London, the Congress passed the Air Pollution Control Act of 1955, which supported data collection. The focus shifted to controlling air pollution with the Clean Air Act of 1963. Subsequent legislation was passed in 1970. Britain passed air pollution legislation in 1956 and 1968.

Air pollution has fallen over time in London and the United States. Using data from

Fouquet (2011b), the top panel of Fig. 4 shows TSP concentrations in London. Pollution increased from 1800 to 1900 and then began a long decline. The top panel of Fig. 4 also includes a shorter national series for TSP concentration in the United States (Clay et al., 2016). TSP concentration in the United States was lower than in London in 1957 and fell somewhat less dramatically up to 2000. The bottom panel of Fig. 4 provides another, longer series for the United States based on data from black carbon in bird feathers in the U.S. manufacturing belt (DuBay and Fuldner, 2017). In periods with higher pollution, birds of the same species will have more black carbon (soot) on their feathers. Z-score measures of black carbon were high from 1880 to the late 1920s, fell during the 1930s, rebounded during the 1940s and then declined over time. The general pattern is similar to the pattern for TSP in London, although the decline begins later.

Water pollution from humans, animals and industry dates to the earliest days of habitation. Most town cities of any size had sewage-related water-borne disease. Cities also passed laws designed to limit slaughterhouses and tanneries in urban areas because of the smells and adverse effects on water. In the nineteenth century, governments sometimes established boards of health to address pollution from waste. Boards focused primarily on human and not industrial waste, because most industrial waste did not have bacteria. Human waste-related pollution was greatly improved with the advent of water treatment, which reduced exposure to pollution, and later sewage treatment plants, which diminished the flow of human waste into waterways. Locations with significant industrial water pollution also established boards to monitor water quality, hear complaints about water pollution, and work with industry to address pollution. Despite these efforts, industrial pollution including oil and chemical spills persisted. In the United States, following Earth Day and the passage of the Clean Air Act of 1970, water pollution began to receive increased attention. This led Congress to pass the U.S. Clean Water Act in 1972.

Exposure to water pollution from human waste fell over time. Using data from Beach et al. (2022), Fig. 5 shows trends in typhoid mortality in U.S. cities over the period 1880-

1930. Typhoid is a waterborne disease and is often used as a marker for water quality, with high levels of typhoid signifying high levels of water pollution from human waste. It is worth noting that the declines in typhoid mortality reflect improvements in population exposure to treated drinking water and may or may not reflect improvements in underlying water pollution. As will be discussed in more detail later, typhoid mortality fell in other geographic areas as well.

Land pollution often receives more limited attention than air or water pollution. It has a variety of causes – agriculture, extraction of mineral and oil resources, industrial waste, and disposal of ordinary garbage. Rachel Carson's book Silent Spring on DDT had worldwide impact (Carson, 1962). In Britain, the Smarden affair, in which a pesticide was released from a factory into a ditch and animals drank from it, received national and international media attention in 1963. Nuclear accidents in the 1950s and 1960s in Russia, the Great Britain, the United States, and Switzerland also highlighted the dangers of nuclear energy and the difficulty of disposing of nuclear waste.

Energy

The energy literature in economic history has centered on four broad questions. What are the effects of energy on the spatial location of economic activity? How has technological change affected the relationship between energy and economic activity? What are the effects of shocks to energy on macroeconomic activity? What is the effect of access to energy on health? In this section, the focus is on the positive effects on health. Negative effects will be covered in the next section.

Some resources are more central to certain questions than others. The importance of endowments of coal have been key for one strand of the first literature on the spatial location of economic activity. A related strand of the literature has focused on the transition to electrification. The second literature on technology generally considers on coal. The third literature on the macroeconomic effects of shocks has focused predominantly on oil shocks. The fourth literature on the effects of access to energy has predominantly examined the effects of access to electricity.

Effects of Energy on the Spatial Location of Economic Activity

Coal

One of the earliest and most hotly debated strands of the literature is about the effects of coal on the spatial location of economic activity. This section begins with two papers on coal and the Industrial Revolution, turns to two papers on coal and the spatial location of economic activity in later periods, and finishes by examining the effects of coal mining on local economic activity.

Clark and Jacks (2007) bring newly-collected data to the question of the importance of coal for the Industrial Revolution. The data include new price series on coal rents, pithead and market prices of coal, and prices of firewood to evaluate the relative importance of technological innovations and demand in the expansion of coal output. The paper analyzes productivity growth in coal mining between the 1730s and the 1860s and concludes that it was modest, less than 0.2% per year. The large increase in coal consumption came instead from increasing demand as a result of rising incomes, increasing industrial demand, falling taxation, and falling transportation costs. Based on counterfactuals in which coal was located in the Netherlands, Ireland, or France or in which wood had to be imported from the Baltic or Russia, the paper concludes that the location of coal reserves in Britain had very small effects on incomes during the Industrial Revolution.

Fernihough and O'Rourke (2021) evaluate the importance of coal on the growth of cities in Europe before and during the Industrial Revolution. To investigate this, the paper uses population data for 2,180 cities between 1300 and 1900 and distance to the nearest of the 124 major coalfields in Europe. To address possible endogeneity, proximity to Carboniferous-era rock strata is used as an instrument for proximity to coalfields in some specifications. The paper finds that access to coal had no effect on city growth prior to 1750, but had a positive and significant effect after. In the IV specification, being 49 km from a coal field as opposed to 134 km led to a 21% difference in population growth after 1750. The paper concludes that fossil fuels played an important role in city growth after the Industrial Revolution.

Crafts and Mulatu (2006) study the importance of factor endowments – agricultural land and coal – and market potential in industrial location in Britain from 1841 to 1911. This period after the Industrial Revolution was marked by changing proximity to markets and falling transportation costs. The question is whether this changed the location of industry. The paper finds that industrial location and patterns of regional specialization were generally quite persistent. The initial patterns and persistence reflect the importance of proximity to resources, primarily coal. One exception was industries with large plant sizes, although the need for central location appears to have diminished with falling transportation costs.

Klein and Crafts (2012) addresses similar questions of the importance of factor endowments and market potential in the U.S. context. The analysis draws on state level data on shares in two digit industries spanning 1880-1920. The estimation approach includes both measures of market potential and of factor endowments including coal and farmland. While market potential, coal, and agricultural land were significant in the late nineteen century, market potential appears to have played a more dominant role and was much higher for states in the manufacturing belt. Market potential mattered because of scale economies and forward and backward linkage effects.

Matheis (2016) uses data for non-urban counties in the United States over the period 1870-1970 to estimate the short (10 and 20 year) and long run (30 year) effects of coal mining on population and manufacturing activity. The analysis suggests that increases in coal mined in a decade increased population in the next two decades but then population began to decline. Population gains were largest in the eastern United States prior to 1930. Coal had small positive short-run effects on some manufacturing outcomes such as earnings and output, but little effect in the long run. Per capita manufacturing workers fell in the short and the long run.

Overall, the papers are divided on the importance of coal. It seems to have shaped economic activity in some contexts, time periods, and time horizons, but not others.

Electricity

A series of papers measure the effects of electrification in the United States on a range of short and long run economic outcomes. The literature is sufficiently large that it is only feasible to discuss a subset of the papers in what follows. In contrast to the abundance of papers in the U.S. context, there has been little work in Europe. One exception is Leknes and Modalsli (2020), which studies the effects of the introduction of hydropower in Norway.

Kline and Moretti (2014) examine the effect of the Tennessee Valley Authority (TVA) on local economies between 1930 and 2000. One thing to note is that the TVA included both energy, in the form hydroelectric dams, and a range of other infrastructure investments, including roads and canals. The paper uses two different sets of control groups: observationally similar counties in the South and elsewhere and six other regional authorities that were considered but never funded. The paper finds that between 1930 and 1960, the TVA generated increases in both agricultural and manufacturing employment. After 1960, when federal funding had largely ended, the effects on agriculture reversed, while the the effects on manufacturing continued to grow. This pattern is consistent with agglomeration economies in manufacturing. A cost-benefit evaluation of the TVA shows that the program generated substantial direct productivity benefits, that indirect effects were minimal, and that the benefits exceeded the costs.

Severnini (2023) investigates the effect of hydroelectric dams on local population density over the period 1870-2010. It draws on data from 110 counties with hydroelectric power potential of 100 megawatts. To estimate the relationship between hydroelectric dams and local population density, the paper uses both event study and synthetic control approaches. For dams constructed before 1950, dams led to both short and long run growth. Population density increased by 50% in the first thirty years and 130 percent in the first sixty years. This is consistent with cheap local power spurring agglomeration. In contrast, for dams constructed after 1950, the effects were modest. This reflects a combination of lower price differentials, with the expansion of long distance electricity transmission, and the characteristics of counties receiving later dams.

Fiszbein et al. (2020) focuses on the effects of the introduction of electricity on the manufacturing industry in large urban counties from 1890-1940. The paper exploits two sources of variation: cross-industry variation in energy use intensity in 1890, before the arrival of electricity, and geographic variation in proximity to hydroelectric power plants, which offered low prices. In contrast to some previous papers, the paper finds electricity led to rapid and persistent gains in labor productivity. Part of the gains appears to stem from cheaper energy prices, but there is evidence consistent with firms changing their production processes. The paper explores the relationship between gains and market structure. In sector-county pairs where firms were already large, productivity increased but there was no impact on employment. In contrast, in county-pairs where firms were relatively small, output and employment increased.

Lewis and Severnini (2020) evaluate the effects of the dramatic increase in electrification of U.S. farm households between 1930 and 1960 on short and long run economic outcomes. Over that period, electrification went from less than 10% of farm households to nearly 100%. The paper finds positive short run effects on agricultural employment, rural farm population, and rural property values. In contrast, there was minimal effect on the non-agricultural economy. A comparison of the costs and benefits suggests that short run benefits exceeded costs both in areas with high population density, where it has traditionally been assumed to be cost-effective, and in areas low population density. Electrification also led to long run growth. The type of growth varied with proximity to urban areas. In remote areas, growth was driven by the agricultural sector, while in areas near urban areas it appears to have been driven by suburban expansion.

Leknes and Modalsli (2020) uses detailed municipality and individual level data from Norway over the period 1891-1920 to study the effects of hydropower on the local economy. To address concerns about the endogeneity of hydropower development, the authors use hydropower potential. IV estimates show that hydropower expanded the labor force and changed the mix of employment. It shifted workers out of primary industries and into manufacturing and services. Turning to the individual level, the paper measures occupational upgrading by workers, who were farmers, unskilled, and skilled workers, and intergenerational upgrading for fathers and sons between 1900 and 1910. The benefits appear to have accrued to unskilled workers and sons of unskilled fathers. The paper also provides evidence showing increases in employment were at the top and bottom of the occupational distribution. Overall, the results suggest that Norway experienced a skill-biased transformation.

Taken together, these papers offer a consistent narrative in which the first wave of electrification brought short run and often long run benefits – population and employment growth, increased productivity, and occupational upgrading.

Technological Change, Energy and Economic Activity

Energy has not been a focus of the technology literature, despite energy's role. Steam engines and later other types of engines become increasingly efficient at transforming energy inputs into useful energy that firms used to produce goods. Mokyr (2010) mentions a number of instances of fuel savings in his chapter in the *Handbook of the Economics of Innovation*.

One exception is Rosenberg and Trajtenberg (2004), which studies the effects of the Corliss steam engine on industrial location and subsequent population growth. The Corliss steam engine was a significant advance, both in fuel efficiency and in other performance characteristics, relative to water power and to previous generations of steam engines. The paper uses both OLS and IV to document which counties adopted Corliss engines and their subsequent growth. More populous counties adopted Corliss engines and counties with more Corliss engines grew more rapidly after adoption than counties with more watermills. The paper argues that this reflects the ability of manufacturing enterprises to locate optimally and take advantage of agglomeration economies once they were not longer constrained by waterpower. It is careful to point out that the effects of Corliss engines may be capturing the effects of steam power more broadly or the dynamism of the sectors that they were used in, namely textiles and metallurgy.

Effects of Shocks to Energy on Economic Activity

While the modern literature on the causal relationship between energy and economic activity is large, the literature that conducts causal analysis on the period before the 1970s energy crises is small. Two key papers are van de Ven and Fouquet (2017), which examines Great Britain over more than 300 years, and Huntington (2017), which examines the United States over more than 100 years. The importance of these papers lies in showing that energy prices affected GDP well before the 1970s.

van de Ven and Fouquet (2017) uses data on the Great Britain over 1700-2008 to investigate the effects of energy shocks on GDP. Following the modern literature, the paper separately evaluates the effects of supply, aggregate demand and residual shocks. The results suggest that the impacts of the types of shocks varied across the two key resources – coal and oil. The impacts of supply shocks rose with increases in dependence on coal, while impacts of demand shocks increased with the rise of oil. The paper documents trends in the aggregate effects of different types of shocks on GDP over time. Aggregate demand and supply shocks had similar negative effects in the eighteenth and nineteenth centuries and then diverged. Demand shocks had less negative and sometimes positive effects than supply shocks, which became more sharply negative. After 1970s, the negative effect of supply shocks has been smaller than the negative effect of demand shocks. Throughout the sample period, residual shocks have had positive effects.

Drawing on U.S. data over the period 1892-2014, Huntington (2017) explores the effects of energy prices on GDP. The paper first shows that energy prices Granger-cause GDP and then evaluates the relationships over the early and later historical periods. Energy prices are more negatively related to GDP in the early period than the later period. This reflects the effects of coal strikes, the lack of imports, and the greater energy intensity of GDP during the early period.

Effects of Access to Energy on Health

A small number of economic history papers have evaluated the impact of gaining access to electricity on health. Improvements are likely to have arisen from reductions in indoor air pollution, as electric lighting replaced kerosene lamps, candles, and gas lighting and as electric stoves replaced wood and coal-fired stoves. In areas without running water, electricity also brought pumped water, which enabled indoor plumbing and more frequent washing of people, clothing, and implements used for cooking and eating. These improvements in sanitation are likely to have improved health.

Lewis (2018) examines the effect of the expansion of electricity to rural communities in the U.S. between 1930 and 1960 on infant mortality and fertility. The paper uses new data on distances to more than 1,000 power plant openings for 2,093 counties. Power plant openings were related to electricity access, but were not driven by rural household demand. Power plant siting was instead dictated by a complex set of factors, such availability of water, land, and transmission infrastructure. A 100-mile decrease in distance to the nearest power plant decreased infant mortality by 3.6-3.7 infant deaths per 1,000. Household electrification accounted for 15 to 19% of the decline in mortality over this period. The benefits are consistent with the increased availability of pumped water and washing machines. In contrast to infant mortality, access to electricity appears to have had little effect on fertility.

Clay et al. (2016) addresses the benefits and the costs for infant mortality associated with the historical expansion in coal-fired electricity generation in the United States. The benefits will be discussed here, and the costs will be discussed in the next section. Using newly digitized data on all major coal-fired power plants for the period 1938-1962, the paper measures the effect of coal burning on infant mortality with difference-in-differences strategies based on the opening of power plants and adding new generating units at existing sites. Annual information on plant-level coal use is combined with the AP3 air pollution model to measure the dispersion of ambient air pollution. The paper finds that initially coal fired generation led to decreases in infant mortality, suggesting that there were net health benefits. In counties with low baseline access to electricity, expansion of coal-fired generation led to increases in homes with electricity, running water, and modern stoves. There were differential benefits to electricity in counties more reliant on coal for cooking and where there was a high baseline incidence of sanitation-related mortality.

Environment

In contrast to the energy section, which was more naturally divided by question, this section is more naturally divided by the type of pollution and the location. The first half of the section focuses on air pollution in the United States and the Great Britain. The second half of the section focuses on water pollution in the United States and Europe.

Air Pollution

United States

Clay et al. (2018) leverage data from 1915 on the location and capacity of coal-fired electricity plants to study the impact of air pollution on pandemic mortality during the 1918 Influenza Pandemic. The pandemic killed millions worldwide and hundreds of thousands in the United States. Human and animal studies have shown that air pollution can increase susceptibility to viral infection and heighten the risk of severe complications. While a range of factors had been hypothesized to explain spatial differences in pandemic mortality, the possible relationship between air pollution and pandemic mortality had been largely overlooked. The analysis combines panel data on infant and all-age mortality with a measure of air pollution based on the burning of coal for electricity generation in U.S. cities. The paper finds that air pollution contributed significantly to pandemic mortality. Relative to cities with similar pre-pandemic socioeconomic conditions and baseline health that used less coal, cities that used more coal experienced tens of thousands of excess deaths in 1918. The paper also evaluates other contributing factors to spatial differences, including poverty, public health, and the timing of onset.

As discussed in the previous section, Clay et al. (2016) examine the historical expansion in coal-fired electricity generation in the United States, which produced large amounts of unregulated air pollution. In counties with high baseline access to electricity, the results show that coal-fired power plants imposed large negative health externalities in counties with high baseline access to electricity. In counties with low baseline access to electricity, initial expansions in coal capacity led to decreases in infant mortality, but subsequent additions led to increases in infant mortality. Using data from openings, a power plant opening is associated with 0.6 additional infant deaths per 1,000 live births in counties within 30 miles. Using both openings and increases in coal capacity, a one standard deviation increase in capacity is associated with 2 additional infant deaths per 1,000 live births. The AP3 estimates are used to evaluate three counterfactual scenarios based on technology that existed at the time: increased smokestack height, earlier development of hydroelectric power, and use of baghouses, which reduce emissions with fabric filters. The three scenarios would have saved 1,000-1,700 infant lives per year. Further, the reductions would have been cost effective, costing less than the estimated value of a statistical life in 1940.

Barreca et al. (2014) study the effect of the decline in the use of bituminous coal for heating on infant and all-age mortality. Air pollution was severe in many urban areas of the United States in the first half of the twentieth century, in part due to the burning of bituminous coal for heat. Coal consumption for heat varied considerably between 1945 and 1960 due to coal-labor strikes, oil and gas restrictions, and the expansion of natural gas pipelines from the Southwest. To separate out the effects of coal for heating from coal for other uses, the paper exploits the fact that coal consumption for heating was highest in the winter. Triple difference estimates using state-year-season suggest that reductions in the use of bituminous coal for heating decreased winter all-age mortality by 1.25% and winter infant mortality by 3.27%, saving 1,923 all-age lives per winter month and 310 infant lives per winter month.

Muller (2020) uses air pollution monitor data, which are available starting in the late 1950s in the United States, to measure of national output inclusive of pollution damage. Monitor data are combined with standard dose-response curves to calculate and monetize the annual number of deaths from air pollution. While there are other costs of air pollution, the large value of a statistical life (VSL) means that deaths dominate the costs. The aggregate costs of deaths from air pollution are then compared to GDP. The paper finds that the aggregate costs of pollution were large in the 1960s, accounting for 30% of GDP. By 2016, the costs had fall to under 10%. One implication is that growth rates that do and do not account for pollution damage – environmentally adjusted value added (EVA) and GDP – differ significantly. Before the passage of the Clean Air Act (1970) the growth rate of GDP outpaced EVA. After 1970, EVA grew more rapidly than GDP. In the 1970s and 1980s, EVA was more than 1% higher than GDP. As the costs of pollution have fallen, the two growth rates became more similar. In the 2010s, EVA was only 0.15% higher than GDP.

The evidence from the United States highlights the harm from air pollution in the early and mid twentieth century. It also highlights that the harm was not inevitable – cost effective interventions could have reduced pollution from coal fired power plants – and that the high GDP growth rates prior to the 1970s came at significant human cost.

Great Britain

Beach and Hanlon (2018) measure the effects of industrial coal use on mortality in Britain over 1851-1860. Estimates of coal use at the district level are constructed based on industry employment by district and industry coal intensity. A range of estimation approaches are taken including baseline estimates, estimates leveraging wind direction, and estimates that use coal as an input into air pollution modeling software. Depending on the estimation approach a one standard deviation increase in coal consumption increased infant mortality by 1.7-10%. It also had adverse effects on mortality for adults and children under 5. This paper provides the earliest estimates of the effects of air pollution on mortality in a setting where air pollution was severe and medical care was extremely limited.

Heblich et al. (2021) leverages a similar approach that combines locations of chimneys, industrial employment and coal intensity, and air quality modeling at extremely fine levels of geographic detail to construct measures of pollution at the neighborhood level. The motivation is the observation that the east sides of many cities are poorer than other parts of the cities and the fact that prevailing winds often blew pollution eastward. The paper shows that neighborhood pollution is related to the share of low skilled workers in the neighborhood in 1881. IV estimates suggest that a one standard deviation increase in air pollution increased the share of low-skilled workers living in the neighborhood by 9 percentage points. This pattern was not present in 1817, before the Industrial Revolution. Strikingly, the paper shows the effects of this pollution-induced neighborhood sorting have persisted to the present.

Hanlon (2020) uses panel data for 31 British cities over the period 1851-1911 to evaluate the effects of industrial air pollution on city growth. Air pollution can make cities less attractive places to live and impair productivity. The paper extends the Rosen-Roback model, which makes it possible to separate the positive employment growth that occurs with industrial expansion from the negative effects when growth occurs in heavily polluting coal-intensive industries. Across a range of specifications, increasing industrial coal consumption substantially reduced employment growth and the working population. Drawing on detailed evidence on inefficiency in coal use, the paper then investigates whether a 10% reduction in the growth of coal use would have led to a higher urbanization rate in 1911. In 1911, 34% of the population lived in the 31 cities in the sample. In the counterfactual 38% would have lived in these cities, suggesting that pollution reduced urbanization in Great Britain.

Clay and Troesken (2011) evaluates evidence put forward by Fredrick Brodie in 1903 that air quality had begun to improve in London after 1890. This prefigured later debates about environmental Kuznets curves. The paper first draws on a range of evidence to understand whether the patterns that Brodie identified are substantiated in other sources. Other weather stations saw similar patterns of foggy days, Brodie's measure of pollution; measures of sunlight increased; and bronchitis and pneumonia fell both in London and in other cities. It then addresses a puzzle – air quality appears to improved after 1890, yet coal consumption did not fall. A number of factors appear to have played roles. Population dispersed, spreading out beyond London proper, which is just 1.2 square miles, to Greater London. Population per hectare in London proper fell from 400 in 1861 to about 100 in 1911. Firms began to use coal more efficiently. This may in part have been in response to the 1891 Public Health Act, which allowed manufacturers to be fined for dense smoke emissions. Firms and households replaced more polluting softer coal with less polluting harder coal. Residential users began to use gas instead of coal for cooking.

Lindmark (2004) draws on data for a wide range of countries including the United Kingdom and the United States to understand the relationship between CO_2 emissions and GDP over time. Different countries have had quite different trajectories, with the United Kingdom and the United States exhibiting patterns consistent with an environmental Kuznets curve. For many other countries, such a transition is less evident. What is evident is convergence in carbon intensity across countries. The paper discusses reasons for the convergence.

The evidence from the Great Britain addresses the effect of air pollution on a broad range of outcomes. In addition to increasing mortality, air pollution had persistent effects on neighborhood sorting, slowed city growth, led to regulation, and influenced carbon intensity.

Water Pollution

Water pollution has been of interest to economic historians, because of its likely role in the urban mortality penalty. The availability of running water, particularly unpolluted running water, supported a range of health promoting behaviors including drinking and cooking with clean water, washing clothes and dishes, cleaning the living space, bathing, washing hands, and the transition to indoor plumbing. One thing to note in both the U.S. and the European literatures is that the pollution is from human waste. Industrial water pollution, because it generally had more limited effects on human health, has received less attention.

United States

In the first modern study of the effects of clean water on mortality, Cutler and Miller (2005) draw on data from 13 large cities spanning 1900-1936. Using a difference in differences approach, the analysis measures the effects of filtration and chlorination on mortality. Because of the politics of approving water systems and the delays in construction, the timing of adoption was plausibly exogenous. The paper finds very large effects of filtration on typhoid, total, infant, and child mortality, with declines of 46%, 16%, 43%, and 46%. These declines account for nearly all of the decline between 1900 and 1936 in typhoid mortality and more than 60% of the declines in infant and child mortality. Back of the envelope calculations suggest the social rate of return was very high and the cost per life-year saved was low.

Recent work by Anderson et al. (2022) has reexamined the effects of clean water on mortality and found much smaller effects. Using data for 25 cities over 1900-1940, the paper finds no effects on total mortality and 11-12% declines in infant mortality. While the two papers differ in the number of cities, time periods, and specifications including controls for sewage and milk standards, Anderson et al. (2022) show that the main differences in estimates arise because of corrections to data. These include corrections for calculation of total mortality rates, infant mortality counts, and dates of filtration and chlorination.

Alsan and Goldin (2019) use data from Massachusetts covering 1880-1920 to understand the separate and combined effects of clean water and sewerage systems on under-5 mortality. In contrast to the cities studied in Cutler and Miller (2005) and Anderson et al. (2022), which used filtration or chlorination to treat water, Massachusetts cities used impounding reservoirs to improve water quality. The other thing to note is that almost all of the water and sewer interventions in Massachusetts occurred prior to 1900 and so predate the interventions in Cutler and Miller (2005) and Anderson et al. (2022). Consistent with Anderson et al. (2022), the effects of water interventions alone on child (under-5) and infant mortality were modest. The effects of sewer interventions alone were also modest. The two combined had larger effects, suggesting that water and sewer interventions were complements. The combination lowered child and infant mortality by 27 and 23 log points, accounting for 34 and 48% of overall declines. The interventions had no effect on tuberculosis and non-child mortality.

Clay et al. (2014) investigate the effect of a different type of pollution – water-borne lead exposure – on infant mortality. Infants are highly sensitive to lead, and more broadly are a marker for current environmental conditions. The paper draws on data from 172 large and medium size U.S. cities. These cities varied in the types of service pipes used and in water acidity. Acidity affected the extent to which lead leached into the water from lead pipes, and so the two jointly affected the extent of lead exposure. The magnitudes of the effects of lead pipes on infant mortality were large. In 1900, a decline in exposure equivalent to an increase in pH from the 25th percentile to the 50th percentile in cities with lead-only pipes would have been associated with a decrease in infant mortality of 7 to 33% or at least 12 fewer infant deaths per 1,000 live births. Further support for the causal link between water-borne lead and infant mortality comes from estimates limited to cities with lead pipes and from panel estimates. This paper built on earlier work by Werner Troesken in Troesken (2006) and Troesken (2008) on lead in water in Massachusetts.

These papers on U.S. cities document the benefits of providing clean water and sewerage for health during the late nineteenth and early twentieth centuries. Some U.S. cities saw larger declines in mortality than others, in part because of decisions by city engineers to use lead pipes to deliver the clean water and in part because early water systems did not use corrosion control to limit lead leaching. Thus, cities with acidic water and lead pipes had high water lead levels, which increased infant mortality.

Europe

Chapman (2019) examines the effect of investment in urban infrastructure on mortality in 380 districts in England and Wales between 1861 and 1900. The infrastructure investment included water and sewer systems as well as roads and bathhouses. IV estimates using two different instruments show that these investments caused declines in mortality rates. These infrastructure-driven declines explain 45-60% of declines in urban mortality. Consistent with a substantial amount of the investment going to water and sewers, analysis by cause of death shows large declines in waterborne diseases. Airborne diseases also fell, perhaps as a result of decreased exposure to disease from sewers or crowding and stronger immune systems. Placebo tests show that investments in urban infrastructure had no impact on mortality in childbirth and violence-related mortality.

Gallardo-Albarrán (2020) draws on data for 34 German cities over 1877-1913 to investigate the impact of water and sewer infrastructure on infant and total mortality. Provision of clean water, which lagged sewerage by a couple of decades, had a statistically significant effect on infant mortality but not total mortality. The introduction of sewers caused statistically significant declines in both types mortality. The joint effect of water and sewer was 11% for each type of mortality. Infrastructure explains 25% of the decline in infant mortality and 21% of the decline in total mortality. There was some heterogeneity in effects, notably the effects were large in Prussia and smaller in Bavaria and elsewhere.

Using data from 80 neighborhoods in Paris over 1885-1913, Kesztenbaum and Rosenthal (2017) measure the effects of sewer connections on life expectancy. Parisians already had access to clean water, so the intervention has some similarities to Alsan and Goldin (2019) in that it measures the effect of having clean water and sewers. The timing of sewer connections were a function of neighborhood willingness to pay. Building owners fought regulations that would have mandated connections to sewers. Thus connections occurred when landlords anticipated that the increase in rent would be greater than the cost of hookup. The authors take a range approaches to addressing the endogeneity including using a rich set of controls, controlling for rent in some specifications, and using instrumental variables. In line with Alsan and Goldin (2019), the paper shows sewer connections contributed several years to life expectancy. Although the paper does not have data for infants, the effects were particularly large for children ages 1-4 and were smaller for prime age adults and the elderly. This is consistent with patterns in other contexts.

These papers find that providing clean water and sewerage decreased mortality during the late nineteenth and early twentieth centuries in England, Germany, and Paris. Together with the previous papers on U.S. cities, they highlight the role that water and sewerage played in the decline in the urban mortality penalty.

Conclusion

This survey of cliometric papers on energy and the environment highlights a number of opportunities for further research in energy and the environment. One opportunity is to broaden the set of countries studied beyond the United States and the Great Britain. Scattered work has been done on other European countries, but there is likely to be further opportunities to expand the existing literatures. Even the relatively more developed literatures on the spatial location of economic activity and the health effects of reducing exposure to water pollution would benefit from studies of new countries.

Another opportunity is to deepen the work on a range of topics where the economic history literature is thin. Some examples include technological change, the effects of energy shocks on economic activity, the effect of access to electricity on health, and the effects of air pollution on health. Technological change played critical roles in the development of engines that powered transportation – cars, tractors, busses, railroads – and the electricity infrastructure, yet very little cliometrics work has been done. The subliteratures on energy shocks on economic activity, the effect of access to electricity on health, and the effects of air pollution on health have a few more papers, but the literature would benefit from exploration of these issues for a greater range of time periods, countries, and outcomes.

The third opportunity is to break new ground on a range of topics that have received almost no attention in the economic history literature, despite having substantial energy and environment literatures. On the energy side, examples include the operation and competitiveness of energy markets – coal, oil, natural gas, and electricity. The modern literature on energy has large literature on a number of these markets, especially electricity, yet there are no historical papers. On the environmental side, examples include industrial pollution, especially water and land pollution. While the modern literatures on these topics are still developing, historical evidence could provide important insights.

References

Alsan, Marcella and Claudia Goldin, "Watersheds in child mortality: The role of effective water and sewerage infrastructure, 1880–1920," *Journal of Political Economy*, 2019, *127* (2), 586–638.

Anderson, D Mark, Kerwin Kofi Charles, and Daniel I Rees, "Reexamining the contribution of public health efforts to the decline in urban mortality," *American Economic Journal: Applied Economics*, 2022, *14* (2), 126–57.

Barreca, Alan, Karen Clay, and Joel Tarr, "Coal, Smoke, and Death: Bituminous Coal and American Home Heating," Technical Report, National Bureau of Economic Research 2014.

Beach, Brian and W Walker Hanlon, "Coal smoke and mortality in an early industrial economy," *The Economic Journal*, 2018, *128* (615), 2652–2675.

—, John Parman, and Martin Saavedra, "Segregation and the Initial Provision of Water in the United States," in "AEA Papers and Proceedings," Vol. 112 2022, pp. 193–98.

Carson, Rachel, *Silent Spring*, Houghton Mifflin, 1962.

Chapman, Jonathan, "The contribution of infrastructure investment to Britain's urban mortality decline, 1861–1900," *The Economic History Review*, 2019, *72* (1), 233–259.

Clark, Gregory and David Jacks, "Coal and the industrial revolution, 1700–1869," *European Review of Economic History*, 2007, *11* (1), 39–72.

Clay, Karen, "The Environment in American Economic History," *The Oxford Handbook of American Economic History, vol. 2*, 2018, p. 349.

— and Werner Troesken, "Did Frederick Brodie Discover the World's First Environmental Kuznets Curve? Coal Smoke and the Rise and Fall of the London Fog," in Gary Libecap and Richard H. Steckel, eds., *The Economics of Climate Change: Adaptations Past and Present*, Chicago, IL: University of Chicago Press, 2011, pp. pp. 281–310.

—, Joshua Lewis, and Edson Severnini, "Canary in a Coal Mine: Impact of Mid-20th Century Air Pollution Induced by Coal-Fired Power Generation on Infant Mortality and Property Values," *NBER Working Paper No. 22155*, 2016.

—, —, and —, "Pollution, infectious disease, and mortality: Evidence from the 1918 Spanish influenza pandemic," *The Journal of Economic History*, 2018, *78* (4), 1179–1209.

—, Werner Troesken, and Michael Haines, "Lead and mortality," *Review of Economics and Statistics*, 2014, *96* (3), 458–470.

Crafts, Nicholas and Abay Mulatu, "How did the location of industry respond to falling transport costs in Britain before World War I?," *The Journal of Economic History*, 2006, *66* (3), 575–607.

Cutler, David and Grant Miller, "The role of public health improvements in health advances: the twentieth-century United States," *Demography*, 2005, *42* (1), 1–22.

DuBay, Shane G and Carl C Fuldner, "Bird specimens track 135 years of atmospheric black carbon and environmental policy," *Proceedings of the National Academy of Sciences*, 2017, *114* (43), 11321–11326.

Fernihough, Alan and Kevin Hjortshøj O'Rourke, "Coal and the European industrial revolution," *The Economic Journal*, 2021, *131* (635), 1135–1149.

Fiszbein, Martin, Jeanne Lafortune, Ethan G Lewis, and José Tessada, "Powering Up Productivity: The Effects of Electrification on US Manufacturing," Technical Report, National Bureau of Economic Research 2020.

Fouquet, Roger, "Divergences in long-run trends in the prices of energy and energy services," *Review of Environmental Economics and Policy*, 2011.

_ , "Long run trends in energy-related external costs," *Ecological Economics*, 2011, *70* (12), 2380–2389.

Gallardo-Albarrán, Daniel, "Sanitary infrastructures and the decline of mortality in Germany, 1877–1913," *The Economic History Review*, 2020, *73* (3), 730–757.

Hanlon, W Walker, "Coal smoke, city growth, and the costs of the industrial revolution," *The Economic Journal*, 2020, *130* (626), 462–488.

Heblich, Stephan, Alex Trew, and Yanos Zylberberg, "East-side story: Historical pollution and persistent neighborhood sorting," *Journal of Political Economy*, 2021, *129* (5), 1508–1552.

Henriques, Sofia Teives and Karol J Borowiecki, "The drivers of long-run CO2 emissions in Europe, North America and Japan since 1800," *Energy Policy*, 2017, *101*, 537–549.

Huntington, Hillard G, "The Historical "Roots" of US Energy Price Shocks," *The Energy Journal*, 2017, *38* (5).

Kander, Astrid, Paolo Malanima, and Paul Warde, "Power to the People-Energy in Europe over the last five Centuries," *Mokyr (ed.) Princeton Economic History of the Western World*, 2013.

Kesztenbaum, Lionel and Jean-Laurent Rosenthal, "Sewers' diffusion and the decline of mortality: The case of Paris, 1880–1914," *Journal of Urban Economics*, 2017, *98*, 174–186.

Klein, Alexander and Nicholas Crafts, "Making sense of the manufacturing belt: determinants of US industrial location, 1880–1920," *Journal of Economic Geography*, 2012, *12* (4), 775–807.

Kline, Patrick and Enrico Moretti, "Local Economic Development, Agglomeration Economies, and the Big Push: 100 Years of Evidence from the Tennessee Valley Authority," *Quarterly Journal of Economics*, 2014, *129* (1), 275–331.

Leknes, Stefan and Jørgen Modalsli, "Who Benefited from Industrialization? The Local Effects of Hydropower Technology Adoption in Norway," *The Journal of Economic History*, 2020, *80* (1), 207–245.

Lewis, Joshua, "Infant health, women's fertility, and rural electrification in the United States, 1930–1960," *The Journal of Economic History*, 2018, *78* (1), 118–154.

_ **and Edson Severnini**, "Short-and long-run impacts of rural electrification: evidence from the historical rollout of the US power grid," *Journal of Development Economics*, 2020, *143*, 102412.

Lindmark, Magnus, "Patterns of historical CO2 intensity transitions among high and low-income countries," *Explorations in Economic History*, 2004, *41* (4), 426–447.

Matheis, Mike, "Local economic impacts of coal mining in the United States 1870 to 1970," *The Journal of Economic History*, 2016, *76* (4), 1152–1181.

Mokyr, Joel, "The contribution of economic history to the study of innovation and technical change: 1750–1914," *Handbook of the Economics of Innovation*, 2010, *1*, 11–50.

Muller, Nicholas Z, "On the divergence between fuel and service prices: The importance of technological change and diffusion in an American frontier economy," *Explorations in Economic History*, 2016, *60*, 93–111.

_ , "Long-run environmental accounting in the US economy," *Environmental and Energy Policy and the Economy*, 2020, *1* (1), 158–191.

Nordhaus, William D, "Do real-output and real-wage measures capture reality? The history of lighting suggests not," in "The economics of new goods," University of Chicago Press, 1996, pp. 27–70.

Rosenberg, Nathan and Manuel Trajtenberg, "A general-purpose technology at work: The Corliss steam engine in the late-nineteenth-century United States," *The Journal of Economic History*, 2004, *64* (1), 61–99.

Severnini, Edson, "The Power of Hydroelectric Dams: Historical Evidence from the United States over the Twentieth Century," *The Economic Journal*, 2023, *133* (649), 420–459.

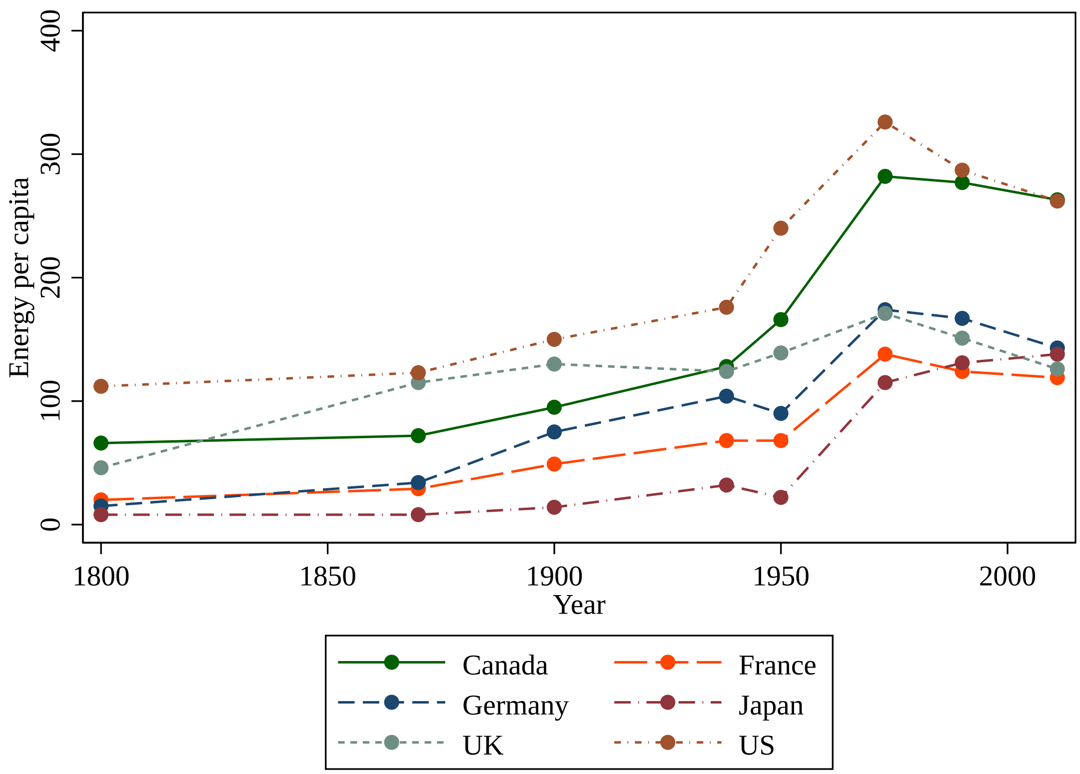
Troesken, Werner, *The great lead water pipe disaster*, Mit Press, 2006.

_ , "Lead water pipes and infant mortality at the turn of the twentieth century," *Journal of Human Resources*, 2008, *43* (3), 553–575.

van de Ven, Dirk Jan and Roger Fouquet, "Historical energy price shocks and their changing effects on the economy," *Energy Economics*, 2017, *62*, 204–216.

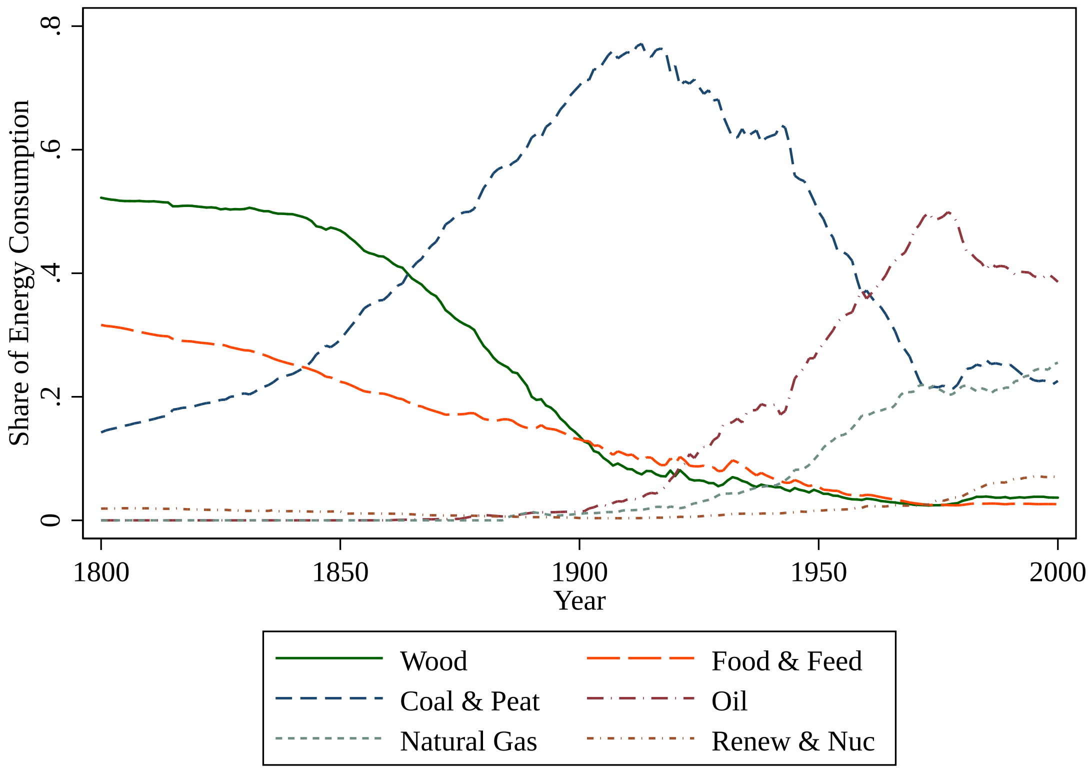
Figures and Tables

Fig. 1: Trends in Per Capita Energy Consumption



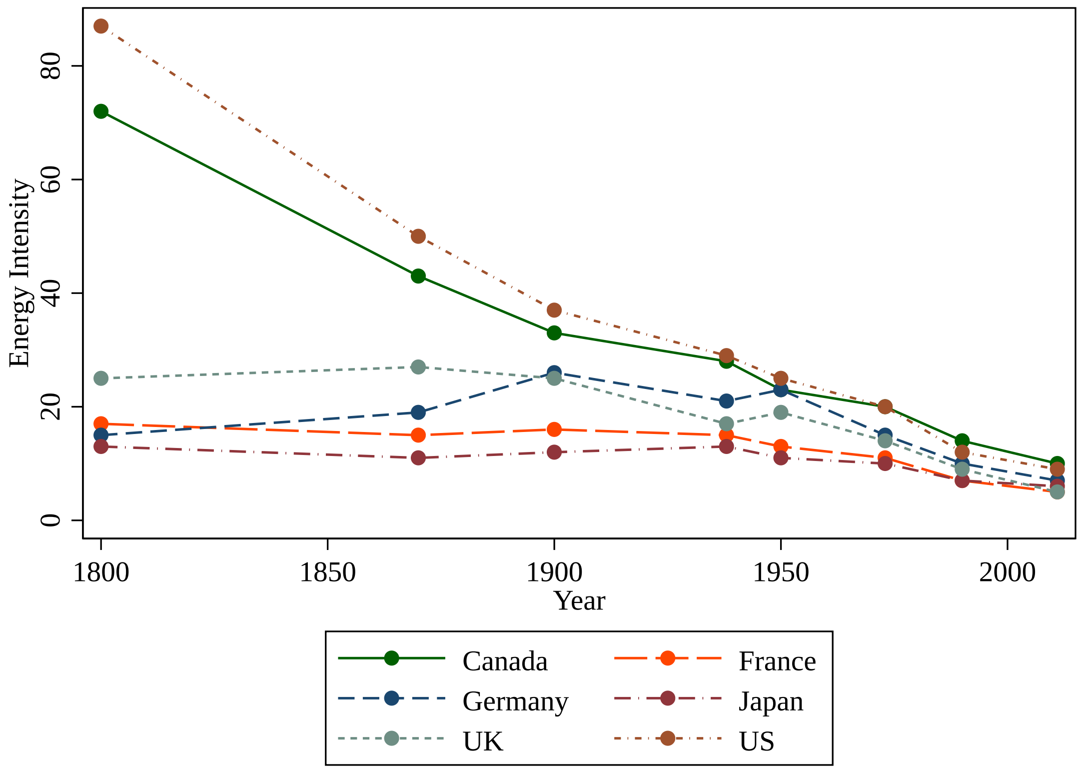
Notes: Energy per capita is in gigajoules per capita. Based on data from Henriques and Borowiecki (2017).

Fig. 2: Trends in Mix of Energy Inputs



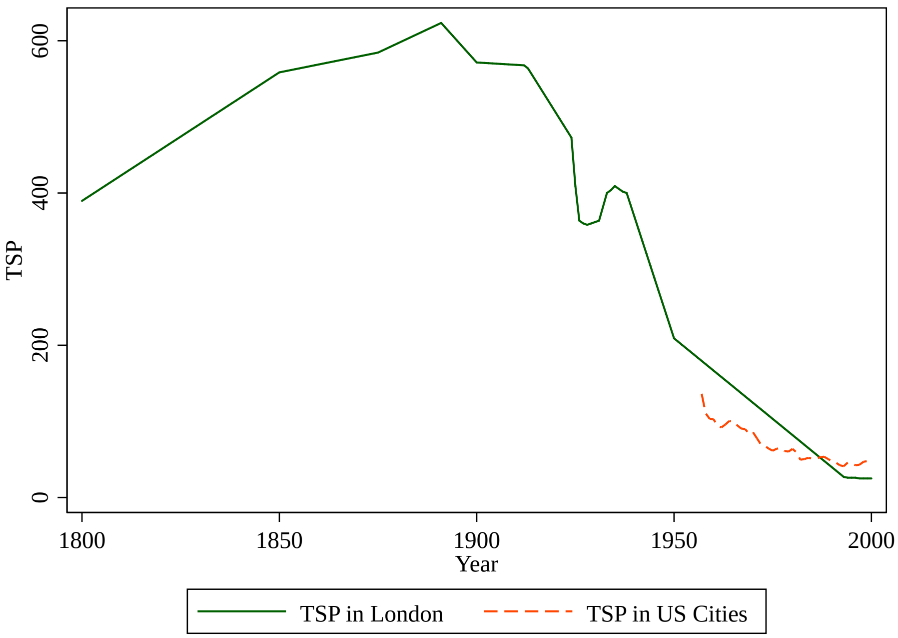
Notes: Based on data from Henriques and Borowiecki (2017).

Fig. 3: Trends in Energy Intensity

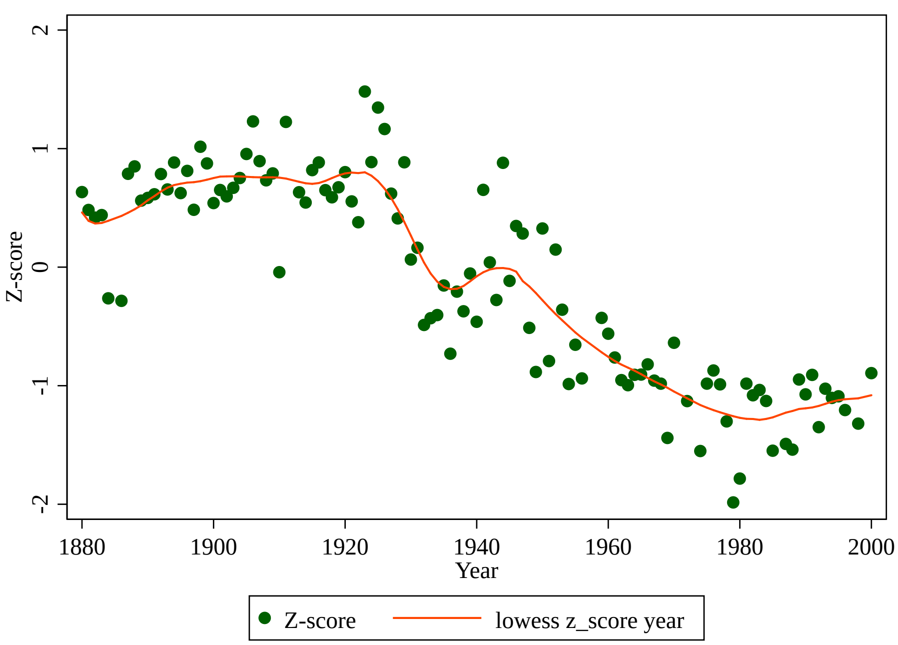


Notes: Energy intensity is in megajoules per 1990 U.S. dollar of GDP. Based on data from Henriques and Borowiecki (2017).

Fig. 4: Trends in Air Pollution



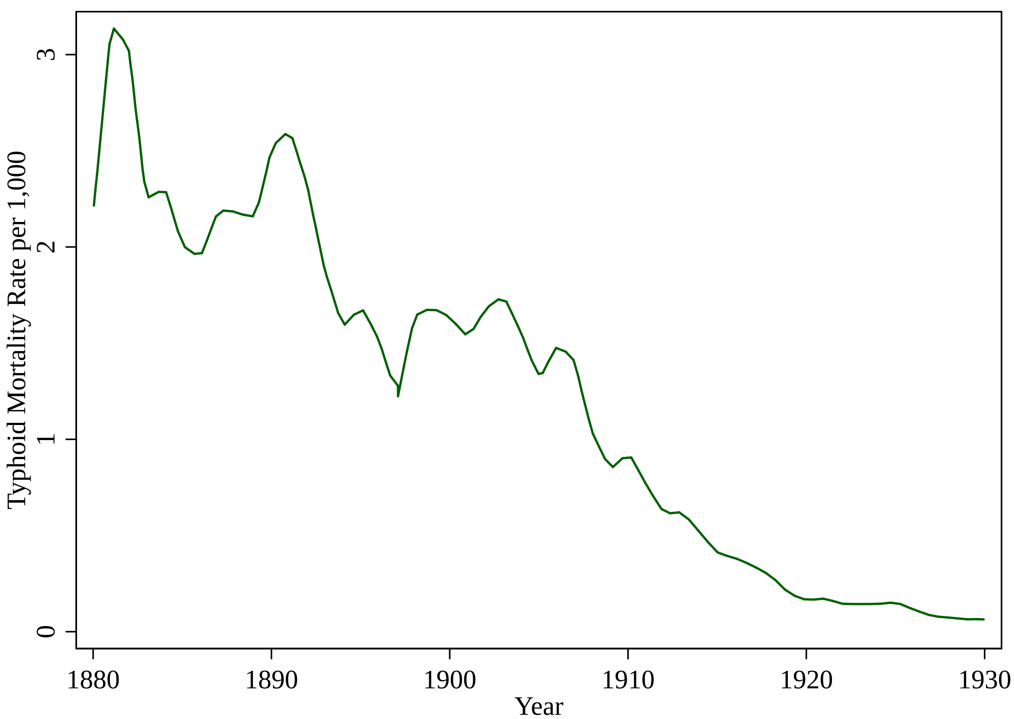
(a) TSP in London and U.S. Cities



(b) Black Carbon Measured from Bird Feathers in the U.S. Manufacturing Belt

Notes: Based on data from DuBay and Fuldner (2017); Fouquet (2011b); Clay et al. (2016). DuBay and Fuldner (2017) use photometric reflectance data for bird specimens to measure black carbon. In periods with higher pollution, bird of the same species will have black carbon (soot) on their feathers. The z-score measures relative reflectance. Each dot is the average z-score for a year. Lowess is bandwidth(.2)

Fig. 5: Trends in the Typhoid Mortality Rate in U.S. Cities



Notes: Typhoid mortality rate is per 1,000 persons in U.S. cities. The figure is based on data from Beach et al. (2022).