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ABSTRACT

The Historical Impact of Coal on Cities*

Historically coal has offered both benefits and costs to urban areas. Benefits include coal's role in fueling industry and thus employment. The primary costs are air pollution and its impact on human health. This paper starts by using a Rosen-Roback style model to examine how differences in local coal availability affect equilibrium city employment. Drawing on the model, the paper surveys papers that examine the net effects of coal on the growth in city population and air pollution on health. The paper then turns to papers that explicitly consider the trade-offs between production benefits and pollution disamenities across space and over time. The paper ends with a discussion of opportunities for future work on coal and cities in historical settings.

JEL Classification: N52, N72, O13, Q53, Q56

Keywords: coal availability, local development, air pollution, trade-offs of coal consumption

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1 Introduction

Historically coal has offered both benefits and costs to urban areas. Benefits include coal's role in fueling industry and thus employment. The primary costs are air pollution and its impact on human health. Figure 1 plots trends in the mix of energy inputs (Henriques and Borowiecki, 2017). Coal was above 10% of energy consumption in 1800, surpassed 50% in the 1870s and peaked at nearly 80% of energy consumption in the early 1900s. Figure 2 plots air pollution in London, U.S. cities, and the U.S. manufacturing belt (DuBay and Fuldner, 2017; Fouquet, 2011; Clay et al., 2022a). Air pollution was high in London in 1800, reflecting its early adoption of coal. It rose to into the 1890s and then began to fall. Air pollution was high in the U.S. manufacturing belt from the start of the series in 1880 through 1920 and then began to fall.

This paper starts by using the Rosen-Roback model to examine how differences in local coal availability affect equilibrium city population.[1] On the worker side, increases in local coal use reduces the quality of city amenities, which will tend to decrease local labor supply. This is the classic urban disamenity. On the producer side, local access to coal may affect labor demand through two channels. First, it will lower the cost of coal inputs, due to reduced transportation costs, and thereby increase coal inputs used in production. This effect will, in turn, increase local labor demand, given the complementarity between the two inputs in the production function. Second, coal access may affect labor demand through changes in total factor productivity. To the extent that access to coal resources improves productivity, this effect will also increase local labor demand.[2] This framework also highlights how the net effects on employment may vary over time as the trade-offs between production benefits versus pollution disamenities evolve.

Drawing on the model, the paper surveys papers that examine the net effects of local air pollution on health and coal on the growth in city population.[3] The first set of papers find

[1]City population and city employment are highly correlated, so the model has implications for both outcomes.
[2]Alternatively, air pollution may have negative effects on worker productivity.
[3]The survey focuses on air pollution as a local disamenity and does not consider the effects of emissions of

negative effects of local air pollution on health, documenting that coal was a disamenity in historical contexts (Bailey et al., 2018; Beach and Hanlon, 2018; Clay et al., 2022a; Barreca et al., 2014a; Hanlon, 2018; Clay et al., 2018). The second set of papers have found positive and negative effects on the growth in city population, depending on the setting and time period (Fernihough and O'Rourke, 2021; Rosenberg and Trajtenberg, 2004; Hanlon, 2020).[4] This is consistent with coal having different effects on city employment in the Rosen-Roback model depending on values of productivity, coal input prices, the housing elasticity, and amenities.

The paper then surveys papers that explicitly consider the trade-offs between production benefits and pollution disamenities across space and over time. While the surveyed papers do not explicitly discuss their results in a Rosen-Roback framework, the empirical findings are consistent with changes in the relative values of production benefits and pollution disamenities in the Rosen-Roback model. The section ends by considering how policies that increase access to health care can change these tradeoffs by mitigating the adverse effects of pollution disamenities.

The final section discusses opportunities for future work on coal and cities in historical settings.

2 Coal in a Rosen-Roback Style Model

To study the local effects of coal on city population growth, we consider a simple Rosen-Roback style model. On the producer side, variation in local access to coal resources can influence firm input choices and affect overall productivity. On the worker side, pollution associated with local coal consumption may act as a local disamenity.

Workers are assumed to have identical Cobb-Douglas preferences over a consumption good, housing, and local amenities in city c. Let $\ln(v)$ denote the reservation utility of

carbon dioxide.

[4]Given the high correlation between employment and population and the lack of data on employment in many historical settings, many papers use city population as an outcome.

moving to a different city. Workers are assumed to be fully mobile, so the local bundle of equilibrium wages, housing costs, and amenities in every city (w_c, r_c, a_c) must make workers indifferent to moving.[5] We have the following equilibrium condition for workers' indirect utility function:

$$V_c = \gamma \ln(w_c) + (1-\gamma)\ln\left(\frac{w_c}{r_c}\right) + \ln(a_c) = \ln(v), \tag{1}$$

where $(1-\gamma)$ denotes the expenditure share on housing.

Workers are assumed to face a housing supply characterized by the following expression:

$$\ln(r_c) = \lambda \ln(L_c), \tag{2}$$

where r_c is the rental cost, and number of housing units is assumed to be equal to total city population, L_c.[6] The parameter $\lambda > 0$ characterizes the elasticity of the supply of housing.[7] Equations (1) and (2) can be combine to derive the labor supply function for city c, which depends on local wages, w_c, and amenities, a_c, (see Appendix **).

On the production side, we assume that each city is a competitive economy that produces one output good, y, which is trade on international markets at price equal to 1. Local firms produce according to a Cobb-Douglas production function:

$$y_c = A_c L_c^{\alpha} C_c^{\beta} \bar{R}^{1-\alpha-\beta} \tag{3}$$

where A_c denotes total factor productivity, L_c denotes labor inputs, and C_c denotes coal inputs, and $\bar{R}$ capture a fixed natural resource, which have costs w_c and p_c, and r_c respectively. Let $\bar{R}$ captures a fixed local resource (land or other natural resources).[8]

[5] In our simple setup, we abstract from heterogeneous worker preferences over different cities, in which case only marginal workers are indifferent across cities (see Moretti, 2011). This form of heterogeneity will not affect the qualitative predictions.

[6] We assume that each worker consumes one unit of housing, so that total city population is synonymous with city employment.

[7] When λ is small, the housing supply is elastic, and new construction can easily accommodate new arrivals to the city.

[8] This fixed resource, $\bar{R}$, could reflect either a fixed supply of suitable land or other natural endowment used in production. Its inclusion in the production function ensures decreasing returns, so that firms operate in

Combining the local labor demand and supply equations, we can derive the following equation for equilibrium city population:

$$\ln L_c = \frac{1}{\sigma}\Big\{ \ln A_c + (1-\beta)\ln a_c - \beta \ln p_c + (1-\alpha-\beta)\ln \bar{R}_c + k \Big\} \tag{4}$$

where $\sigma = (1-\alpha-\beta) + (1-\beta)(1-\gamma)\lambda > 0$, and k denotes a term term that depends only on parameters.[9]

Equation (4) establishes how differences in local coal availability affect equilibrium city population. On the worker side, increases in local coal use reduces the quality of city amenities, a_c, which will tend to decrease local labor supply. This is the classic urban disamenity. On the producer side, local access to coal may affect labor demand through two channels. First, it will lower the cost of coal inputs, p_c, due to reduced transportation costs, and thereby increase coal inputs used in production. This effect will, in turn, increase local labor demand, given the complementarity between the two inputs in the production function. Second, coal access may affect labor demand through changes in total factor productivity, A_c. To the extent that access to coal resources improves productivity (for example, through greater availability of cheap coal-powered electricity), this effect will also increase local labor demand.[10]

2.1 Implications

The previous analysis demonstrates that empirical studies focused on the reduced form impacts of coal access on city population growth capture a combination of the production effects of coal (due to productivity and/or prices) and the disamenity effects (due to urban air pollution).[11] Equation (4) shows that the overall population response to changes in coal

multiple cities with differing productivity levels (see Kline and Moretti, 2014; Hanlon, 2020). For simplicity, we exclude capital from the model. Assuming international capital markets with a common price, capital will not influence the predictions for the spatial equilibrium.

[9]Specifically, it is given by: $k = (1-\beta)\ln\alpha + \beta\ln\beta - (1-\beta)\ln v$.

[10]Alternatively, air pollution may have negative effects on worker productivity.

[11]Although the model is static, it can readily be applied to city population dynamics over the past two centuries. For example, the Industrial Revolution fundamentally altered the role of coal in the production

use are informative to net impact of these two channels: population decreases imply that the disamenity effect dominates, while population increases imply that the production effect dominates. Nevertheless, without additional information, we cannot disentangle the effects of coal on producers or workers.[12] Similarly, if one were study how the effects of coal are capitalized into housing prices, it is clear from equation (2), that this net response will not allow us to disentangle production effects from the disamenity effects.[13]

One was to disentangle the production effects of coal from the disamenity effects is to exploit heterogenous treatment effects. Intuitively, if we can hold constant the benefits to producers from coal access, while varying the disamenity from air pollution, we can potentially disentangle these two channels. Models that incorporate the geographic patterns of pollution dispersion can be useful in this regard.

Relatedly, this framework highlights how the net effects on population may vary over time as the tradeoffs between production benefits versus pollution disamenties evolve. For example, the marginal benefits associated with increases in local coal-fired electricity generation are likely to be diminishing as electricity access becomes more widespread. Technological changes that *offset* the disamenity from air pollution will cause the effects to be increasingly driven by the (benefits) to local producers. These technologies include the advances in electricity transmission and power plant efficiency that led to a relocation of coal-fired plants outside of urban areas, pollution abatement technologies at the plant level, or improvements in transportation technology that allowed workers to reside farther from sources of pollution. The evolution of these tradeoffs will influence the long-run relationship between coal and city growth.

process, and subsequent city population growth may have been driven by baseline coal endowments.

[12]Specifically, to separate production effects from disamenity effects, we require additional information on city-level wages (see Appendix A.1).

[13]The impacts of coal on population growth versus housing prices depend inversely on the parameter λ, which characterizes how easily the housing market can respond to inflows on new workers.In the classic Rosen-Roback setup, housing supply is perfectly inelastic ($\lambda = \infty$), implying that the net effects of coal are fully capitalized into local housing costs, r_c.

3 Coal and City Growth

For centuries prior to the Industrial Revolution, coal was used both as a source of domestic heating and in industrial production. Nevertheless, following several technological innovations, most notably the development of the steam engine, the First Industrial Revolution represented a dramatic shift in the role of coal for production. Industrial coal-use rose sharply in the 19th century, with steam powering production across a range of sectors.[14]

In the 20th century, the Second and Third Industrial Revolutions were powered by electricity, which replaced steam power in production and ushered a host of new labor-saving technologies into the household.[15] In many regions, coal was the dominant source of electric power, so the shift from steam to electricity did not spell the decline of coal.[16]

Local availability of coal resources may have impacted the spatial distribution of population growth following the introduction of new coal-using technologies. Given the high cost of transportation, there were large cost savings if coal could be used near where it was mined Wrigley (1961).[17] Local availability of coal resources may have impacted labor demand, both through producer input costs and through their willingness to incorporate new coal-based technologies into production processes. Indeed, economic historians have long debated the role of coal resources in influencing cross-national development during the Industrial Revolution.[18]

Despite the large literature on the Industrial Revolution, only a few papers examine the causal effect of coal on city growth. Fernihough and O'Rourke (2021) evaluate the importance of coal on the growth of cities in Europe before and during the Industrial Revolution. To

[14] Another major technological innovation was the 1709 discover of how to use of coke to smelt iron, which led to a dramatic expansion of the iron and steel industries.

[15] Investment in electricity infrastructure has been linked to local manufacturing development, structural change, and improvements in health and women's economic opportunities through changes in home technologies (Lipscomb et al., 2013; Kline and Moretti, 2014; Gaggl et al., 2021; Lewis, 2018; Vidart, 2023).

[16] In the U.S., more than 80 percent of electricity was steam powered by mid-century. At the same time, nationwide coal consumption per capita remained virtually unchanged between 1900 and 1950.

[17] Crafts and Mulatu (2006), Crafts and Wolf (2014), and Gutberlet (2014) find that local coal resources influenced the spatial distribution of industrial activity in Britain and Germany.

[18] See, for example, Landes (1966), Pollard (1981), Mathias (1983), Mokyr (1976), and Mokyr (1983).

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. Proximity can be thought of as a proxy for the price of coal. 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.

Rosenberg and Trajtenberg (2004) 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 its more efficient use of coal and in other performance characteristics, relative to water power and to previous generations of steam engines. The authors discuss Corliss as being equivalent to a decline in fuel costs and thus implicitly a decline in the costs of coal. It may also have represented an increase in total factor productivity. 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.

The two prior papers examine the aggregate effects of coal or a major innovation in coal consuming steam engines on population growth. Hanlon (2020) extends the Rosen-Roback model and uses it to separate the positive direct effect that growth in local industry can have on city employment from the negative indirect effects of any pollution that the industry generates. The negative pollution effects can occur either because pollution makes decreases amenities, or because pollution makes workers and firms less productive. Hanlon uses panel data on city-industry employment for 31 English cities for every decade from 1851 to 1911, and infers industrial emissions of coal smoke based on coal consumption by industry. Considering a counterfactual in which the growth of coal usage from 1851 to 1911 was reduced by 10%, the 31 analysis cities would have had an additional 1.5 million residents by 1911 and their share of the English population would have been higher by four percentage points.

In sum, depending on the setting and time period, coal can have positive or negative effects on growth in city population. These findings are unsurprising, given the potential evolving benefits and costs associated with urban coal use.

4 Air Pollution in Cities

Air pollution from coal burning was often severe in cities. Figure 2 shows trends in air pollution in London and the U.S. Table 1 provides historical TSP concentrations for selected large U.S. cities in specific years and modern benchmarks for comparison. Table 2 lists U.S. cities that were considered to have smoke problems in 1912 (Flagg, 1912). Although the health effects were not understood until later in the twentieth century, city residents disliked pollution because of the dust and smog. The dust increased the need to clean everything from floors to windows to clothes. Smog dampened visibility, increased the need for lighting during the day, and generally blocked sunlight. As a result, beginning in the 1880s many cities began to pass smoke legislation (Stern, 1982). Historical evidence suggests that city legislation was not particularly effective at alleviating the problem. Big polluters would often resist reductions on economic grounds, pay off inspectors, or intimidate them. Smaller polluters were difficult to regulate because of their large numbers (Stern, 1982; Tarr, 1996; Brimblecombe, 2011).

While modern studies have shown that air pollution adversely affects human health, a smaller number of papers have considered historical periods. Bailey et al. (2018) document that childhood air pollution decreased the heights of British army servicemen who were born in England and Wales and enlisted in WWI. The paper uses a random sample of data on recruits and OLS and IV estimation. Coal intensity is computed following Beach and Hanlon (2018) by data on coal use per employee and data on occupational structure in 1901. The IV uses coal intensity in 1851 as an instrument for coal intensity in 1901. The difference in final height between those from the least and the most coal-intensive districts was about an inch.

Three papers find increased coal use caused increased mortality in historical settings. Beach and Hanlon (2018) measure the effects of industrial coal use on infant and child mortality in Britain over 1851-1860. They find that a one standard deviation increase in coal consumption increased infant mortality by 1.7-10%. Clay et al. (2022a) examine the effect expansion in coal-fired electricity generation in the United States between 1938 and 1962, which produced large amounts of unregulated air pollution, on infant mortality. The paper finds that a one standard deviation increase in capacity is associated with 2 additional infant deaths per 1,000 live births. Barreca et al. (2014b) study the effect of the decline in the use of bituminous coal for heating between 1945 and 1960 in the United States on all-age and infant mortality. 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%.

Two papers examine the relationship between air pollution from coal and mortality from infectious diseases in cities. Hanlon (2018) examines the acute impact of exposure to high-levels of pollution in London from 1866 to 1965. Using data on inversions, the paper finds both direct effects of pollution and that the presence of measles and tuberculosis substantially increase the mortality effects of pollution. 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. Human and animal studies have shown that air pollution can increase susceptibility to viral infection and heighten the risk of severe complications. The paper finds that air pollution contributed significantly to pandemic mortality.

In sum, all of these papers find negative effects of pollution on health, documenting that coal was a disamenity in historical contexts.

5 Tradeoffs Associated with Urban Coal Consumption

Coal usage may represent a local disamenity due to air pollution, but could enhance local productivity to the extent that it enables more efficient production processes, both at the marketplace and at home. Naturally, tradeoffs will emerge with increases in coal consumption.

Clay et al. (2022a) provides new evidence on the tradeoffs across space and over time between air pollution and electricity between 1938 and 1962 as measured by infant mortality. The paper combines newly digitized data on the location, year of opening, and characteristics of all major coal-fired power plants with annual county-level infant mortality rates for the period 1938-1962. They use two complementary strategies to estimate the effects of coal-fired plants on infant health. The first strategy exploits the sharp change in local amenities resulting from the openings of new power plants in an event-study framework. The second strategy is a continuous difference-in-differences framework that relies on variation in local capacity from both new power plant openings and the openings of new generating units at existing sites.

The net effects of electricity capacity expansion on infant mortality varied across space with the initial levels of electricity access and baseline levels of electricity-related air pollution. In counties with low baseline access to electricity, infant mortality was unaffected by coal capacity changes, consistent with the health benefits from increased generation having offset the health costs from air pollution. In contrast, in counties with high baseline access to electricity, coal capacity expansions increased infant mortality significantly. In counties with low baseline levels of electricity-related air pollution, coal capacity expansions decreased infant mortality significantly, suggesting that the health benefits from increased electricity generation outweighed the pollution costs. In counties with high levels of electricity-related air pollution, coal capacity expansions increased infant mortality significantly, suggesting that the health costs from increased air pollution outweighed the benefits from electricity infrastructure.

When exploring potential mechanisms that might account for the health tradeoffs, Clay et al. (2022a) find that the benefits arose from two channels: increased household access to electricity and increased local economic activity. In low access counties, coal capacity expansions led to increases in the fraction of homes with electricity, running water, and a modern stove. Household access to electricity brought numerous benefits to infant health through both improved indoor air quality and better household sanitation (Lewis, 2018). Similarly, the authors find that expansions in coal-fired capacity led to modest employment growth that was concentrated in the manufacturing sector, but did not stimulate widespread local economic development.

The tradeoffs may not only vary across space, but might also evolve over time with economic development. This could happen, for instance, if marginal damages of coal consumption are constant, but marginal benefits are decreasing. In fact, Clay et al. (2022a) show that the infant health impacts of coal-fired plants evolved as the stock of generating capacity expanded over time. In fact, the mid-twentieth century United States witnessed a striking reversal in the relationship between coal-fired generation and infant mortality. Initially, coal-fired generation was associated with net decreases in infant mortality. Later, coal-fired generation was associated with net increases in infant mortality. This reversal appears to have been driven by a change in the net health impact of coal capacity additions as the existing stock of local generating capacity expanded.

Besides environmental regulation, infrastructure projects and technological innovation can also change the tradeoffs of coal consumption, as implied by the spatial equilibrium model introduced in Section 2. Infrastructure projects such as the construction of the U.S. interstate highway system starting in the late 1950s caused suburbanization and allowed individuals to live farther away from work (Baum-Snow, 2007). Technological innovation also creates opportunities for infrastructure investment. The invention of the steam railway, for instance, led to the first large-scale separation of workplace and residence in London in the 19th and early 20th century (Heblich et al., 2020). Similarly, China's recent expansion of high-speed railways facilitated intercity travel and reduced travelers' exposure to extreme air pollution by 7%, leading to substantial health benefits (Barwick et al., 2022). Improvements in transmission technology and the buildup of high-tension transmission lines in the U.S. starting in the late 1950s also allowed coal-fired power plants to move away from urban centers, as evident in Figure 3. Lastly, environmental regulation such as the Clean Air Act has led to reductions in air pollution at a relatively low cost in terms of drops in coal-fired plant productivity (Clay et al., 2021; Cropper et al., 2022).

Clay and Troesken (2011) point out that these changes can occur concomitantly, using the example of London in the late 19th and early 20th century. Three changes were instrumental in reducing the impact of coal, even without a decrease in consumption. Firstly, the dispersal of people and smoke over a larger area diluted the smoke's concentration. As the London population grew, both coal consumption and smoke production increased. However, the expansion of the city's boundaries and the settlement of migrants in previously unsettled areas countered this effect by redistributing the population and altering the smoke distribution. Secondly, the implementation of the Public Health Act granted police the authority to fine manufacturers throughout metropolitan London for emitting dense smoke. This enforcement incentivized firms to conserve soft coal, despite it potentially being costlier to economize on it than its actual value. If it were more economical, firms would have adopted smoke abatement technologies independently of the Act. Lastly, households in London, in alignment with manufacturers' efforts, became more conscious of coal conservation. They transitioned to using gas for cooking and heating, or invested in grates and boilers designed to minimize smoke emissions and fuel wastage.

The tradeoffs of coal consumption may be experienced differently across subgroups of the population, as predicted by the spatial equilibrium model. Heblich et al. (2021) present the first long-run analysis of the effects of pollution on the composition of neighborhoods within cities. They create a measure of historical pollution by geolocating industrial chimneys from the 70 largest metropolitan areas in England over the period 1880-1900, and applying an atmospheric dispersion model. Heblich et al. combine this measure of pollution exposure with unique panel data for 5,500 low-level administrative units over nearly 200 years. There is no excess deprivation in neighborhoods downwind from industrial chimneys prior to the rise of industrial coal use, but they find a strong effect of air pollution on the share of low-skilled workers in a neighborhood in 1881. A pollution differential equivalent to that between the 10th and 90th percentiles in Manchester would be associated with a gradient of 16 percentage points in the share of low-skilled workers. They find substantial persistence in the effect of historical pollution on within-city distribution of low-skilled workers, even after the Clean Air Act of 1968 abruptly decreased pollution from coal burning. The previous 10th-90th-percentile difference would explain a similar gradient in neighborhood composition in 2011 and a 40% difference in property prices.

Interestingly, the tradeoffs might be attenuated with the implementation of nonenvironmental policies. Clay et al. (2022b) show that the provision of health care to the poor after the introduction of Medicaid reduced pandemic-related mortality associated with pollution arising from coal-fired power plants.

6 Conclusion

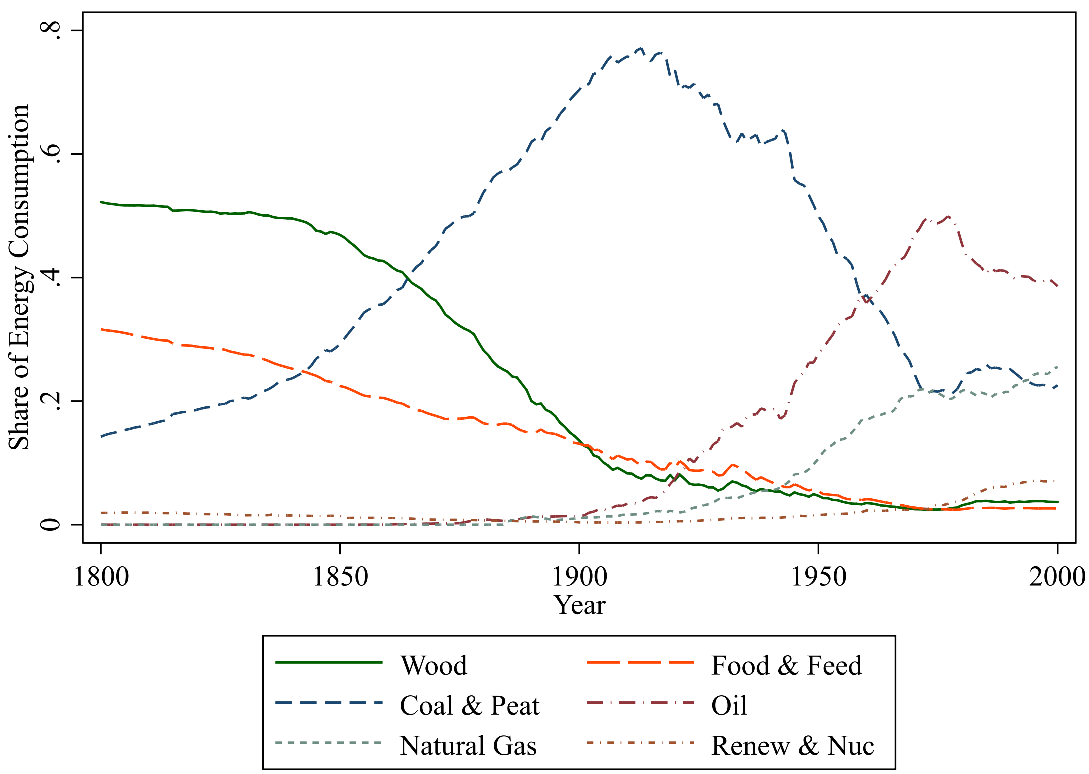
This paper used a Rosen-Roback style spatial equilibrium model to examine how differences in local coal availability would affect equilibrium city population. Drawing on the model, the paper surveyed three interrelated strands of the literature: coal-driven air pollution and health, coal and city growth, and tradeoffs associated with urban coal. Papers on air pollution and health find negative effects of coal-driven pollution on health, documenting that coal was a disamenity in historical cities. Papers on coal and city growth highlight that coal could have positive or negative effects on growth in city population, depending on the setting and time period. Papers on tradeoffs associated with urban coal highlight the changing nature of production benefits and pollution disamenities across space and over time.

One implication of the evolution of tradeoffs is that policymakers may underweight longer-run health impacts when choosing to regulate air pollution. They might put more weight on the benefits of polluting activities, which in the short run might outweight the pollution costs. As a result, it may take time for policymakers to experience the negative effects and chose to enact environmental regulation. The evolving tradeoffs highlight the importance of accounting for both current and future payoffs when designing environmental regulation.

A number of possible avenues for future work on the historical impact of coal on cities are suggested by this survey. The existing historical literatures on air pollution and health and coal and city growth include a very limited range of geographic locations and historical time periods. The literature on the effect of air pollution on spatial location within cities, its evolution across decades, and the associated inequality and environmental justice issues is tiny. The historical literature has virtually no coverage of topics such as the effects of air pollution on schooling, worker productivity, and crime. The literature also focuses almost exclusively on industrial air pollution and so has little to say about heating- and transportation-related air pollution. Future work could add to the literature by expanding the range of geographic locations, time periods, outcomes, and types of pollution that are studied. Finally, future work would benefit from a stronger connection with spatial equilibrium models.

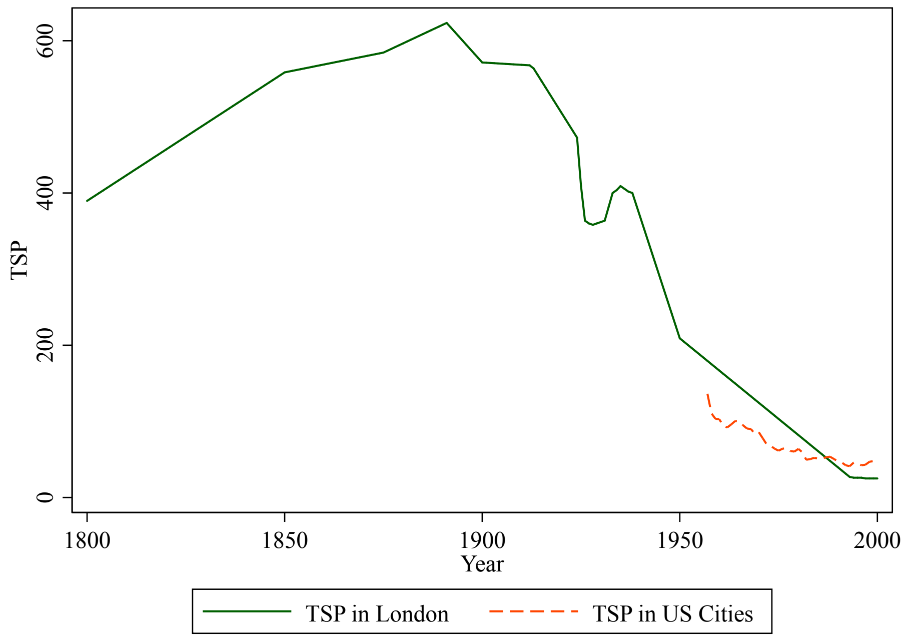
Figures and Tables

Fig. 1: Trends in Mix of Energy Inputs

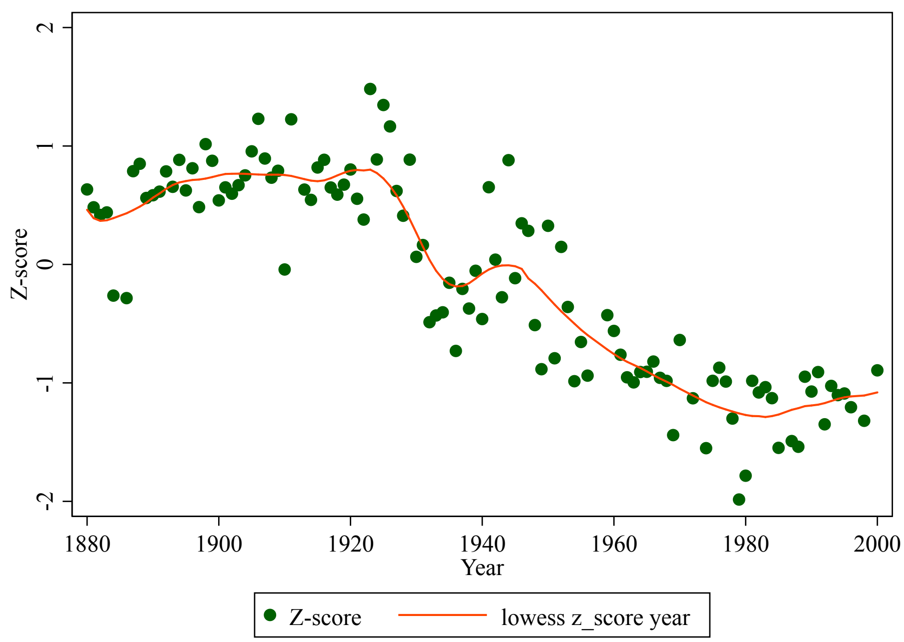


Notes: Based on data from Henriques and Borowiecki (2017).

Fig. 2: Trends in Air Pollution



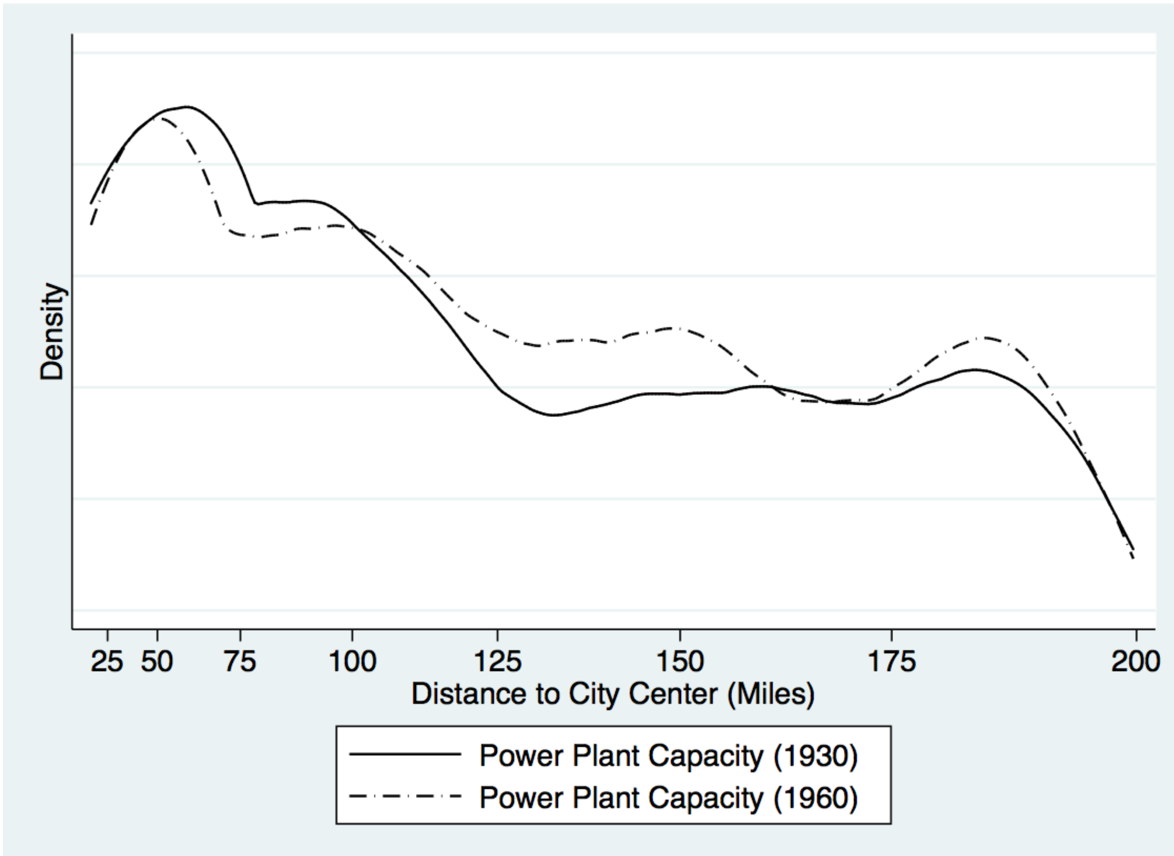
(a) TSP in London and U.S. Cities



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

Notes: Based on data from DuBay and Fuldner (2017); Fouquet (2011); Clay et al. (2022a). 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. 3: Distribution of Fossil-Fuel Capacity Across Space in the U.S. – 1930 and 1960



Notes: This figure displays the density of fossil-fuel capacity within 200 miles of the city-centroid for the 50 largest cities in the United States.

Table 1: Total Suspended Particulates Concentrations in Various Years

Year	Location	TSP
1912-1913	Chicago	760
1931-1933	Baltimore, Boston, Chicago, Pittsburgh, St. Louis	630
1931-1933	Buffalo, Cleveland, New Orleans, New York, Philadelphia	520
1931-1933	Detroit, Los Angeles, San Francisco, Washington	350
1990	U.S. National Average	60
1980-1993	58 Chinese Cities	538
1999	Worldwide, 18% of urban pop is greater than	240

Sources: Eisenbud (1978), Ives et al. (1936), Chay and Greenstone (2003a), Almond et al. (2009), and Cohen et al. (2004).

Table 2: Cities with Smoke Problems and Legislation

Year	Cities with Smoke Problems
1912	Baltimore, Boston, Buffalo, Chicago, Cincinnati, Cleveland, Denver, Detroit, Indianapolis, Jersey City, Kansas City, Louisville, Milwaukee, Minneapolis, Newark, New York, Philadelphia, Pittsburgh, Providence, Rochester, St. Louis, St. Paul, Washington
Decade	**Cities Passing Smoke Legislation**
1880-1890	Chicago, Cincinnati
1890-1900	Cleveland, Pittsburgh, St. Paul
1900-1910	Akron, Baltimore, Boston, Buffalo, Dayton, Detroit, Indianapolis, Los Angeles, Milwaukee, Minneapolis, New York, Newark, Philadelphia, Rochester, St. Louis, Springfield (MA), Syracuse, Washington
1910-1920	Albany County (NY), Atlanta, Birmingham, Columbus, Denver, Des Moines, Duluth, Flint, Hartford, Jersey City, Kansas City, Louisville, Lowell, Nashville, Portland (OR), Providence, Richmond, Toledo

Sources: Top: Flagg (1912); Bottom: Stern (1982), Table III, p. 45.

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A Online Appendix (Not For Publication)

A.1 Coal in the Rosen-Roback Model

To study the local effects of coal on city growth, we consider a simple Rosen-Roback style model. On the producer side, variation in local access to coal resources can influence firm input choices and affect overall productivity. On the worker side, pollution associated with local coal consumption may act as a locational disamenity.

Each city is a competitive economy that produces one output good, y, which is traded on international markets at price equal to 1. Workers and firms are fully mobile, and locate where utility and profits are maximized.

Workers are assumed to have identical Cobb-Douglas preferences over a consumption good, housing, and local amenities in city c. Let $\ln(v)$ denote the reservation utility of moving to a different city. Since workers are fully mobile, the bundle of equilibrium wages, housing costs, and amenities in every city (w_c, r_c, a_c) must make workers indifferent to moving.[19] We have the following equilibrium condition for workers' indirect utility function:

$$V_c \equiv \gamma \ln(w_c) + (1-\gamma) \ln\left(\frac{w_c}{r_c}\right) + \ln(a_c) = \ln(v), \tag{A.1}$$

where $(1-\gamma)$ denotes the expenditure share on housing.

We assume that the housing supply is characterized by

$$\ln(r_c) = \lambda \ln(L_c), \tag{A.2}$$

where r_c is the rental cost, L_c is total city population, and the parameter $\lambda > 0$ characterizes the inverse price elasticity of the supply of housing. When λ is small, the housing supply is elastic, and new construction can easily accommodate new arrivals to the city.

Equations (A.1) and (A.2) can be combined to derive the labor supply equation for city

[19] In our simple setup, we abstract from heterogeneous worker preferences over different cities, in which case only marginal workers are indifferent across cities (see Moretti, 2011). This form of heterogeneity will not affect the qualitative predictions.

c:

$$\ln(L_c) = \frac{1}{(1-\gamma)\lambda}\ln(w_c) + \frac{1}{(1-\gamma)\lambda}\ln(a_c) - \frac{1}{(1-\gamma)\lambda}\ln(v). \tag{A.3}$$

From equation (A.3), we can see that the two ways that differences in local coal resources might affect the supply of workers to city c. On the one hand, if these resources increase demand for labor, higher wages will attract workers to the city. On the other hand, if these resources lead to increased local levels of pollution, the disamenity will lead to reduce employment in these cities. Importantly, the sensitivity of these labor supply responses depends on the elasticity of housing supply, as reflected by λ. If housing supply is elastic, small changes in local wages or amenity levels will generate large responses in the local labor supply. Alternatively, when housing supply is inelastic, these effects will be reflected primarily in local housing market prices.[20]

We assume that local firms produce according to a Cobb-Douglas production function:

$$y_c = A_c L_c^{\alpha} C_c^{\beta} \bar{R}^{1-\alpha-\beta} \tag{A.4}$$

where A_c denotes total factor productivity, L_c denotes labor inputs, C_c denotes coal inputs, and $\bar{R}$ captures land or other fixed local natural resources, which have costs w_c, p_c, and r_c respectively.[21] The inclusion of this fixed resource, which could reflect either a fixed supply of suitable land or other natural endowment used in production, introduces decreasing returns. Thus, we ensure that firms operate in multiple cities with differing productivity levels (see Kline and Moretti, 2014; Hanlon, 2020).

Solving the firm's maximization problem and rearranging for the labor demand yields the following expression:

[20] In the classic Rosen-Roback setup, housing supply is perfectly inelastic ($\lambda = \infty$), implying that local labor supply will not change as a result of local coal resources. Instead, any changes in local amenities or wages are fully capitalized into local housing costs, r_c.

[21] For simplicity, we exclude capital from the model. Assuming international capital markets with a common price, capital will not influence the predictions in the spatial equilibrium.

$$\ln L_c = \frac{1}{1-\alpha-\beta}\ln A_c - \frac{1-\beta}{1-\alpha-\beta}\ln w_c - \frac{\beta}{1-\alpha-\beta}\ln p_c + \frac{(1-\beta)\ln\alpha+\beta\ln\beta}{1-\alpha-\beta} + \ln\bar{R} \tag{A.5}$$

Local access to coal may affect labor demand through three channels. First, it will lower the cost of coal inputs, p_c, due to reduced transportation costs, and thereby increase coal inputs used in production. This effect will, in turn, increase local labor demand, given the complementarity between the two inputs in the production function. Second, coal access may affect labor demand through changes in total factor productivity, A_c. To the extent that access to coal resources improves productivity (for example, through greater availability of cheap coal-powered electricity), this effect will also increase local labor demand.[22] Finally, local pollution disamenities will shift down labor supply, raising the wages needed to attract workers, and ultimately reducing city employment.

Combining equations (A.3) and (A.5), we can derive the following equation for equilibrium city employment:

$$\ln L_c = \frac{1}{\sigma}\Big\{\ln A_c + (1-\beta)\ln a_c - \beta\ln p_c + (1-\alpha-\beta)\ln\bar{R}_c + k\Big\} \tag{A.6}$$

where $\sigma = (1-\alpha-\beta)+(1-\beta)(1-\gamma)\lambda > 0$, and k denotes a term that depends only on parameters.[23]

Equation (A.6) establishes how differences in local coal availability affect equilibrium city population. These effects can arise through differences in local producer productivity, A_c, differences in coal input prices, p_c, and differences in local amenities, a_c.

The responsiveness of city population to each of these factors will, in turn, depend on the elasticity of housing supply. When the housing supply is completely inelastic ($\lambda=\infty$), population will not be affected by local coal (either through A_c, p_c, or a_c). Instead, effects of these shocks will arise solely through changes in local housing prices, as in the classic Roback

[22]Alternatively, air pollution may have negative effects on worker productivity.

[23]Specifically, it is given by $k = (1-\beta)\ln\alpha + \beta\ln\beta - (1-\beta)\ln v$.

model. In contrast, the population will be most responsive to local coal when the housing supply is completely elastic ($\lambda = 0$). In this scenario, the local labor supply is completely elastic, and so the magnitude of the city population response to either A_c, p_c, or a_c will be governed entirely by the shape of labor demand curve.

Without more information on housing costs and wages, it is impossible to assess the respective influence of these various factors.