

## **East Side Story: Historical Pollution and Persistent Neighborhood Sorting**

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MEEM-PSE

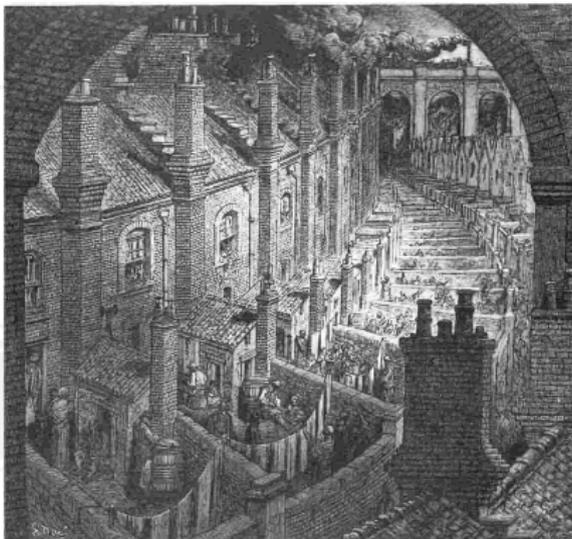
During the 19th century, pollution was extremely high in industrial cities, with wide within-city variations.

*“In Manchester ... prevailing and strongest winds [blow] from the south west. **This meant that when the dense sulphurous smoke left Manchester’s tall chimneys it usually moved north east, and this was to have a marked effect on the shaping of the city.**”*

*Stephen Mosley (2008), The Chimney of the World.*

*“But it appears to me very remarkable that while so many of the tradesmen live out of town (for hardly live in Manchester) **in other directions than those in which the vast mass of smoke is carried, few reside in the outskirts on the eastern part of the town.**”*

*Reverend John Molesworth (1843).*



Methodological contributions:

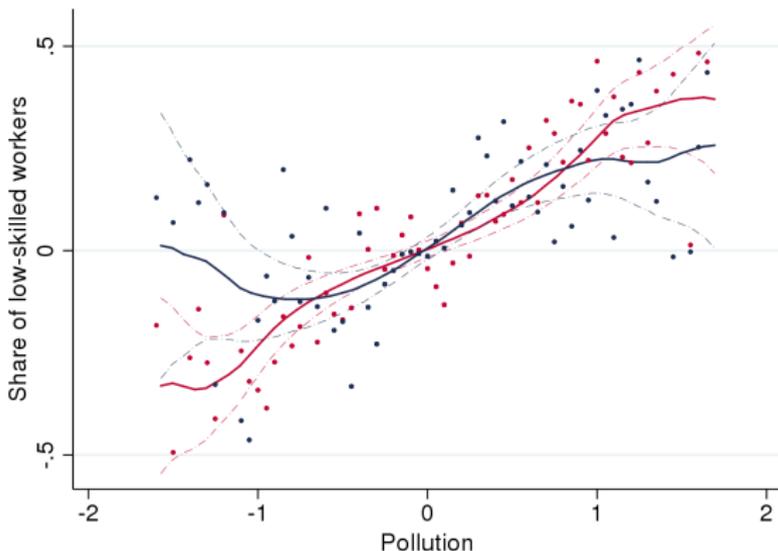
- ▶ We locate all industrial chimneys on **historical maps** (1880–1900) of the 70 largest industrial areas in England.
- ▶ We use a pollution model to predict **air pollution levels** with 50m precision.
- ▶ We geolocate past Censuses and construct **indices of neighborhood composition** in 1817, 1881 and 1971–2011.

We find that:

**[Pollution]** The factories that emerged during the industrial revolution generated a very unequal distribution of pollution exposure.

**[Sorting]** The polluted neighborhoods were **markedly poorer** than others in 1881, while they were similar in 1817.

**[Persistence]** These neighborhoods are **still poorer** in 2011.

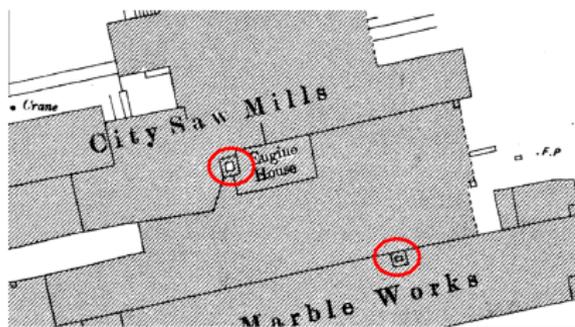


Data

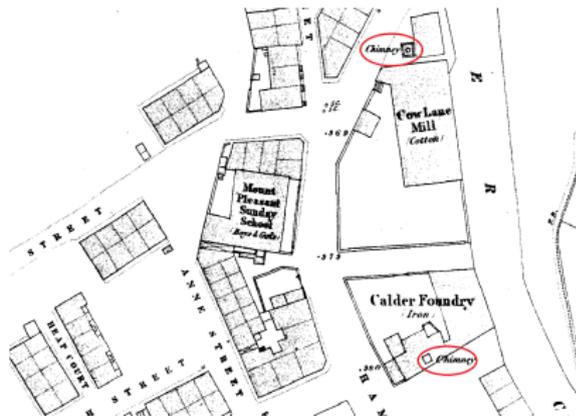
# 1. Town maps and chimney locations

**Ordnance Survey Maps - 25 inch to the mile, 1880–1900**, the most detailed topographic mapping that covers all of England and Wales (here, we keep the 70 largest cities in England and Wales).

Town maps – chimney symbols.



(a) Example 1.



(b) Example 2.

# 1. Marking chimneys

Town maps – marking and identifying chimneys.



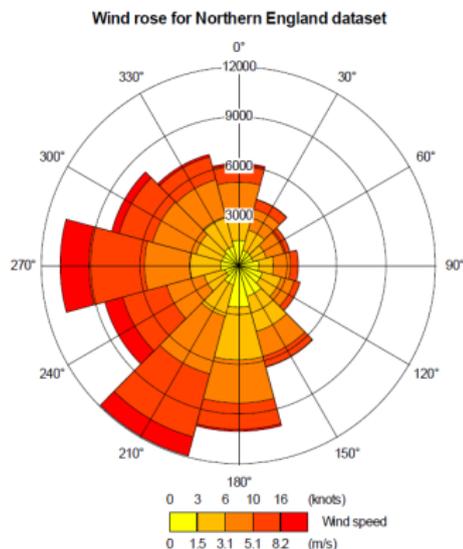
Sources: Ordnance Survey Maps - 25 inch to the mile, 1880–1900.

- ▶ Symbol: the red symbol **X** can easily be identified by any recognition algorithm.
- ▶ Id: the chimney **00007** belongs to *Eastbrook Dye Works* while **00006** belongs to *Britannia Saw Mills*.

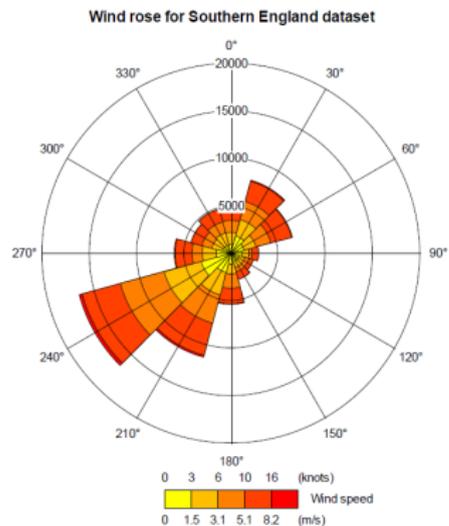
## 2. Dispersion

For **each chimney**, we create a pollution shape using *ADMS 5*:

- ▶ pollution sources ( ▶ External validity , ▶ Different height ),
- ▶ **wind directions** ( ▶ Stable conditions ) and complex terrain.



(c) North England.

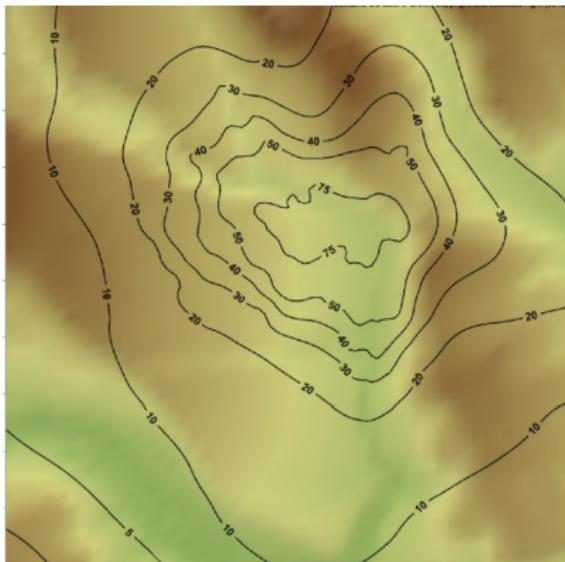


(d) South England.

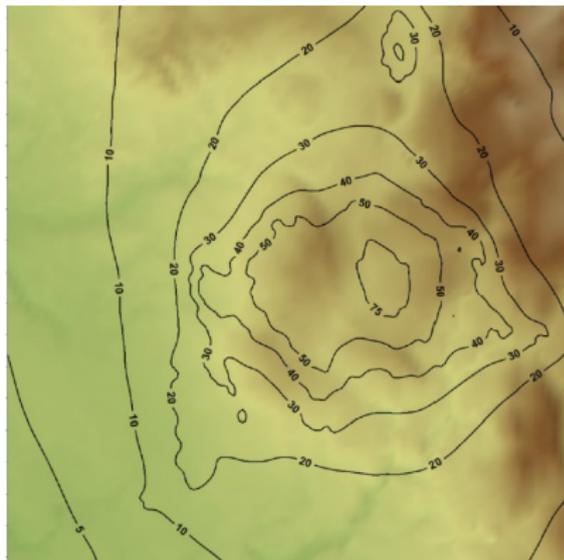
## 2. Dispersion

For **each chimney**, we create a pollution shape using *ADMS 5*:

- ▶ pollution sources ( ▶ External validity , ▶ Different height ),
- ▶ wind directions ( ▶ Stable conditions ) and **complex terrain**.



(e) Halifax.



(f) Oldham.

## 2. Pollution and variations within cities

National Ambient Air Quality Standards:

- ▶ Primary standards:  $12 \mu\text{g}/\text{m}^3$ .
- ▶ Secondary standards:  $15 \mu\text{g}/\text{m}^3$ .

Pollution in various neighborhoods of Manchester (1915):

|                  | Deposits (1915) | Our estimates            |
|------------------|-----------------|--------------------------|
| Station          | m. tons/ sq. m. | $\mu\text{g}/\text{m}^3$ |
| Ancoats hospital | 30.59           | 119.95                   |
| Philips Park     | 22.59           | 74.49                    |
| Whitworth Street | 22.51           | 102.47                   |
| Queen's Park     | 20.18           | 70.00                    |
| Moss Side        | 18.69           | 29.11                    |
| Whitefield       | 15.53           | 11.92                    |
| Fallowfield      | 13.24           | 17.69                    |
| Davyhulme        | 12.68           | 6.93                     |
| Cheadle          | 10.63           | 9.40                     |
| Bowdon           | 6.25            | 0.02                     |

Source: First Annual Report of the Sanitary Committee on the Work of the Air Pollution Advisory Board, 1915.

### 3. Census Data (geo-location)

**1817:** Baptism records over 1813–20 from Shaw-Taylor, et al. (2010) to reconstruct a quasi-census (834 parishes).

**1881:** Micro-census with coded occupations (**parish code** and **address**). We develop a method to assign individual records to 2001 LSOAs:

- ▶ We match addresses with a registry of addresses: 20% perfect matches and 35% good enough matches.
- ▶ We infer the geo-references of unmatched entries given (i) their location in the census books and (ii) their well-matched neighbors.

▶ geocode

**1971–2011:** Micro-censuses with coded occupations (2001 LSOAs).

Empirical strategy

We estimate the following equation ( $i$ : LSOA,  $p$  parish,  $c$ : city,  $t$ : time):

$$Y_{it} = \alpha + \beta P_i + \gamma \mathbf{X}_i + \nu Y_p + \delta_c + \varepsilon_{ict}$$

with:

- ▶  $Y_{it}$ : our measures of occupational structure in 1881 or 2011,
- ▶  $Y_p$ : our measures of occupational structure in 1817,
- ▶  $P_i$  is the **treatment**: pollution as predicted by the model and actual industry locations.
- ▶  $X_i$ : geographic controls (elevation, distance to the town hall, longitude/latitude etc.).
- ▶  $\delta_c$ : city FE.

Two concerns:

1. Omitted variable: distance to industries, and unobserved fixed amenities,
  - ▶ counterfactual pollution imprints,
  - ▶ placebo tests.
2. Reverse causality and strategic industry location upwind of poor neighborhoods,
  - ▶ instrument with pollution as predicted by waterways,
  - ▶ instrument with pollution as predicted by a uniform allocation of chimneys.

With the IVs, we look at the effect cleaned of the endogenous industry response (political decisions, and market ones).

Neighborhood sorting (19th century)

## 1. Benchmark results in 1881

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| Share of low-skilled  | (1)     | (2)     | (3)     | (4)     | (5)     | (6)     |
|-----------------------|---------|---------|---------|---------|---------|---------|
| Pollution             | .0417   | .0421   | .0379   | .0350   | .0327   | .0307   |
|                       | (.0070) | (.0068) | (.0065) | (.0063) | (.0071) | (.0072) |
|                       | [.1686] | [.1700] | [.1532] | [.1415] | [.1317] | [.1238] |
| Observations          | 4,524   | 4,524   | 4,524   | 4,519   | 4,519   | 4,519   |
| Fixed effects (city)  | No      | Yes     | Yes     | Yes     | Yes     | Yes     |
| Controls (1817)       | No      | No      | Yes     | Yes     | Yes     | Yes     |
| Controls (topography) | No      | No      | No      | Yes     | Yes     | Yes     |
| Controls (industry)   | No      | No      | No      | No      | Yes     | Yes     |
| Controls (lat./lon.)  | No      | No      | No      | No      | No      | Yes     |

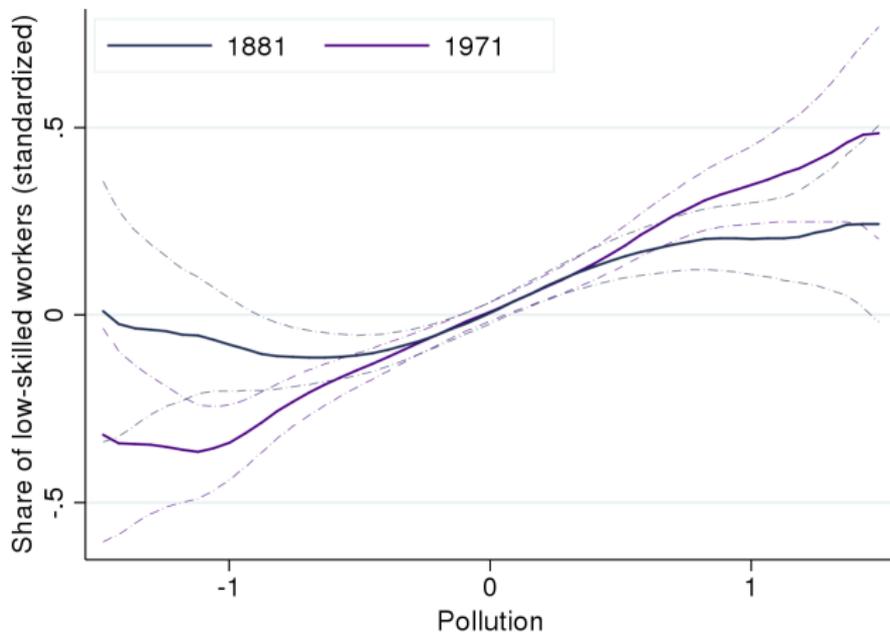
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## 2. Robustness checks

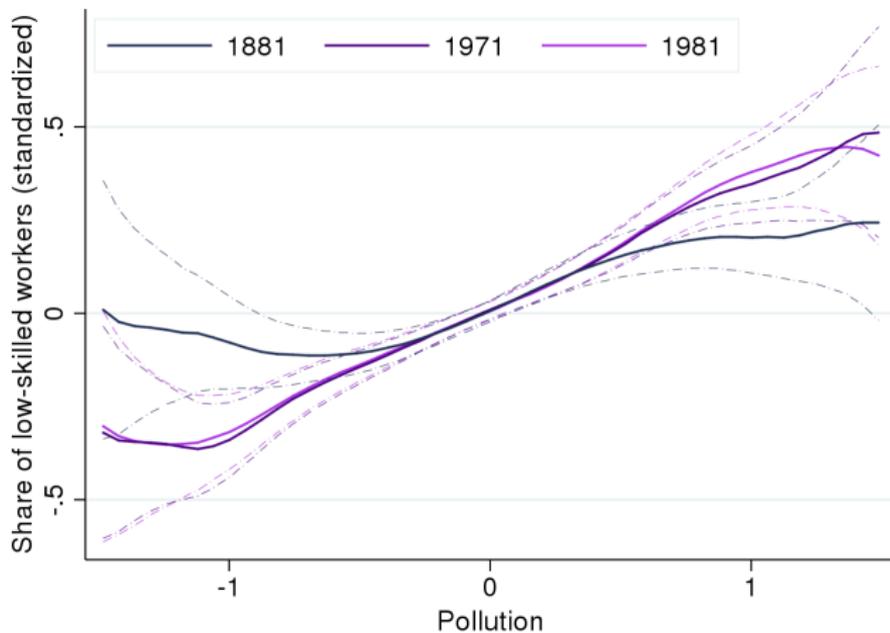
We run a series of robustness checks to ensure that our estimates are not driven by a non-random location of industries within cities:

1. balance test: [▶ Table](#).
2. difference-in-difference specifications: [▶ Table](#).
3. counterfactual pollution imprints: [▶ Table](#).
4. IV: [▶ Table](#).
5. fixed effects, clusters, and sample selection: [▶ Table](#).

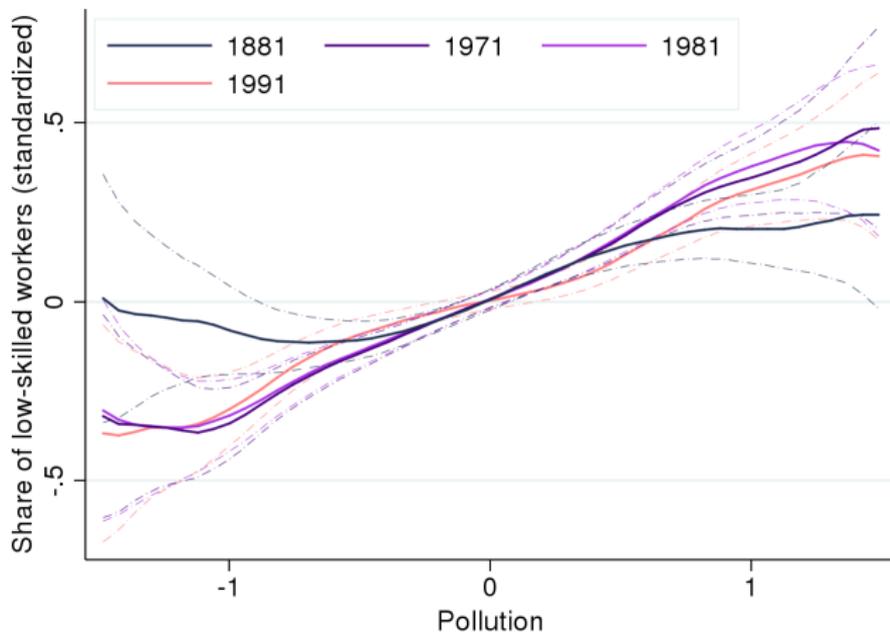
Dynamics of Persistence (end of 20th century)



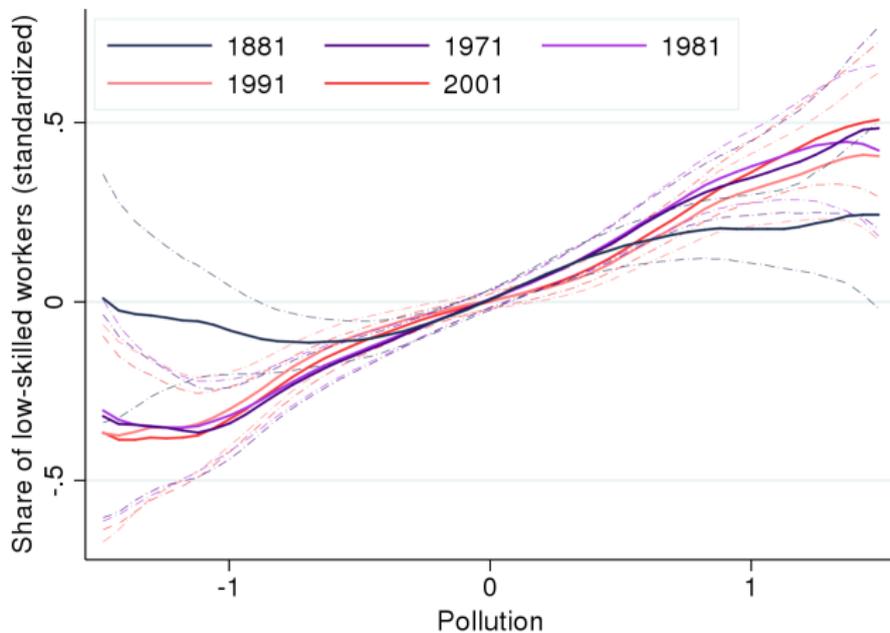
Notes: This Figure represents the locally weighted regressions on all observations between the (standardized) shares of low-skilled workers and our measure of past pollution. We consider the residuals of all measures once cleaned by city Fixed-Effects, geographic and topographic controls.



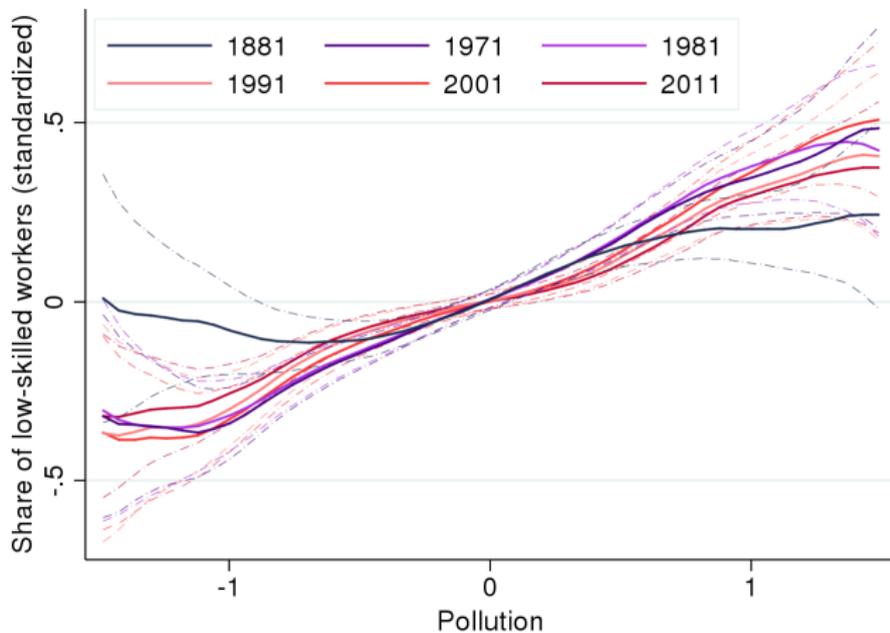
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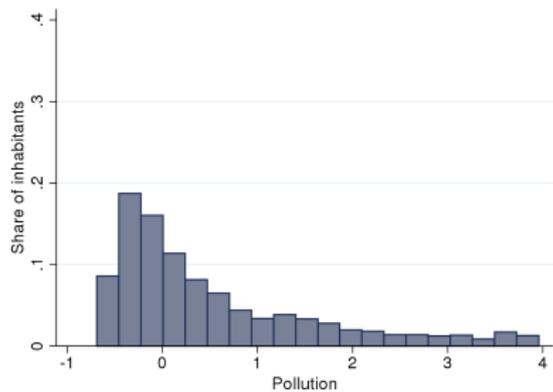
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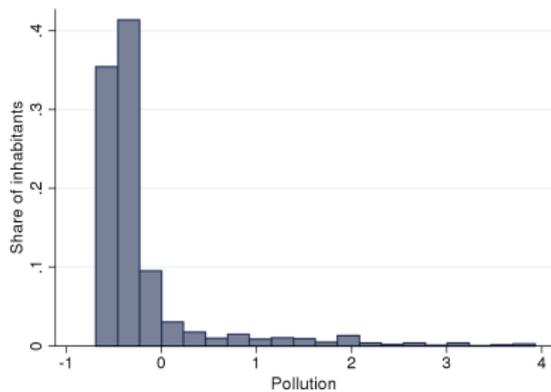
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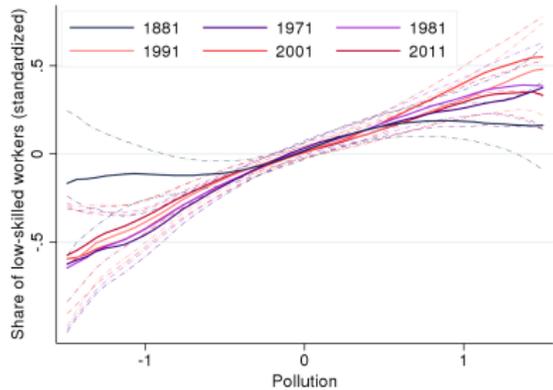
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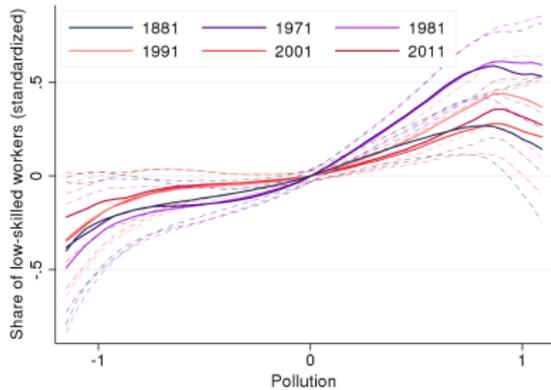
(g) Distribution (high pollution).



(h) Distribution (low pollution).



(i) Persistence (high pollution).



(j) Persistence (low pollution).

1. The graphs for 1971–2011 show two patterns:

- ▶ **Persistence for extreme values** of pollution.
- ▶ **Reversion to the mean for intermediate values** of pollution.

2. To study this non-linear persistence, we consider a dynamic model of neighborhood sorting and add an endogenous amenity:

- ▶ **estimate** the model using within-city residuals of low-skill share between 1881–1971 and within-city residuals of atmospheric pollution for the 4,519 neighborhoods.
- ▶ run **counterfactual** experiments.
- ▶ provide some **over-identification** tests.

3. Results indicate that there is a tail effect generating tipping dynamics: the impact of the initial distribution of pollution can be very large.

## Policy implications:

1. Economies in the process of structural transformation where pollution presents a major challenge should consider:

- ▶ the effects of pollution on neighborhood sorting,
- ▶ the long-run costs of the resulting spatial distribution of residents and activities.

2. The success of urban policies to revitalize deprived areas depends on their distance to tipping points.

## Extensions:

- ▶ incorporating dynamics in productive and consumptive amenities (1870-1940),
- ▶ environmental justice and how political decisions (pollution exemptions, public investments) may reinforce spatial inequalities (1900-1950),
- ▶ effect on agriculture, land use and rural-urban migration in urban outskirts (1870-1940)

Thanks!

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# Appendix I

Williamson, J. G.: 1980, Earnings inequality in nineteenth-century Britain, *The Journal of Economic History* **40**(3), 457–475.

## A static model of neighborhood sorting (1/2)

Two neighborhoods in a city  $j \in \{W, E\}$ , no moving costs.

A portion  $\gamma$  of workers earn  $\theta^l$ ;  $1 - \gamma$  earn  $\theta^h > \theta^l$ .

Workers maximize,

$$V(j, \ell) = A(j, \ell)c(j, \ell) \quad \text{subject to} \quad c(j, \ell) + R(j, \ell) = \theta, \quad (1)$$

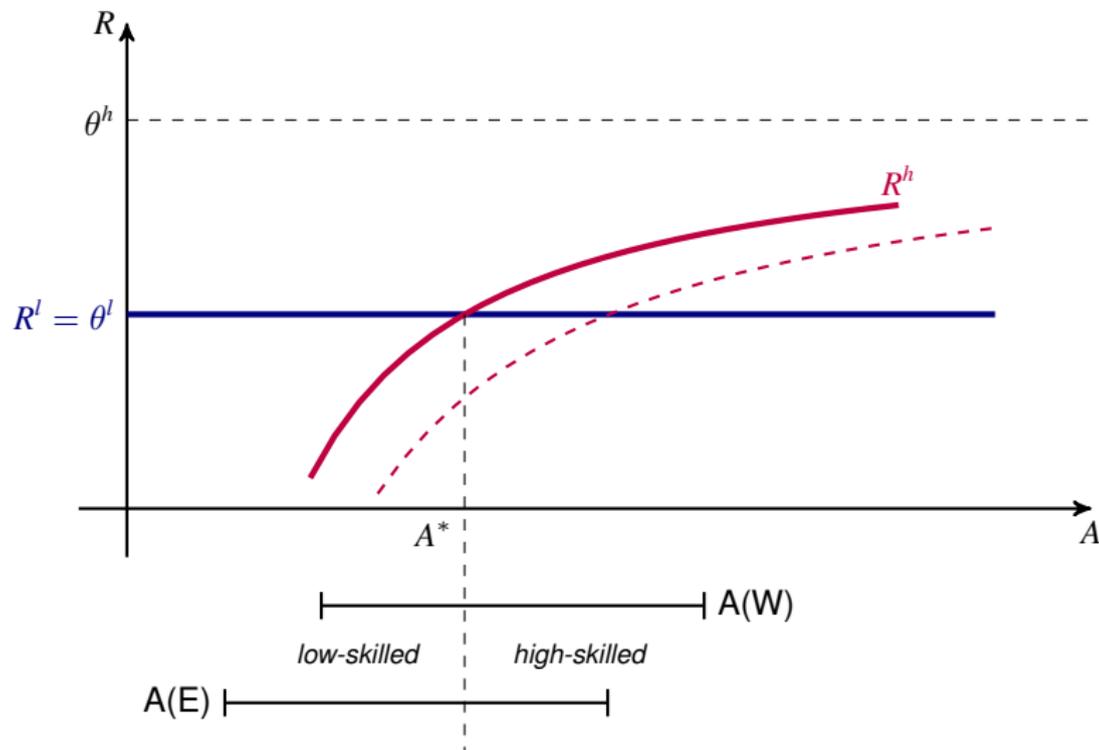
where  $A(j, \ell)$  is the amenity level in location  $\ell$  of neighborhood  $j$ ,  $c(j, \ell)$  is consumption and  $R(j, \ell)$  is rent.

$$A(j, \ell) = a(j) + x(\ell, j). \quad (2)$$

- ▶  $a(j)$  is *air quality* in neighborhood  $j$ ;
- ▶  $x(\ell, j)$  is a *location amenity* at location  $\ell$  within neighborhood  $j$  (distributed uniformly over  $[0, 1]$ ).

## A static model of neighborhood sorting (2/2)

Amenities and Neighborhood Sorting:  $a(E) \leq a(W)$ ,  $\gamma = \frac{1}{2}$ .



## A dynamic and quantitative model (1/2)

Workers are infinitely-lived and choose their location (no moving costs) in each period to maximize,

$$V(j, \ell, t) = A(j, \ell, t)c(j, \ell, t) \quad \text{subject to} \quad c(j, \ell, t) + R(j, \ell, t) = \theta,$$

where  $A(j, \ell, t)$  is the amenity level in location  $\ell$  of neighborhood  $j$  in calendar year  $t$ .

$$A(j, \ell, t) = a(j, t) + x(\ell, j) + d(j, t). \tag{3}$$

- ▶  $a(j, t)$  is *air quality* in neighborhood  $j$  (exogenous!);
- ▶  $x(\ell, j)$  is a *location amenity* at location  $\ell$ ,
- ▶  $d(j, t)$  is the *endogenous amenity* at the neighborhood level.

## A dynamic and quantitative model (2/2)

We assume:

$$d(j, t) = (1 - \delta)d(j, t - 1) + e(j, t) + b(j, t) \quad (\text{E})$$

where:

1.  $1 - \delta$  captures the inertia of the AR(1) process,
2. there are two endogenous perturbations:
  - ▶  $e$  is continuous in average income,
  - ▶  $b$  is a tail effect.

## Calibration and estimation (1/2)

1. We first calibrate observable parameters:

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| Parameter                        | Value | Rationale   |
|----------------------------------|-------|---|
| $\theta^h$ High income           | 2     | Williamson [1980], highest quartile to the lowest |
| $\theta^l$ Low income            | 1     | Williamson [1980]                                 |
| $\tilde{\gamma}$ Low-skill share | 0.50  | Normalization                                     |
| $\alpha$ Pollution sensitivity   | 0.102 | Correlation pollution/occupation in 1881          |
| $d$ Initial amenity              | 1     | Normalization                                     |

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2. We estimate the equation (E) in the data using:

- ▶ the within-city residuals of low-skill share between 1881–1971,
- ▶ the within-city residuals of atmospheric pollution for the 4,519 neighborhoods.

We treat neighborhoods as independent observations (the residuals are cleaned from city-FEs).

## Calibration and estimation (2/2)

| Parameter  | Description                           | Estimate | Standard error |
|------------|---------------------------------------|----------|----------------|
| $\phi_1^e$ | Coefficient for the continuous effect | 0.11     | 0.04           |
| $\phi_2^e$ | Curvature for the continuous effect   | 0.89     | 0.08           |
| $\phi_1^b$ | Coefficient for the tail effect       | 0.10     | 0.06           |
| $\phi_2^b$ | Curvature for the tail effect         | 1.45     | 0.30           |
| $\bar{S}$  | Tail point                            | 0.76     | 0.08           |
| $\delta$   | Depreciation factor                   | 0.08     | 0.03           |

These estimates are such that:

- ▶  $\delta = 0.08$  implies that half of the gap between neighborhoods would be bridged after only 9 years,
- ▶ the continuous effect is positive but too small to generate persistent sorting,
- ▶ the tail effect is large and convex. The tipping point is 0.76.

## Model fit

We simulate the model over the period 1971–2011.

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|                                | Data  | 1. Baseline | 2. SH-L |
|--------------------------------|-------|-------------|---------|
| Spread in 1971                 | .0550 | .0555       | .0555   |
| Spread in 2011                 | .0278 | .0235       | .0281   |
| Correlation $\rho_{2011,1971}$ | .4337 | .4010       | .4331   |

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To improve the model fit, we re-estimate with social housing accounting for the 1979 liberalization (“SH”).



## Robustness checks: balance test [▶ Back](#)

| <i>Panel A:</i>              |                             |                               |                             |                               |                               |
|------------------------------|-----------------------------|-------------------------------|-----------------------------|-------------------------------|-------------------------------|
| Share of low-skilled in 1817 | (1)                         | (2)                           | (3)                         | (4)                           | (5)                           |
| Pollution                    | .0000<br>(.0125)<br>[.0004] | -.0048<br>(.0196)<br>[-.0427] | .0123<br>(.0235)<br>[.1083] | .0052<br>(.0245)<br>[.0463]   | .0062<br>(.0241)<br>[.0549]   |
| Observations                 | 480                         | 480                           | 480                         | 480                           | 480                           |
| Fixed effects (city)         | No                          | Yes                           | Yes                         | Yes                           | Yes                           |
| Controls (geography)         | No                          | No                            | Yes                         | Yes                           | Yes                           |
| Controls (topography)        | No                          | No                            | No                          | Yes                           | Yes                           |
| Controls (lat./lon.)         | No                          | No                            | No                          | No                            | Yes                           |
| <i>Panel B:</i>              |                             |                               |                             |                               |                               |
| Wealth in 1815               | (1)                         | (2)                           | (3)                         | (4)                           | (5)                           |
| Pollution                    | .3795<br>(.1472)<br>[.3000] | .2322<br>(.1487)<br>[.1838]   | .0907<br>(.1318)<br>[.0718] | -.0516<br>(.1261)<br>[-.0408] | -.0583<br>(.1345)<br>[-.0461] |
| Observations                 | 450                         | 450                           | 450                         | 450                           | 450                           |
| Fixed effects (city)         | No                          | Yes                           | Yes                         | Yes                           | Yes                           |
| Controls (geography)         | No                          | No                            | Yes                         | Yes                           | Yes                           |
| Controls (topography)        | No                          | No                            | No                          | Yes                           | Yes                           |
| Controls (lat./lon.)         | No                          | No                            | No                          | No                            | Yes                           |

# Robustness checks: difference-in-difference

▶ Back

| <i>Panel A: LSOA, 1817-1881</i>   |                             |                             |                             |                             |
|-----------------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| Share of low-skilled workers      | (1)                         | (2)                         | (3)                         | (4)                         |
| Pollution                         | .0355<br>(.0057)<br>[.1863] | .0338<br>(.0058)<br>[.1774] | .0320<br>(.0063)<br>[.1681] | .0316<br>(.0064)<br>[.1662] |
| Observations                      | 8,696                       | 8,696                       | 8,696                       | 8,696                       |
| Fixed effects (LSOA)              | Yes                         | Yes                         | Yes                         | Yes                         |
| Trends (city)                     | Yes                         | Yes                         | Yes                         | Yes                         |
| Trends (geography)                | No                          | Yes                         | Yes                         | Yes                         |
| Trends (topography)               | No                          | No                          | Yes                         | Yes                         |
| Trends (coordinates)              | No                          | No                          | No                          | Yes                         |
| <i>Panel B: parish, 1817-1881</i> |                             |                             |                             |                             |
| Share of low-skilled workers      | (1)                         | (2)                         | (3)                         | (4)                         |
| Pollution                         | .0535<br>(.0171)<br>[.3076] | .0520<br>(.0173)<br>[.2993] | .0350<br>(.0192)<br>[.2012] | .0332<br>(.0194)<br>[.1913] |
| Observations                      | 1,034                       | 1,034                       | 1,034                       | 1,034                       |
| Fixed effects (parish)            | Yes                         | Yes                         | Yes                         | Yes                         |
| Trends (city)                     | Yes                         | Yes                         | Yes                         | Yes                         |
| Trends (geography)                | No                          | Yes                         | Yes                         | Yes                         |
| Trends (topography)               | No                          | No                          | Yes                         | Yes                         |
| Trends (coordinates)              | No                          | No                          | No                          | Yes                         |

## Robustness checks: counterfactual pollution [▶ Back](#)

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| Share of low-skilled workers | (1)                           | (2)                         | (3)                         | (4)                         |
|------------------------------|-------------------------------|-----------------------------|-----------------------------|-----------------------------|
| Pollution                    | .0372<br>(.0086)<br>[.1505]   | .0322<br>(.0108)<br>[.1302] | .0336<br>(.0068)<br>[.1356] | .0339<br>(.0068)<br>[.1370] |
| Mirror Pollution             | -.0030<br>(.0062)<br>[-.0123] |                             |                             |                             |
| Static Pollution             |                               | .0021<br>(.0088)<br>[.0085] |                             |                             |
| Domestic Pollution           |                               |                             | .0087<br>(.0154)<br>[.0330] |                             |
| Current Pollution            |                               |                             |                             | .0106<br>(.0056)<br>[.0431] |
| Observations                 | 4,519                         | 4,519                       | 4,519                       | 4,519                       |
| Fixed effects (city)         | Yes                           | Yes                         | Yes                         | Yes                         |
| Extended controls            | Yes                           | Yes                         | Yes                         | Yes                         |

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Note: there is a correlation between the mere proximity to industries and neighbourhood composition, but pollution explains most of this covariance.

## Robustness checks: IV [▶ Back](#)

| <i>First stage</i>              |                             | Pollution                           |                             |                             |
|---------------------------------|-----------------------------|-------------------------------------|-----------------------------|-----------------------------|
|                                 | (1)                         | (2)                                 | (3)                         | (4)                         |
| Synthetic pollution (waterways) | .3010<br>(.0093)            | .2999<br>(.0094)                    |                             |                             |
| Synthetic pollution (uniform)   |                             |                                     | .2497<br>(.0090)            | .2478<br>(.0090)            |
| <i>Second stage</i>             |                             | Share of low-skilled workers (1881) |                             |                             |
|                                 | (1)                         | (2)                                 | (3)                         | (4)                         |
| Pollution                       | .1017<br>(.0169)<br>[.4107] | .0995<br>(.0172)<br>[.4016]         | .0683<br>(.0190)<br>[.2760] | .0644<br>(.0194)<br>[.2599] |
| Observations                    | 4,084                       | 4,084                               | 4,519                       | 4,519                       |
| Fixed effects (city)            | Yes                         | Yes                                 | Yes                         | Yes                         |
| Extended controls               | No                          | Yes                                 | No                          | Yes                         |

# Robustness checks: house prices and transactions (2001-2011)

▶ Back

| VARIABLES             | Nationwide                    |                               | Land registry                 |                               |                               |                               |
|-----------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
|                       | House prices                  |                               | House prices                  |                               | Transactions                  |                               |
|                       | (1)                           | (2)                           | (3)                           | (4)                           | (5)                           | (6)                           |
| Pollution             | -.1042<br>(.0190)<br>[-.1668] | -.0801<br>(.0147)<br>[-.1282] | -.1067<br>(.0185)<br>[-.1888] | -.0513<br>(.0109)<br>[-.0908] | -.0781<br>(.0226)<br>[-.1421] | -.1515<br>(.0248)<br>[-.2757] |
| Observations          | 4,519                         | 4,519                         | 4,519                         | 4,519                         | 4,519                         | 4,519                         |
| Fixed effects (city)  | Yes                           | Yes                           | Yes                           | Yes                           | Yes                           | Yes                           |
| Controls (house ch.)  | No                            | Yes                           | No                            | Yes                           | No                            | Yes                           |
| Controls (topography) | Yes                           | Yes                           | Yes                           | Yes                           | Yes                           | Yes                           |
| Controls (1817)       | Yes                           | Yes                           | Yes                           | Yes                           | Yes                           | Yes                           |

## Robustness checks: social housing/migrant shares (1971-2011)

▶ Back

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| Effect of pollution on ...  | 1971                             | 1981                             | 1991                             | 2001                             | 2011                             |
|-----------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| Social housing              | .0089<br>(.0072)<br><i>.287</i>  | .0504<br>(.0099)<br><i>.358</i>  | .0659<br>(.0084)<br><i>.297</i>  | .0597<br>(.0071)<br><i>.260</i>  | .0572<br>(.0073)<br><i>.232</i>  |
| Owners                      | -.0413<br>(.0072)<br><i>.429</i> | -.0543<br>(.0083)<br><i>.494</i> | -.0694<br>(.0085)<br><i>.580</i> | -.0720<br>(.0086)<br><i>.583</i> | -.0740<br>(.0095)<br><i>.535</i> |
| Migrants (New Commonwealth) | .0129<br>(.0034)<br><i>.041</i>  | .0189<br>(.0046)<br><i>.060</i>  | .0173<br>(.0046)<br><i>.064</i>  | .0195<br>(.0054)<br><i>.085</i>  | .0307<br>(.0073)<br><i>.128</i>  |
| Migrants (Other)            | .0012<br>(.0010)<br><i>.034</i>  | .0008<br>(.0008)<br><i>.035</i>  | .0006<br>(.0008)<br><i>.043</i>  | .0028<br>(.0009)<br><i>.053</i>  | .0061<br>(.0013)<br><i>.075</i>  |
| Observations                | 4,517                            | 4,519                            | 4,519                            | 4,519                            | 4,519                            |
| Fixed effects (city)        | Yes                              | Yes                              | Yes                              | Yes                              | Yes                              |

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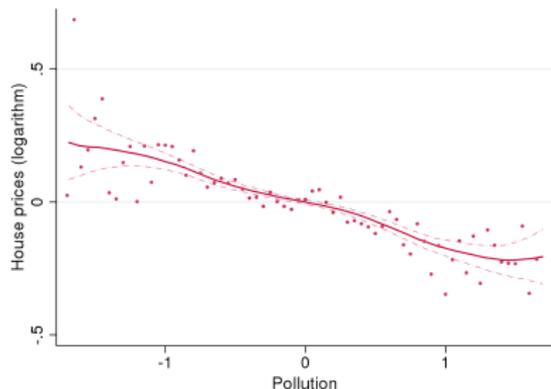
| <i>Panel A: Amenities</i>               | 1881                        |                             | 2011                        |                             |
|---|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| Share of low-skilled workers            | (1)                         | (2)                         | (3)                         | (4)                         |
| Pollution                               | .0309<br>(.0065)<br>[.1250] | .0285<br>(.0066)<br>[.1153] | .0339<br>(.0071)<br>[.1933] | .0280<br>(.0065)<br>[.1599] |
| Observations                            | 3,814                       | 3,814                       | 3,814                       | 3,814                       |
| Controls (amenities 1881)               | Yes                         | Yes                         | Yes                         | Yes                         |
| Controls (amenities 2011)               | No                          | Yes                         | No                          | Yes                         |
| <i>Panel B: Housing characteristics</i> |                             | 2011                        |                             |                             |
| Share of low-skilled workers            | (1)                         | (2)                         | (3)                         | (4)                         |
| Pollution                               | .0545<br>(.0102)<br>[.3109] | .0380<br>(.0080)<br>[.2167] | .0203<br>(.0056)<br>[.1161] | .0114<br>(.0041)<br>[.0650] |
| Observations                            | 995                         | 4,228                       | 4,228                       | 4,228                       |
| Sample                                  | New housing                 | All                         | All                         | All                         |
| Controls (building age)                 | Yes                         | Yes                         | Yes                         | Yes                         |
| Controls (social housing)               | No                          | No                          | No                          | Yes                         |
| Controls (house characteristics)        | No                          | No                          | Yes                         | Yes                         |
| <i>Panel C: Education and crime</i>     |                             | 2011                        |                             |                             |
| Share of low-skilled workers            | (1)                         | (2)                         | (3)                         | (4)                         |
| Pollution                               | .0313<br>(.0059)<br>[.1788] | .0219<br>(.0056)<br>[.1251] | .0356<br>(.0070)<br>[.1933] | .0276<br>(.0057)<br>[.1599] |
| Observations                            | 4,519                       | 1,792                       | 4,519                       | 4,519                       |
| Controls (school supply)                | Yes                         | Yes                         | No                          | No                          |
| Controls (composition/scores)           | No                          | Yes                         | No                          | No                          |
| Controls (police station)               | No                          | No                          | Yes                         | Yes                         |
| Controls (crime)                        | No                          | No                          | No                          | Yes                         |

# Robustness checks: fixed effects, clusters and sample selection

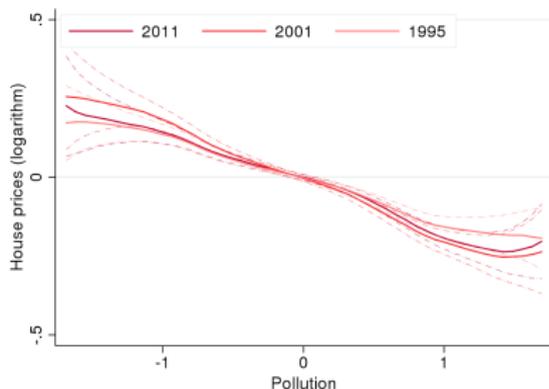
▶ Back

| <i>Panel A: Fixed effects</i> |                             | Share of low-skilled workers (1881) |                             |  |
|-------------------------------|-----------------------------|-------------------------------------|-----------------------------|--|
|                               | (1)                         | (2)                                 | (3)                         |  |
| Pollution                     | .0391<br>(.0079)<br>[.1580] | .0364<br>(.0088)<br>[.1471]         | .0303<br>(.0090)<br>[.1225] |  |
| Observations                  | 4,519                       | 4,519                               | 4,519                       |  |
| Fixed effects                 | Parish                      | Ward                                | MSOA                        |  |
| <i>Panel B: Clusters</i>      |                             | Share of low-skilled workers (1881) |                             |  |
|                               | (1)                         | (2)                                 | (3)                         |  |
| Pollution                     | .0350<br>(.0052)<br>[.1415] | .0350<br>(.0057)<br>[.1415]         | .0350<br>(.0076)<br>[.1415] |  |
| Observations                  | 4,519                       | 4,519                               | 4,519                       |  |
| Clusters                      | MSOA                        | Ward                                | City                        |  |
| <i>Panel C: Sample</i>        |                             | Share of low-skilled workers (1881) |                             |  |
|                               | (1)                         | (2)                                 | (3)                         |  |
| Pollution                     | .0329<br>(.0061)<br>[.1328] | .0558<br>(.0116)<br>[.2255]         | .0358<br>(.0064)<br>[.1447] |  |
| Observations                  | 3,056                       | 3,533                               | 4,285                       |  |
| Excluding...                  | London                      | NW                                  | NE                          |  |

**Figure:** House transaction prices (y-axis) and pollution (x-axis) across neighborhoods – average and evolution between 1995 and 2011.



(a) Average



(b) Evolution

Notes: The left (resp. right) panel represents the relationship between the (logarithm of the) average transaction prices between 2000 and 2011 (resp. in 1995, 2000, and 2011) and our (standardized) measure of past pollution. We consider the residuals of all measures once cleaned by city Fixed-Effects, geographic and topographic controls. For the sake of exposure, we group neighborhoods, create 100 bins of neighborhoods with similar past pollution and represent the average house prices within a pollution-bin. The lines are locally weighted regressions on all observations.

# The Mill of the World

Between 1700-1870, the UK went through a period of **economic growth and structural transformation**:

- ▶ with a large take-off around 1830: [▶ Description](#)

- ▶ essentially fostered by the textile industry: [▶ Raw cotton](#)

This transformation had been accompanied by a **huge rural-urban migration** which was strongest between 1780 and 1850.

- [▶ Growth rates in cities](#)

# The Chimney of the World

In parallel, coal became the main energy source with a large acceleration around 1850 due to the adoption of large boilers.

▶ Coal use: [▶ Figure](#) .

▶ Industry share: [▶ Figure](#) .

It leads to high levels of pollution: [▶ Figure](#) .

## Timeline

**1760–1800:** start of the industrial revolution.

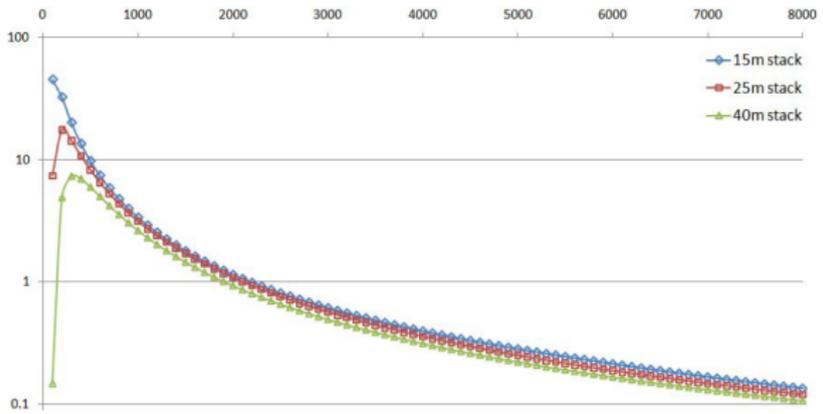
**1800–1840:** small acceleration and large migration to the cities.

**1840–1900:** rapid economic growth, stable urban population and take-off for pollution.

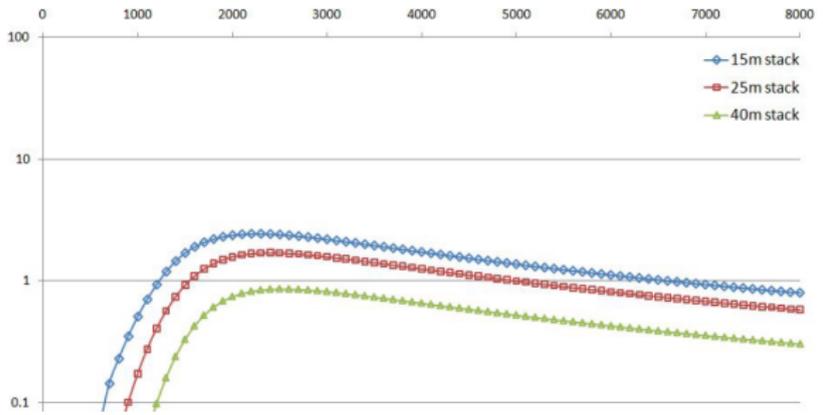
**1900–1915:** stabilisation.

**1930–1968:** de-industrialisation and first Clean Air Act of 1956 following London fog.

**1968–today:** end of coal pollution after more restrictive Clean Air Acts of 1968.

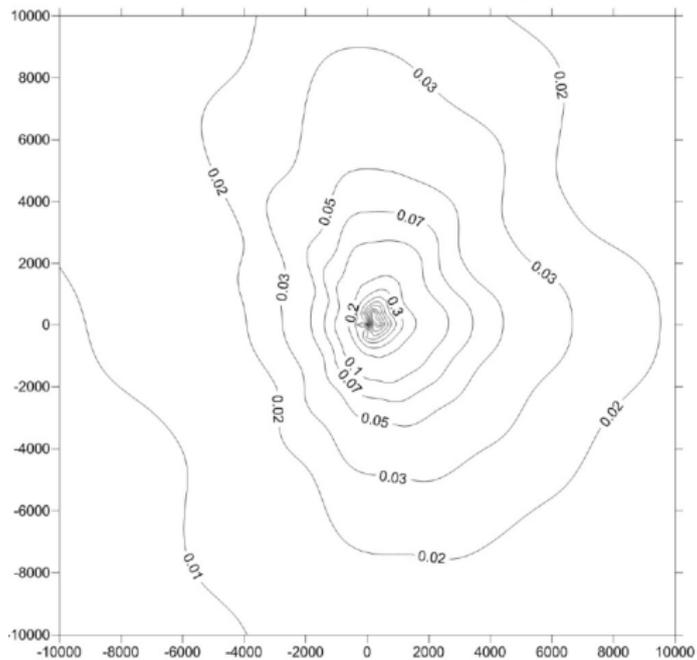


(c) Unstable conditions.



(d) Stable conditions.

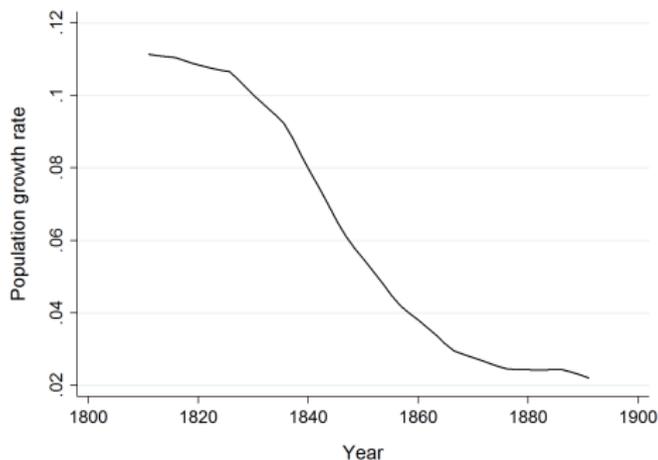
**40m stack; North England meteorological data**  
**Normalised by maximum concentration ( $0.57 \mu\text{g}/\text{m}^3$ )**



# Population growth (1/2)

► Descriptive Statistics

Population Growth Rates in cities, 1801-1891.



Notes: The figure plots the average decadal population growth rate for the period 1801-1891 in our sample cities.

## Population growth (2/2)

► Descriptive Statistics

Huge rural-urban migration flows between 1800 and 1850:

| Population | Manchester | Salford | Liverpool | Leeds   |
|------------|------------|---------|-----------|---------|
| Period     |            |         |           |         |
| 1801       | 75,281     | 18,179  | 82,000    | 53,000  |
| 1851       | 303,382    | 85,108  | 376,000   | 172,000 |
| 1861       | 338,722    | 102,449 | 443,938   | 207,165 |
| 1871       | 351,189    | 124,801 | 493,346   | 259,201 |

Source: Historical censuses (1801-1871).

# Economic growth

## ► Descriptive Statistics

### Output growth, 1700-1870:

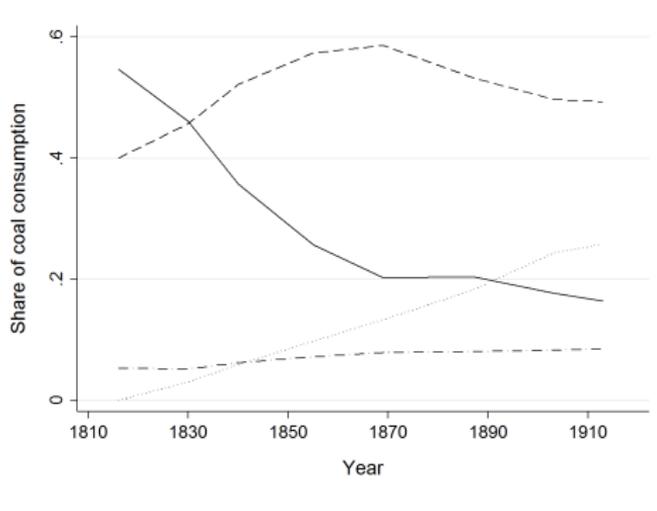
| Period    | Industry | Services | Total | Population |
|-----------|----------|----------|-------|------------|
| 1700-1760 | 0.49     | 0.71     | 0.63  | 0.32       |
| 1760-1780 | 1.00     | 0.66     | 0.81  | 0.62       |
| 1780-1801 | 2.18     | 1.40     | 1.54  | 0.97       |
| 1801-1830 | 2.59     | 1.79     | 1.69  | 1.43       |
| 1830-1870 | 3.01     | 2.58     | 2.40  | 1.18       |

Source: *British Economic Growth, 1270-1870* (Broadberry et al, 2010).

# Energy

## ▶ Descriptive Statistics

Coal consumption (shares), domestic, industrial and mining, 1560–2001.

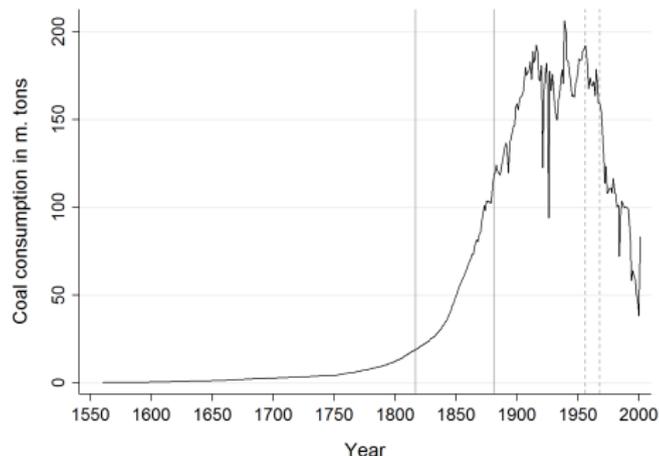


Notes: The figure illustrates the coal consumption share for domestic use (solid), industrial use in manufacturing and iron and steel production (dash), mining (dash-dot) and other sectors as composite of railways building, ship building, gas and electrics. Sources: Mitchell, 1988.

# Coal output and consumption

► Descriptive Statistics (pollution)

Coal consumption in million tons, 1560–2001.



Notes: The figure illustrates the increase in coal consumption over the period 1560–2001. The figure is based on Warde (2007) who reports coal consumption in petajoule. To convert numbers from petajoule to tons, we use a conversion factor of 1:34,140. The two solid grey lines indicate the years 1817 and 1881 for which we have detailed occupational information within cities. The dashed grey lines mark the introduction of the 1956 Clean Air Act and the stricter 1968 Clean Air Act. Sources: Warde, 2007.

A list of entries in a parish is:

| <i>id i</i> | <i>folio f</i> | address                             |
|-------------|----------------|-------------------------------------|
| 1.          | $f_1$          | 5, Chruch Street, Clifton, Bristol  |
| ⋮           | ⋮              | ⋮                                   |
| 45.         | $f_1$          | 23, Church Street, Clifton, Bristol |
| 46.         | $f_1$          | 18 Ambrose Vale Cliftonwoods        |
| ⋮           | ⋮              | ⋮                                   |
| 78.         | $f_1$          | Ambrose villas, Clifton, Bristol    |
| 79.         | $f_2$          | Ambrose villas, Clifton, Bristol    |

## Geo-locating individuals in census data (1881) [▶ Back](#)

A list of entries in a parish is:

| <i>id i</i> | <i>folio f</i> | <i>address</i>                      | <i>block n</i> |
|-------------|----------------|-------------------------------------|----------------|
| 1.          | $f_1$          | 5, Chruch Street, Clifton, Bristol  | $n_1$          |
| ⋮           | ⋮              | ⋮                                   |                |
| 45.         | $f_1$          | 23, Church Street, Clifton, Bristol | $\mathbf{n}_1$ |
| 46.         | $f_1$          | 18 Ambrose Vale Cliftonwoods        | $n_2$          |
| ⋮           | ⋮              | ⋮                                   |                |
| 78.         | $f_1$          | Ambrose villas, Clifton, Bristol    | $\mathbf{n}_2$ |
| 79.         | $f_2$          | Ambrose villas, Clifton, Bristol    | $\mathbf{n}_2$ |

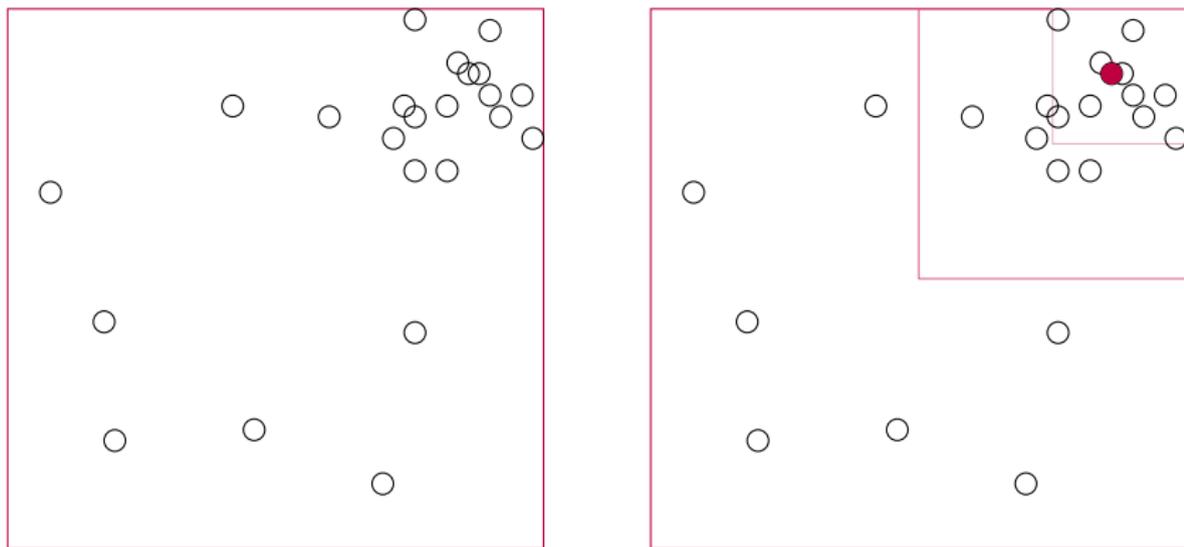
## Geo-locating individuals in census data (1881) [▶ Back](#)

A list of entries in a parish is:

| id $i$ | folio $f$ | address                             | block $n$ | break |
|--------|-----------|-------------------------------------|-----------|-------|
| 1.     | $f_1$     | 5, Chruch Street, Clifton, Bristol  | $n_1$     |       |
| ⋮      | ⋮         | ⋮                                   |           |       |
| 45.    | $f_1$     | 23, Church Street, Clifton, Bristol | $n_1$     |       |
| 46.    | $f_1$     | 18 Ambrose Vale Cliftonwoods        | $n_2$     | $B_1$ |
| ⋮      | ⋮         | ⋮                                   |           |       |
| 78.    | $f_1$     | Ambrose villas, Clifton, Bristol    | $n_2$     |       |
| 79.    | $f_2$     | Ambrose villas, Clifton, Bristol    | $n_2$     | $B_2$ |

## Geo-locating individuals in census data (1881) [▶ Back](#)

1. We run a **fuzzy-matching** process (20% perfect match, 35% good enough).
2. We locate all matched households within their parish.
3. We then **define a new id**, e.g., a folio number, and run:



4. We associate all households with the same id to the matched LSOA.

Notes: sensitivity tests to id definition, fuzzy threshold, iteration in the algorithm.

# What are the potential channels?

| <i>Panel A: Deprivation indices</i> |                               |                               |                             |                               |                               |                               |                             |                               |
|-------------------------------------|-------------------------------|-------------------------------|-----------------------------|-------------------------------|-------------------------------|-------------------------------|-----------------------------|-------------------------------|
|                                     | Index                         | Inc.                          | Empl.                       | Educ.                         | Health                        | Housing                       | Crime                       | Environ.                      |
| Pollution                           | .0640<br>(.0138)<br>[.2501]   | .0701<br>(.0164)<br>[.2465]   | .0539<br>(.0140)<br>[.1928] | .0787<br>(.0135)<br>[.2699]   | .0338<br>(.0107)<br>[.1292]   | .0034<br>(.0053)<br>[.0113]   | .0312<br>(.0068)<br>[.1263] | .0394<br>(.0146)<br>[.1657]   |
| Observations                        | 4,519                         | 4,519                         | 4,519                       | 4,519                         | 4,519                         | 4,519                         | 4,519                       | 4,519                         |
| <i>Panel B: Education and crime</i> |                               |                               |                             |                               |                               |                               |                             |                               |
|                                     | Private School                | Student Score                 | Disad. Students             | School VA                     | Anti-social Behaviors         | Burglary                      | Drug-rel. Crimes            | Violent Crimes                |
| Pollution                           | -.0050<br>(.0027)<br>[-.0371] | -.0038<br>(.0012)<br>[-.0791] | .0072<br>(.0012)<br>[.0826] | -.0000<br>(.0001)<br>[-.0025] | .0038<br>(.0047)<br>[.0287]   | .0428<br>(.0101)<br>[.1225]   | .0123<br>(.0021)<br>[.1561] | .0645<br>(.0126)<br>[.1796]   |
| Observations                        | 4,519                         | 4,519                         | 4,519                       | 4,519                         | 4,519                         | 4,519                         | 4,519                       | 4,519                         |
| <i>Panel C: Housing quality</i>     |                               |                               |                             |                               |                               |                               |                             |                               |
|                                     | Building 1900                 | Building 1970                 | Building 2000               | Year of construction          | Square meters                 | Bedrooms                      | Flats                       | Detached                      |
| Pollution                           | -.0164<br>(.0104)<br>[-.0638] | -.0078<br>(.0109)<br>[-.0372] | .0118<br>(.0060)<br>[.0678] | 2.287<br>(1.719)<br>[.0668]   | -1.832<br>(.7066)<br>[-.0703] | -.0140<br>(.0170)<br>[-.0220] | .0550<br>(.0138)<br>[.1996] | -.0227<br>(.0056)<br>[-.1481] |
| Observations                        | 4,519                         | 4,519                         | 4,519                       | 4,228                         | 4,228                         | 4,228                         | 4,519                       | 4,519                         |
| <i>Panel D: Amenities</i>           |                               |                               |                             |                               |                               |                               |                             |                               |
|                                     | Parks                         | Entert.                       | Church                      | Hospital                      | Public                        | Justice                       | Transport                   | Botanical                     |
| Pollution                           | .0401<br>(.0169)<br>[.0735]   | -.0011<br>(.0204)<br>[-.0016] | .0180<br>(.0095)<br>[.0571] | -.0050<br>(.0023)<br>[-.0498] | .0322<br>(.0203)<br>[.0653]   | .0116<br>(.0093)<br>[.0559]   | .0361<br>(.0118)<br>[.1181] | -.0090<br>(.0041)<br>[-.0401] |
| Observations                        | 4,519                         | 4,519                         | 4,519                       | 4,519                         | 4,519                         | 4,519                         | 4,519                       | 4,519                         |