Killer Cities: Past and Present *

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Abstract

Industrial pollution was endemic to the industrial cities of the 19th century and remains a feature of some modern cities, particularly industrial cities in emerging economies. This study compares the relationship between pollution and mortality in both the historical and modern context, focusing on English cities in the mid-19th century and Chinese cities in 2000. For both contexts, we construct proxies for district pollution levels based on their industrial composition and information on the pollution level of industries, as well as a similar set of control variables. Our results reveal a positive relationship between industrial pollution and mortality in both contexts, but the relationship was roughly five times stronger in historical England than in modern China. This suggests that, while substantial progress has been made, industrial pollution remains an important health risk in modern cities.

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Pollution remains a substantial health threat in modern cities. For example, a 2012 World Health Organization report attributed 3.7 million premature deaths to ambient air pollution. Of these, about 88% occur in low- and middle-income countries, chiefly in East and South Asia. In Chinese cities, one of the subjects of this study, the air of booming mega-cities is sometimes so thick with soot that news reports have dubbed it an "airpocalypse" and the contribution of air pollution is estimated to have led to 1.2 million excess deaths in 2010 (*New York Times*, April 1, 2013). While striking, these experiences are not unprecedented. In the industrial cities late 19th and early 20th century England – the second focus of this study – pollution was also substantial. Troesken & Clay (2011) estimate that in the winter of 1890-91, adverse weather conditions that trapped the smoke in London led to 7,405 excess deaths in that city alone, while the Great London Fog of 1956 is estimated to have killed over 5,000.

How similar is the pollution experience of modern China to that experienced by industrial countries in history? How much progress has been made in reducing the effects of pollution in urban areas? One reason that we care about the answers to these questions stems from work on the Environmental Kuznets Curve (Grossman & Krueger (1995)), which suggests that pollution will respond to rising income by following a predictable inverted U-shaped path. Support for this idea rests in part on the observed evolution of pollution levels in early industrializing countries, including England. This point is highlighted by Zheng & Kahn (2013), who write, "A long-run urban environmental history for developed nations suggests that local environmental problems could improve in Chinese cities." Similarly, Vennemo *et al.* (2009) argue that, "China's development with respect to environmental pollution appears to be following a path that is similar to the one established by more industrialized countries when they were at earlier stages of development." A second reason to care about the questions above is that we may be able to use the experiences of early industrial cities in places like England, where richer data are often available, to learn about the impacts of high pollution levels in modern cities, where some types of data are often less available.

This study evaluates the similarity of modern and historical experiences by focusing on the impact of industrial pollution in two settings, England from 1861-1890 and China in 2000. This comparison is motivated in part by the fact that historical England and modern China were major industrial producers. It has also been suggested that, there are similarities in the pollution issues they faced.

We consider one important outcome – mortality – which can be observed in both of these settings. Specifically, we construct measures of industrial pollution, as well as a set of control variables, that are similar across these two settings. Comparing mortality levels across urban districts within each setting, we obtain estimates of the relationship between pollution and mortality that are reasonably comparable across the historical and modern settings.

The approach used in this study bypasses the need for direct measures of pollution measures and instead substitutes proxies for the level of pollution being produced in a location based on the composition of industries and information about the pollution intensity of different industries. One advantage of this approach is that it can be applied in both historical and developing settings, where direct pollution measures are often unavailable. A second advantage is that our measure will reflect a multi-dimensional version of pollution, rather than a single pollution measure. However, this also means that we cannot differentiate the impact of specific types of pollution.

This approach is similar to that used by Glaeser & Kahn (2008) for the U.S. and Zheng *et al.* (2011) for China, except that we focus on industrial sources of pollution rather than pollution produced by households. One motivation for our focus on industrial pollution is that industry is a major pollution producer. For example, Zheng & Kahn (2013) report that industry consumes 89.1 percent of total energy in China. A second reason to focus on industry is that it tends to be geographically concentrated, leading some areas to have much higher pollution levels than others.

This study is related to a substantial literature documenting the relationship between pollution and mortality using data from developed countries (e.g., Samet *et al.* (2000), Pope III *et al.* (2002), Chay *et al.* (2003), etc.). Less is known about pollution in developing countries, where pollution levels can be substantially higher than those observed in developed countries today. However, recent studies have begun to explore this issue (Jayachandran (2009), Almond *et al.* (2009), **?**, Ebenstein (2012), Greenstone & Hanna (2014), etc.). The major challenge faced by this literature is a lack of reliable data on pollution levels, pollution causes, and outcomes. For similar reasons, our understanding of historical pollution patterns is also somewhat limited, though recently this topic has been studied more intensively (see, e.g., Troesken & Clay (2011), Barreca *et al.* (2014), Clay *et al.* (2014)).

Data

We have attempted to construct data sets that are as similar across our two settings as possible. In England, detailed mortality data are available for each Registration District from the Registrar General's reports. We use decadal average mortality data for three decades from 1861-1890. The data we use come from 64 districts corresponding to the largest British cities.[1] For China, we use mortality data for urban district or county-level cities (hereafter just districts) from the Fifth Population Census. We focus primarily on 221 urban districts, defined as those above the 90th percentile in terms of the share of population with non-agricultural registration status.[2]

We also require similar measures of industrial pollution in districts in both of our settings. Because direct pollution measures are unavailable, we use data describing the industrial composition of districts, together with information on the pollution level of different industries, to approximate the level of industrial pollution in cities. In both settings we use the same list of heavily polluting industries. This list was produced by the Chinese government, but it corresponds well to information on the major polluting industries in the 19th century based on historical sources. For example, almost all of the heaviest coal using industries based on the 1907 British Census of Production are included in the Chinese list of heavily polluting industries. Table 1 provides a list of the polluting and less polluting industries mapped to the industrial categories available in the English data.

[1]This set does not include London, which is an outlier in many ways, as well as three smaller cities, Chichester, Lancaster, and Leeds, for which we were not able to construct all of the control variables in a consistent way.

[2]These cities have a share of population with non-agricultural registration status greater than or equal to 45 percent.

Table 1: List of heavily polluting and less polluting industries

Heavily polluting industries	**Less polluting industries**
Chemicals & drugs	Apparel
Earthenware & bricks	Food processing
Leather goods	Instruments & jewelry
Metal and machinery manuf.	Oils & soaps
Mining and related activity	Shipbuilding
Paper manufacturing	Tobacco processing
Brewing & distilling	Vehicle production
Textiles	Wood & furniture
Gas, electricity & water utilities	

This list is based on a classification of polluting industries produced by the Chinese government which has been mapped to the less detailed industry categories available in the British city-industry database.

In England, information on the industrial composition of cities comes from a database constructed by Hanlon & Miscio (2014) based on the Census of Population. From this database we use data on employment, by industry, from 1861 for 27 analysis industries, spanning nearly the entire private sector economy. Our measure of industrial pollution in cities is constructed by taking the ratio of employment in polluting industries to employment in all private sector manufacturing industries. We use only manufacturing industries in the denominator, rather than all private sector employment, to increase comparability with the Chinese data.[3] The geographic unit for the city-industry data is the town level. Town boundaries do not correspond directly to the registration district boundaries available in our mortality data, but we believe that the town-level polluting industry employment shares can still provide a reasonable indicator of the overall pollution level in a location.[4]

In China, our data are based on the Industrial Enterprise Survey (IES) from 2000. This survey covers all state-owned industrial enterprises and privately-owned industrial firms with sales above five million RMB annually, a total of around 163,000 firms. The employment levels reported in this survey are suspect, so instead our pollution measure for each district is constructed by taking the share of polluting industry sales to total manufacturing sales in the IES database.

[3]Our results are robust to using all private sector employment in the denominator.

[4]Towns are sometimes larger and sometimes smaller than the main associated district.

Finally, we have tried to construct a similar set of control variables for both settings. In both settings, we control for the population and population density of each district. This may reflect both positive factors, such as income, and negative factors, such as the disease environment of the district (particularly in the 19th century). For China, we include controls for the Norther provinces because the North is known to have higher pollution levels for home heating (Almond *et al.* (2009)). Similarly, for England we collect information on the average number of air frost days based on modern data from the Met. We control for whether the district was a seaport (in England) or whether it was in a coastal province (in China). For England we also include a measure of the size of trade handled by the port, based on import levels in 1885, because trade was an important carrier of disease in the 19th century.

Table 2 provides summary statistics for our key variables. We can see that mortality was much higher in 19th century England than in China in 2000. The share of employment in polluting industries was also somewhat higher. Not surprisingly, Chinese urban districts tended to have much larger populations than the English districts in our database, though the English districts were smaller and thus actually had higher population density on average.

Table 2: Summary statistics for key variables

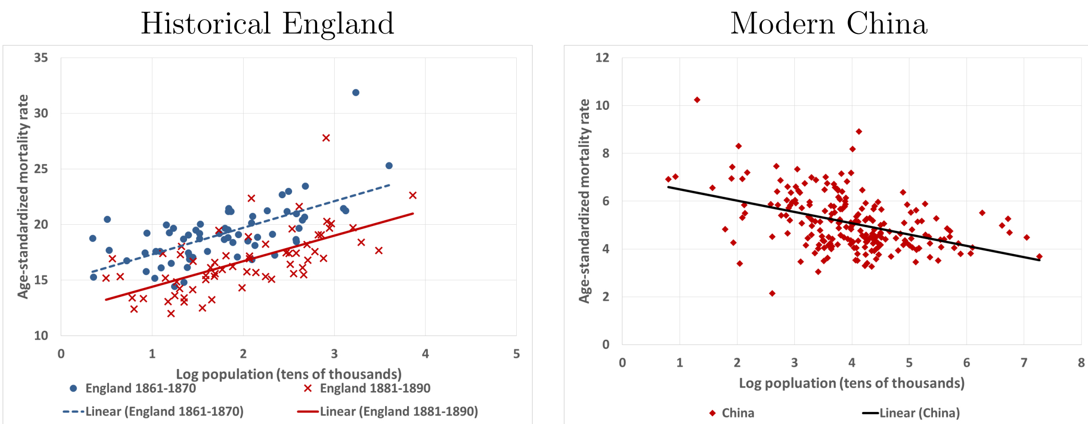
	Obs.	Average	Std. Dev.	Min.	Max.
Mortality (age-standardized)					
England in 1861	64	19.2	2.66	14.4	31.9
England in 1871	64	18.6	2.61	13.9	28.3
England in 1881	64	16.7	2.76	12.0	27.8
China in 2000	221	5.1	1.14	2.1	10.2
Polluting employment or sales share					
England in 1861 (employment share)	64	0.47	0.21	0.17	0.91
China in 2000 (sales share)	221	0.60	0.27	0.002	1.00
District population					
England in 1861	64	76,035	62,935	14,123	365,083
England in 1871	64	86,286	70,862	15,520	416,229
England in 1881	64	98,640	81,666	16,370	475,385
China in 2000	221	993,662	1,645,818	22,326	14,348,535
District population density (thousands per square kilometer)					
England in 1861	64	3.18	5.72	0.05	24.71
England in 1871	64	3.44	6.12	0.05	24.71
England in 1881	64	3.79	6.28	0.05	24.71
China in 2000	221	1.19	1.16	0.0002	6.35

District population density is reported in thousands of person per square kilometer. Population density is censored at 100 persons per acre in the English data, which generates a maximum density measure of 24.71 thousand persons per square kilometer. This censoring affects only 2-3 cities in each decade. For England, the pollution measure in all regressions is based on data from 1861.

Analysis

A good starting point for our analysis is to consider the raw relationship between city size and mortality. This is done in Figure 1, which compares the natural log of population to mortality in historical England (left panel) and modern China (right panel). Already we can see that there are striking differences between the observed patterns. In England, there is a clear urban mortality penalty. In contrast, larger Chinese cities appear to be healthier than smaller cities. The reduction of infections diseases, which were a substantial contributor to mortality in 19th century England, may explain part of this reversal. However, this reversal may also be due, in part, to changes in the impact of urban pollution.

Figure 1: Population and mortality



Our examination of the impact of urban pollution begins in Figure 2. The left-hand panel of the figure shows the strong positive relationship between mortality and the polluting industry employment share in British cities for two period, 1861-1870 and 1881-1890.[5] While we can see that the overall mortality rate is falling over time, the relationship between pollution and mortality remains steadily positive. The clear positive relationship in England contrasts with the U-shaped relationship that we observe for urban districts in China. In China, it appears that districts with high levels of pollution have higher mortality, but low pollution levels are also correlated with somewhat higher mortality.[6]

To understand these patterns, it is important to keep in mind that these raw correlations will pick up two opposing forces related to the pollution measure. While the pollution produced by industry is likely to have negative health effects, industries also mean jobs and income, which can positively affect health. This income effect may explain why, in China, we observe a negative relationship between our measure of pollution and mortality when there is a low polluting industry share.

[5]The same pattern appears in the 1871-1880 period. These data are omitted only to keep the graph from becoming too cluttered.

[6]This U-shape observed in the fitted line is not driven by our use of a second order polynomial here; it is even more apparent when higher order polynomials are used.

Figure 2: Industrial pollution and mortality

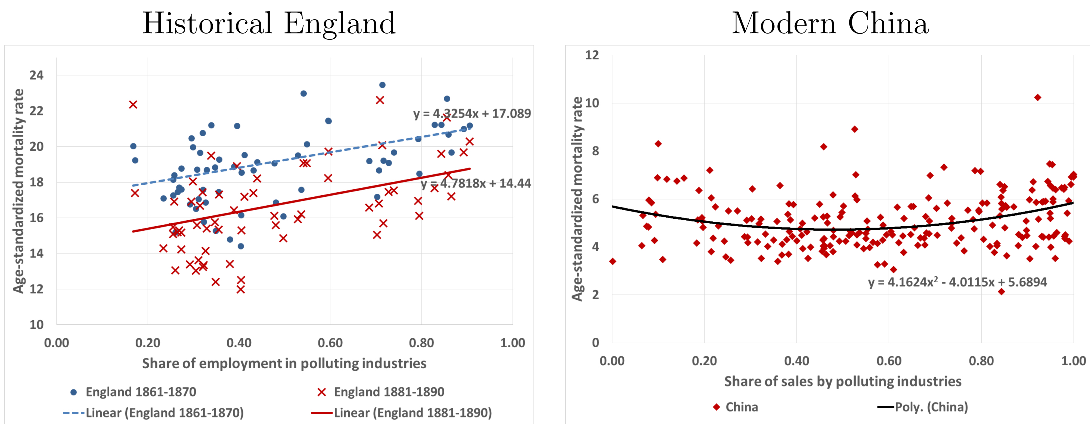


Table 3 displays regression results exploring the relationship between mortality and our proxy for district industrial pollution levels while controlling for district population, population density, and other geographic features. The first three columns describe the regressions run on British data for each of the three decades from 1861-1890. The fourth column describes results for urban districts in China. In both the British and the Chinese results, we can see that there is a fairly clear positive relationship between our measure of industrial pollution and overall age-standardized mortality. The coefficients suggest that the relationship between pollution and mortality was substantially stronger in 19th century England than it is in China today. However, as shown in the last row of the table, relative to the overall mortality level the estimated industrial pollution coefficients are not much smaller in China today than they were in historical Britain.

Table 3: Regression results for the impact of pollution on age-standardized mortality

	Historical England			**Modern China**
	1861-70	1871-80	1881-90	2000
Polluting industry shr.	2.351*	3.280**	1.614	0.430*
	(1.315)	(1.249)	(2.258)	(0.245)
Log Population	1.262**	1.492***	1.617***	-0.289***
	(0.514)	(0.430)	(0.513)	(0.0708)
Population density	0.0740**	0.0931***	0.0703*	-0.194***
	(0.0313)	(0.0295)	(0.0387)	(0.0646)
Other controls	Yes	Yes	Yes	Yes
Observations	64	64	64	221
R-squared	0.669	0.691	0.618	0.294
Avg. mortality rate	19.2	18.6	16.7	5.1
Pollution coefficient /average mortality	0.122	0.176	0.097	0.085

*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parenthesis. Additional control variables in regressions for England: average number of air frost days, seaport indicator variable, seaport import tonnage. Additional control variables in regressions for China: indicator for provinces north of the Huai River, indicator for coastal provinces.

We have also explored the robustness of our results to including additional control variables. For both England and China, we have constructed additional control variables describing the level of education in each district. In China, our measure, which is based on the average years of schooling of district residents, is strongly negatively related to mortality.[7] Including this variable slightly increases the estimated strength of the relationship between pollution and mortality. In Britain, our education measure is based on the share of the district population attending school in 1851 from the 1851 Census of Population.[8] This measure does not have a strong relationship to mortality and including this variable does not influence our results.

For China, we have run additional regressions including a measure of county-level GDP, and the latitude and longitude of the district. Our results are robust to including these alternative controls.[9] We have also explored adding province fixed

[7] This is consistent with previous findings such as Lleras-Muney (2005).

[8] This was the only 19th century Census in which educational information was collected.

[9] For England, it is not possible to include latitude as a control variable because, with most of England's industrial activity concentrated in the North, latitude is too strongly correlated with our pollution measure. While our coefficient estimates remain stable, this multicolinearity increases the confidence intervals substantially. However, given that we have a direct measure of the amount of heating required in a location through the air frost days variable, there is little reason to include

effects to our regressions using Chinese data. Our results are not substantially affected by the inclusion of province fixed effects.[10] We have also produced results using all of the districts in China, while controlling for the share of agricultural employment in the district. These results suggest a statistically significant positive relationship between mortality and pollution that is roughly half as large as that found for only the urban districts, consistent with our expectation that the impact will be lower in more rural areas where industry is less densely concentrated.

We may be concerned that the relationship between polluting industries and mortality is due to factors other than pollution, such as higher on-the-job accident rates in polluting industries. It is possible to explore this concern in the English data, where detailed cause-of-death information is available.[11] These results (available upon request) show that the relationship between polluting industry employment share and mortality in England is driven primarily by higher levels of mortality due to respiratory causes. There is also evidence of an increase in mortality in childbirth and mortality due to infections diseases of the lungs, such as tuberculosis, measles, and whooping cough. These relationships are consistent with the impact of industrial pollution operating mainly through pollution, and air pollution in particular. These findings also suggest that infectious diseases and pollution may have combined to further increase mortality rates in 19th century England. Thus, the reduction in infectious diseases may be an important cause for the reduction in mortality due to pollution that we observe when comparing 19th century England to modern China.

It is also possible to look at the impact of pollution and mortality by age group. Table 4 describes the coefficient on the pollution variable for a series of regressions, where the dependent variable is the mortality rate within a particular age group. Each regression includes the same set of control variables as the baseline regressions described in Table 3.

Three interesting patterns are visible in Table 4. First, the pollution measure is strongly associated with higher pollution among children younger than 10 years old in 19th century England. However, this pattern appears to have largely disappeared in modern China. Second, in both England and China, pollution is associated with

latitude as well.

[10]For the British data, it is not possible to add similar region or county fixed effects because we have fewer observations.

[11]We have not been able to obtain similarly detailed cause-of-death data for Chinese districts.

higher levels or mortality for people in the early 20s. While it is not clear what is behind this pattern, it appears in a fairly consistent way across both settings. Third, we observe higher levels of mortality at ages over 50 in more polluted locations. This is consistent with a cumulative effect of pollution that has an effect increasing in years of exposure.

Table 4: Pollution effects by age group

	Ages 0-4	Ages 5-9	Ages 10-14	Ages 15-19	Ages 20-24	Ages 25-34	Ages 35-44	Ages 45-54	Ages 55-64	Ages 65-74	Ages 75 +
England	11.74	2.486***	1.172	3.207***	2.296*	0.185	-2.594	-1.176	4.652	16.28**	21.98***
1861	(14.00)	(0.832)	(0.706)	(1.068)	(1.147)	(1.184)	(2.044)	(2.445)	(3.948)	(6.333)	(6.079)
England	17.43	1.860**	0.555**	2.264***	2.184**	-1.313	0.185	1.204	8.216**	14.92*	43.99**
1871	(12.25)	(0.831)	(0.244)	(0.642)	(0.932)	(1.570)	(1.845)	(2.727)	(4.038)	(8.227)	(19.20)
England	12.45	1.066	0.305	0.803	1.508*	1.999	0.311	4.721*	11.36**	20.36***	23.05**
1881	(9.904)	(0.662)	(0.531)	(0.561)	(0.755)	(1.605)	(2.237)	(2.542)	(4.334)	(6.915)	(10.00)
China	0.0629	-0.0303	0.0116	0.0453	0.210**	0.0851	0.114	0.0115	0.245	2.682*	0.00688*
2000	(1.250)	(0.0649)	(0.0440)	(0.0666)	(0.0982)	(0.0976)	(0.135)	(0.264)	(0.725)	(1.498)	(0.00408)

Table describes coefficients and standard errors for the pollution measure from regressions where the dependent variable is the mortality rate for a particular age group. All regressions include the log of district population, district population density. Additional control variables in regressions for England: average number of air frost days, seaport indicator variable, seaport import tonnage. Additional control variables in regressions for China: indicator for provinces north of the Huai River, indicator for coastal provinces.

Discussion

The results of this study suggest that, even in some of the most polluted cities on earth, substantial progress has been made in reducing the impact of polluting industries on health. A number of potential channels may be behind the progress we observe. It may be that polluting industries have become cleaner than they were, even in areas where they are lightly regulated. Or it may be that people have adopted strategies, such as wearing disposable masks or staying inside on high-pollution days, that help them better cope with high pollution levels. A third alternative is that improved public health and medical technology has reduced the impact of pollution on mortality. A fourth possibility is that the results in 19th century England were largely due to sorting, and that there was less sorting in China in 2000 due to the *hukou* system. However, analysis of the causes of death results in England suggest that this explanation is less likely, because we do not observe higher death rates in more polluted cities across all types of causes. Understanding the relative importance of these potential channels is an interesting avenue for future research.

Despite the progress we have documented, we still observe a clear relationship between polluting industry employment and mortality in modern China. Based on our estimates, a one standard deviation increase in the polluting industry share of an urban district in China (0.27) is associated with an increase in the mortality rate of about 0.117, which is 2.3% of the average mortality rate in these districts. This finding suggests that industrial pollution may be an important cause of mortality in modern Chinese cities.

References

Almond, Douglas, Chen, Yuyu, Greenstone, Michael, & Li, Hongbin. 2009. Winter Heating or Clean Air? Unintended Impacts of China's Huai River Policy. *American Economic Review*, **99**(2), 184–90.

Barreca, Alan, Clay, Karen, & Tarr, Joel. 2014 (February). *Coal, Smoke, and Death: Bituminous Coal and American Home Heating.* NBER Working Paper No. 19881.

Chay, Kenneth, Dobkin, Carlos, & Greenstone, Michael. 2003. The Clean Air Act of 1970 and Adult Mortality. *Journal of Risk and Uncertainty*, **27**(3), 279–300.

Clay, Karen, Lewis, Joshua, & Severnini, Edson. 2014 (November). *Benefits and Costs of Electricity Pre-Clean Air Act.* Working paper.

Ebenstein, Avraham. 2012. The Consequences of Industrialization: Evidence from Water Pollution and Digestive Cancers in China. *Review of Economics and Statistics*, **94**(1), 186–201.

Glaeser, Edward L, & Kahn, Matthew E. 2008 (August). *The Greenness of Cities: Carbon Dioxide Emissions and Urban Development.* NBER Working Paper No. 14238.

Greenstone, Michael, & Hanna, Rema. 2014. Environmental Regulations, Air and Water Pollution, and Infant Mortality in India. *American Economic Review*, **104**(10), 3038–72.

Grossman, Gene M., & Krueger, Alan B. 1995. Economic Growth and the Environment. *The Quarterly Journal of Economics*, **110**(2), pp. 353–377.

Hanlon, W.W., & Miscio, A. 2014 (December). *Agglomeration: A Dynamic Approach.* NBER Working Paper No. 20728.

Jayachandran, Seema. 2009. Air Quality and Early-Life Mortality: Evidence from Indonesias Wildfires. *Journal of Human Resources*, **44**(4), 916–954.

Lleras-Muney, A. 2005. The Relationship Between Education and Adult Mortality in the U.S. *Review of Economic Studies*, **72**(1), 189–221.

Pope III, C, Burnett, RT, Thun, MJ, & et al. 2002. Lung Cancer, Cardiopulmonary Mortality, and Long-Term Exposure to Fine Particulate Air Pollution. *JAMA*, **287**(9), 1132–1141.

Samet, Jonathan M., Dominici, Francesca, Curriero, Frank C., Coursac, Ivan, & Zeger, Scott L. 2000. Fine Particulate Air Pollution and Mortality in 20 U.S. Cities, 19871994. *New England Journal of Medicine*, **343**(24), 1742–1749. PMID: 11114312.

Troesken, W, & Clay, K. 2011. Did Frederick Brodie Discover the World's First Environmental Kuznets Curve? Coal Smoke and the Rise and Fall of the London Fog. *In:* Libecap, G., & Steckel, R. H. (eds), *The Economics of Climate Change: Adaptations Past and Present.* University of Chicago Press.

Vennemo, Haakon, Aunan, Kristin, Lindhjem, Henrik, & Seip, Hans Martin. 2009. Environmental Pollution in China: Status and Trends. *Review of Environmental Economics and Policy*, **3**(2), 209–230.

Zheng, Siqi, & Kahn, Matthew E. 2013. Understanding China's Urban Pollution Dynamics. *Journal of Economic Literature*, **51**(3), 731–772.

Zheng, Siqi, Wang, Rui, Glaeser, Edward L., & Kahn, Matthew E. 2011. The Greenness of China: Household Carbon Dioxide Emissions and Urban Development. *Journal of Economic Geography*,

11(5), 761–792.