FROM SPATIAL SEGREGATION TO ENVIRONMENTAL INEQUALITIES

(Work in progress)

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Introduction

Plan

- Introduction
- Methodological analysis
  - Environmental areal-level data
  - Environmental points data
- Empirical evidence
  - Global analysis
  - Zoom on socio-professional status
- Conclusions

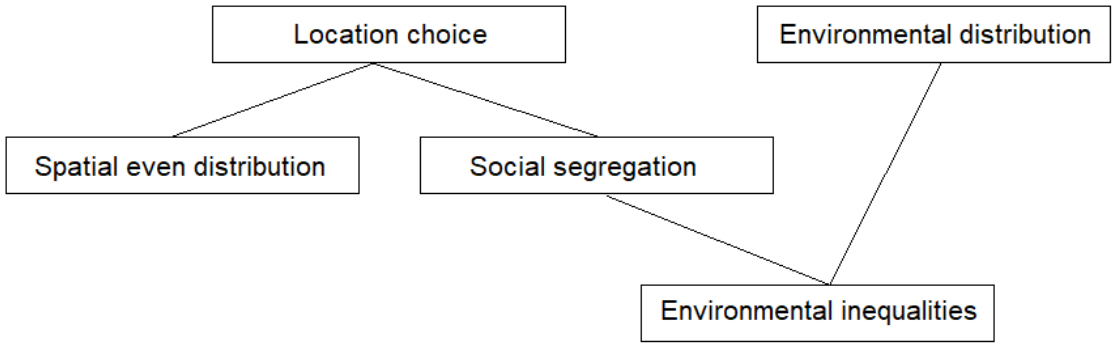
Introduction

Definitions

- **Social segregation**: spatial separation between social groups
- Between-group **environmental inequalities**: unequal exposure/access of different social groups to an environmental variable (air pollutants, green amenities…)

Intuition

- Both social segregation and between-group environmental inequalities arise from the fact that social groups have different relative spatial distribution



Introduction

Methodology

- Segregation indices
  - Dimensions: evenness, exposure, concentration, clustering, centralization (Massey and Denton, 1988)
  - Types:
    - one group, between-group, multigroup
    - aspatial vs. spatial

- Environmental inequality measurement
  - Between-group comparisons of means or medians
  - Bivariate correlations and (spatial) regressions
  - **Adaptation of segregation indices** (Schaeffer and Tivadar, 2019) for 2 types of environmental data:
    - **surface/areal** (e.g. green spaces)
    - **points** (e.g. industrial hazards)

Introduction

Objectives

- Use segregation based environmental inequality indices (Schaeffer and Tivadar, 2019) to bring mathematical proofs of relations **between environmental inequalities and segregation**

- Show empirical evidence on French urban areas for environmental inequalities related to the spatial distributions of **tree canopy cover** and **dangerous industrial sites**

Environmental areal-level data

From social dissimilarity to environmental inequality

- **Dissimilarity index** (Duncan and Duncan, 1955a)
  - Simple, widely used, intuitive interpretation
  - Measures the departure from even population distribution across spatial units (evenness)
  - Interpretation: proportion of a group that would need to relocate in order to achieve an evenly distributed spatial distribution compared to another group.

$$D^{x,y} = \frac{1}{2}\sum_{i=1}^{n}\left|\frac{x_i}{X} - \frac{y_i}{Y}\right|$$

$$0 \leq D^{k_1,k_2} \leq 1$$

Where n is the number of spatial units, x_i and y_i the population of each group in spatial unit i, and $X = \sum_{i=1}^{n} x_i$ and $Y = \sum_{i=1}^{n} y_i$ are each group total population.

Environmental areal-level data

From social dissimilarity to environmental inequality

- **Delta index** (Duncan and Duncan, 1961)
  - Adaptation of dissimilarity index to measure spatial concentration
  - Combines population and areal data (one group index)
  - It measures the dissimilarity between the distribution of a group and the distribution of available land

$$\Delta^k = \frac{1}{2}\sum_{i=1}^{n}\left|\frac{x_i^k}{X^k} - \frac{A_i}{A}\right|$$

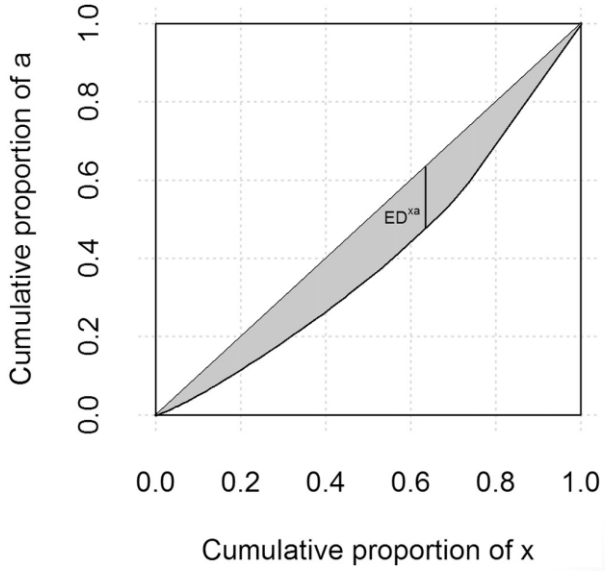
$$0 \leq \Delta^k \leq 1$$

Environmental areal-level data

From social dissimilarity to environmental inequality

- **Environmental Dissimilarity Index** (Schaeffer and Tivadar, 2019)
  - The dissimilarity between the distribution of a group and of an environmental variable (one group index)
  - Same properties and interpretations

$$ED^{x,a} = \frac{1}{2}\sum_{i=1}^{n}\left|\frac{x_i}{X} - \frac{a_i}{A}\right|$$



Environmental areal-level data

From social dissimilarity to environmental inequality

- **Environmental Dissimilarity Gap** (Schaeffer and Tivadar, 2019)
  - The difference in the degrees of environmental segregation of two social groups (between group index)

$$\Delta ED^{x,y} = ED^{x,a} - ED^{y,a} = \frac{1}{2}\sum_{i=1}^{n}\left(\left|\frac{x_i}{X} - \frac{a_i}{A}\right| - \left|\frac{y_i}{Y} - \frac{a_i}{A}\right|\right)$$

  - Values from -1 to 1

- **Property**
  - EGP (absolute value) is bounded by dissimilarity index

$$\left|\Delta ED^{x,y}\right| \leq D^{x,y}$$

⇒ Mathematical interpretation: **the social segregation is a necessary but insufficient condition to environmental inequality**

⇒ Statistical expectations: **positive correlation between environmental inequalities and segregation, with heteroscedasticity**

Environmental areal-level data

Spatial interactions

- **Morrill dissimilarity index** (Morrill 1991)
  - Introduction of spatial interactions (contiguity matrix)
  - Generalization to k-th order contiguity matrix (Tivadar, 2019)

$$D^{x,y}(adj_K) = D^{x,y} - \sum_{k=1}^{K} f(k) \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}^{k}\delta_{ij}^{x,y}}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}^{k}}$$

Where

- $f(k)$ is a distance-decay function defined by contiguity order k, with $f'(k) < 0$, $f(1) = 1$ and $f(k)_{k\to\infty} = 0$.
- w_{ij}^{k} are the elements of the spatial weights matrix
- $\delta_{ij}^{x,y}$ are the spatial interactions terms between groups x and y, located in two contiguous (of order k) spatial units i and j.

Environmental areal-level data

Spatial interactions

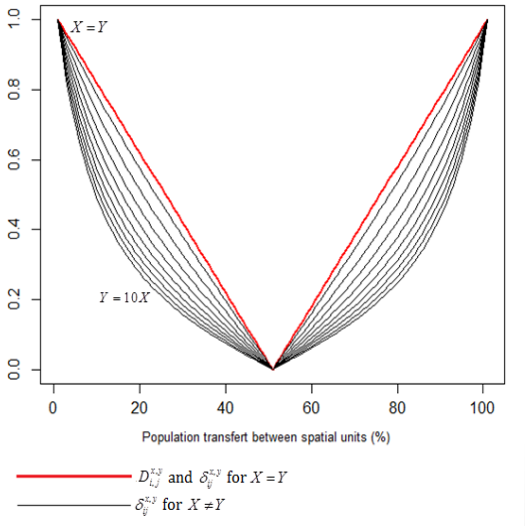
- **Social interactions matrix**
  - Morrill's social interactions matrix

$$\delta_{ij}^{x,y} = \left| \frac{x_i}{x_i + y_i} - \frac{x_j}{x_j + y_j} \right|$$

  - Dissimilarity social interactions: dissimilarity index between *x* and *y* for a zone formed only by spatial units *i* and *j*

$$D_{i,j}^{x,y} = \frac{1}{2}\left(\left| \frac{x_i}{X_{ij}} - \frac{y_i}{Y_{ij}} \right| + \left| \frac{x_j}{X_{ij}} - \frac{y_j}{Y_{ij}} \right| \right)$$

where $X_{ij} = x_i + x_j$ and $Y_{ij} = y_i + y_j$.



Spatial interactions by population structure in two contiguous spatial units

Environmental areal-level data

Spatial interactions

- **Spatially Adjusted Environmental Dissimilarity** (Schaeffer and Tivadar, 2019)

$$ED^{x,a}(adj_K) = ED^{x,a} - \sum_{k=1}^{K} f(k) \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}^{k} ED_{ij}^{x,a}}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}^{k}}$$

$$ED_{i,j}^{x,a} = \frac{1}{2}\left(\left|\frac{x_i}{X_{ij}} - \frac{a_i}{A_{ij}}\right| + \left|\frac{x_j}{X_{ij}} - \frac{a_j}{A_{ij}}\right|\right)$$

$$ED_{ij}^{x,a} = \left|\frac{x_i}{X_{ij}} - \frac{a_i}{A_{ij}}\right|$$

Environmental areal-level data

Spatial interactions

- **Spatially Adjusted Environmental Dissimilarity Gap** (Schaeffer and Tivadar, 2019)

$$\Delta ED^{x,y}(adj_K) = \Delta ED^{x,y} - \sum_{k=1}^{K} f(k) \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}^{k} \Delta ED_{ij}^{x,y}}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}^{k}}$$

- **Property:**
  - The environmental inequality is bounded by the level of social segregation increased by an aggregated positive spatial interaction term (less restrictive)

$$\Delta ED^{x,y}(adj_K) \leq D^{x,y}(adj_K) + \sum_{k=1}^{K} f(k) \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}^{k} \left(D_{ij}^{x,y} - \Delta ED_{ij}^{x,y}\right)}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}^{k}} -$$

$$D_{ij}^{x,y} - \Delta ED_{ij}^{x,y} \geq 0$$

Environmental points data

Environmental Centralization

- **Relative Centralization Index** (Duncan and Duncan, 1955b)
  - Compares the locations of two groups around a point (the city center)

$$RCE^{k_1,k_2} = \left(\sum_{i=2}^{n} X_{i-1}^{k_1} X_i^{k_2} \right) - \left(\sum_{i=2}^{n} X_i^{k_1} X_{i-1}^{k_2} \right)$$

$$-1 \leq RCE^{k_1,k_2} \leq 1$$

where x_i and y_i are ordered by the distance to the city centre. If $RCE^{x,y} > 0$, population x is located closer to the centre than population y, and conversely if $RCE^{x,y} < 0$.

  - Generalization to multiple points (Tivadar, 2019)
  - Local version of RCE (Folch and Rey, 2016)

Environmental points data

Environmental Centralization

- **Environmental Relative Centralization Index** (Schaeffer and Tivadar, 2019)

$$EC_d^{x,y} = \left(\sum_{i=2}^{k} x_{i-1} y_i\right) - \left(\sum_{i=2}^{k} x_i y_{i-1}\right)$$

where x_i and y_i are ordered by the distance to the closest environmental (dis-)amenity, and k is the rank of the last spatial unit who respect the spatial constraint: $d_i = \min_a\{d_i^a\} \leq d$. If $EC_d^{x,y} > 0$ population x is located closer to environmental (dis-)amenities than population y, and conversely if $EC_a^{x,y} < 0$.

- **Property**
  - EC (absolute value) is bounded by Gini segregation index

$$\left| EC_d^{x,y} \right| \leq G^{x,y}$$

$\Rightarrow$ Same **mathematical interpretation** and **statistical expectations**

Empirical evidence: global

Data

- Sociodemographic data at subcommunal level (INSEE IRIS 2017)
  - 60 social groups (at household or population levels) : socio-professional category, size, structure, gender, age, marital status
- Environmental data:
  - Areal: tree canopy cover (high resolution Copernicus data)
  - Points: all, dangerous and very dangerous industrial sites (Seveso data)

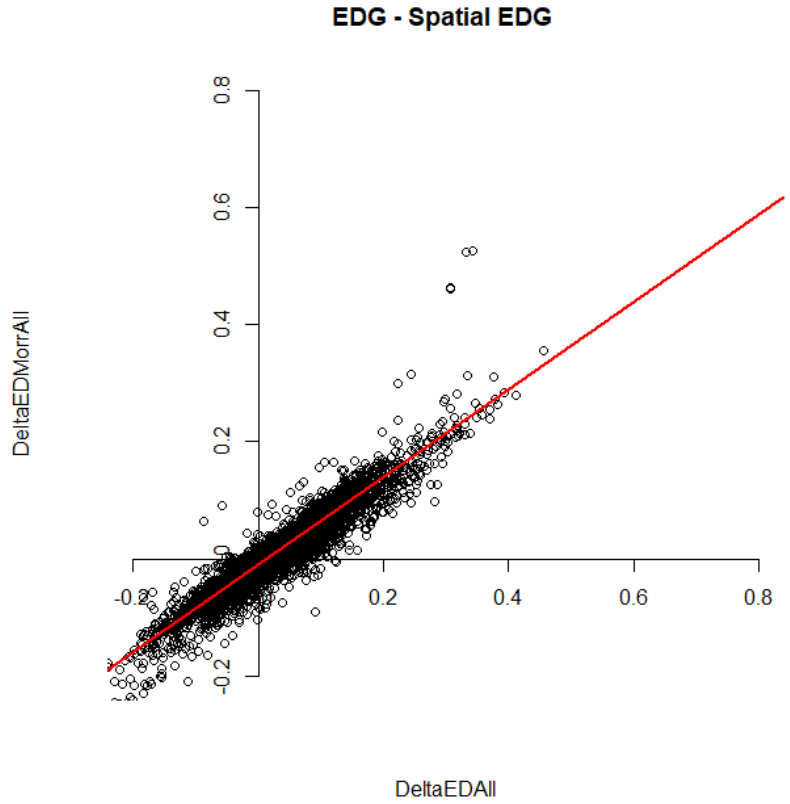
Method

- Correlations between one-group segregation and environmental inequality indices for 60 groups in 98 French urban areas
  - each group (minority) vs. all other groups (majority)
  - segregation : IS, IS-spatial, Gini
  - inequality/tree cover : EDG, EDG-spatial
  - Inequality/industrial sites : EC-all, EC-dangerous, EC-very-dangerous

Statistical expectations: **positive correlation between environmental inequalities and segregation, with heteroscedasticity**

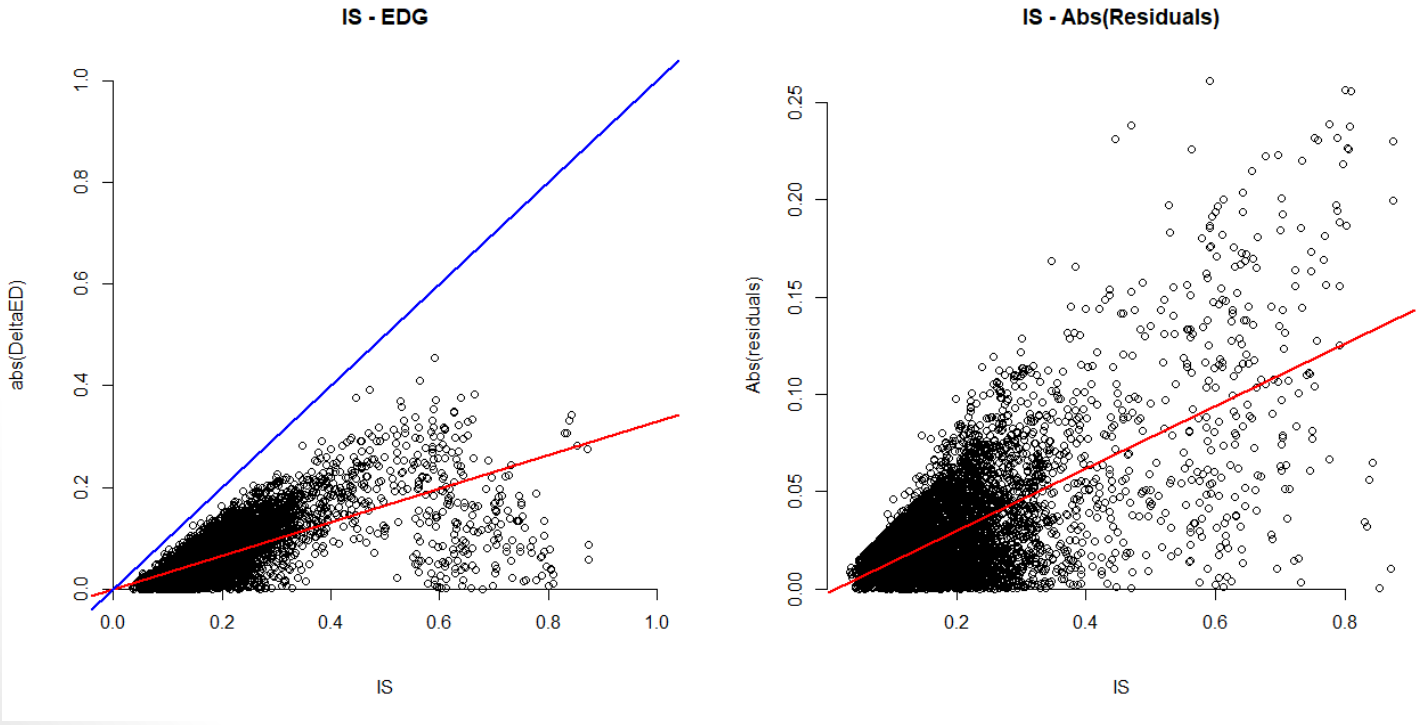
Empirical evidence: global

- **Areal data measures (tree canopy cover):**
  - Correlation between aspatial and spatial versions of EDG (r = 0.94)



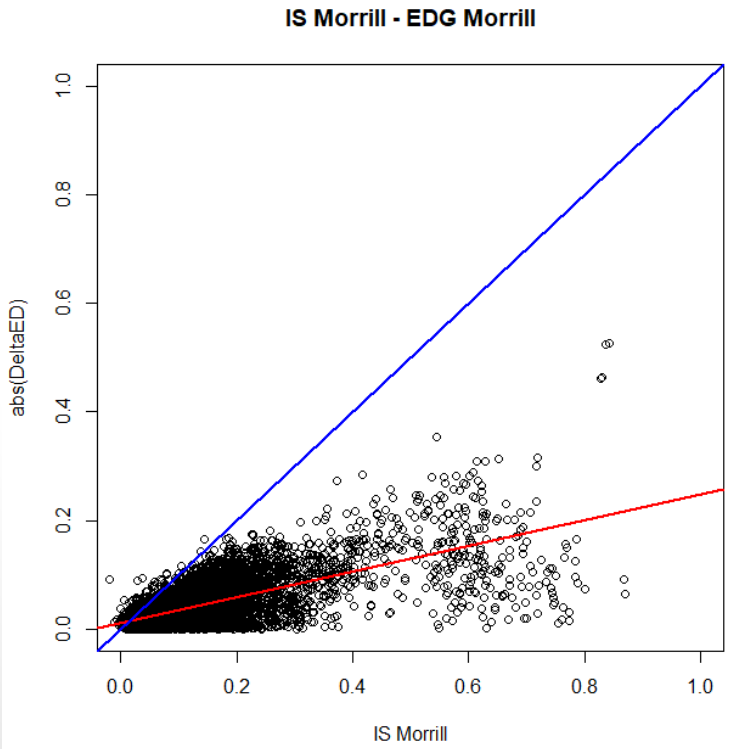
Empirical evidence: global

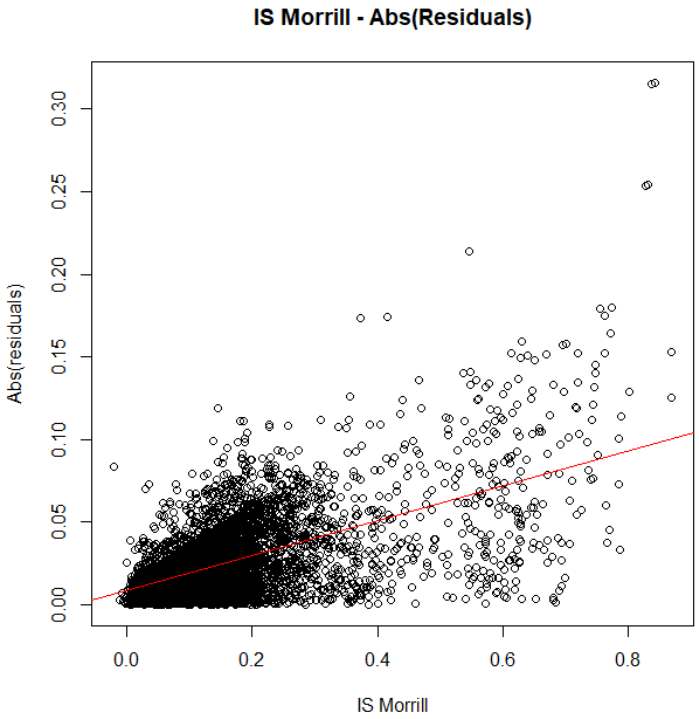
- **Areal data measures (tree canopy cover):**
  - Correlation between environmental inequalities and segregation
    r1 = cor (IS, EDG) = 0.68
  - Heteroscedastic distribution: r2 = cor(IS, abs(residuals)) = 0.64



Empirical evidence: global

- **Areal data measures (tree canopy cover):**
  - Similar results for spatial versions: r1=0.67 and r2=0.57
  - The less restricted constrain is confirmed (especially for small values of IS Morrill)

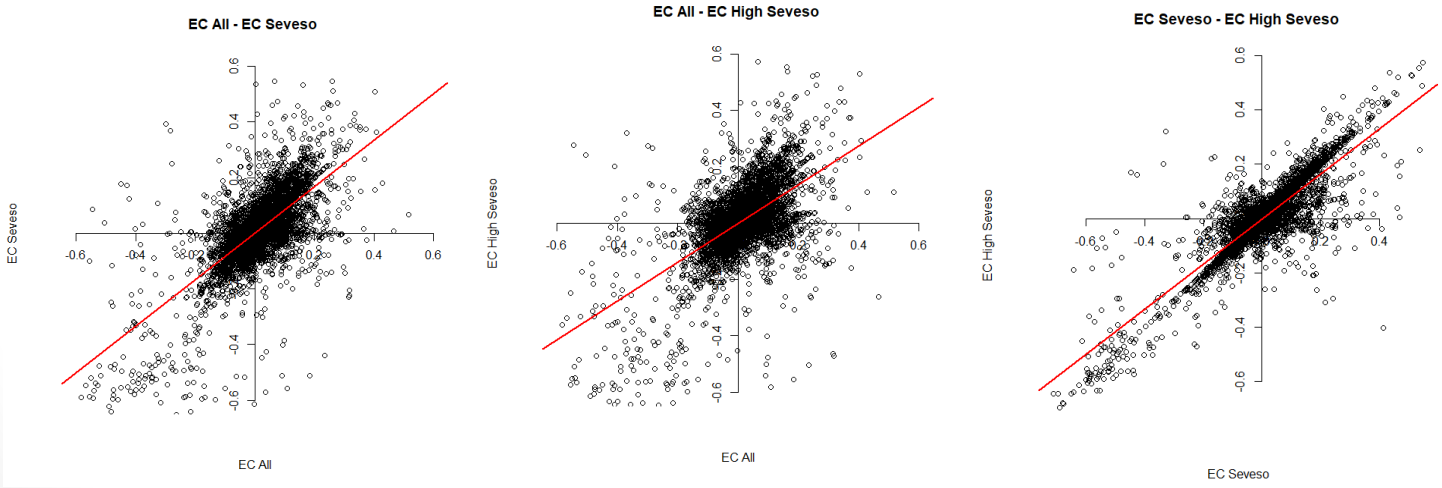




Empirical evidence: global

- **Points data measures (industrial sites):**
  - Correlations between EC indices for 3 industrial types

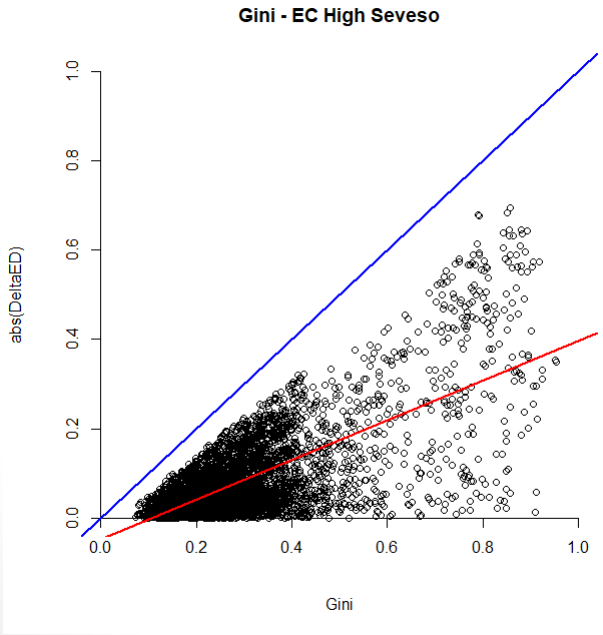
All Sites	Seveso	0,63
All Sites	High Seveso	0,58
Seveso	High Seveso	0,87

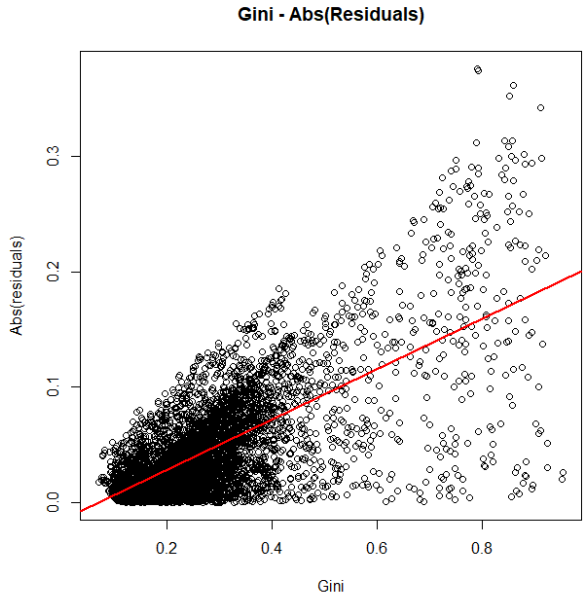


Empirical evidence: global

- **Points data measures (industrial sites):**
  - Correlations between EC and Gini indices

	r1	r2
All Sites	0,75	0,60
Seveso	0,74	0,68
High Seveso	0,71	0,70





Empirical evidence: global

Partial conclusion

⇒ Statistical expectations are met both for environmental inequalities relative to **tree cover** and to **industrial sites**, examined among **60 social groups** and **98 urban areas**: **positive correlation between environmental inequalities and segregation, with heteroscedasticity**

Empirical evidence: zoom

Environmental inequalities between high-income and low-income groups

Proxied by the socioprofessional status:

- executives and intellectual professions (hence "**executives**")
- blue-collar workers (hence "**workers**")
- white-collar workers (hence "**employees**")
- unemployed people, including students (hence "**unemployed**")

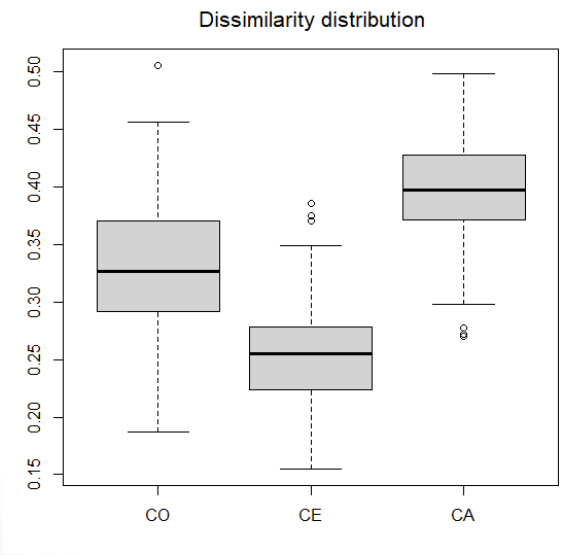
Between-groups indices:

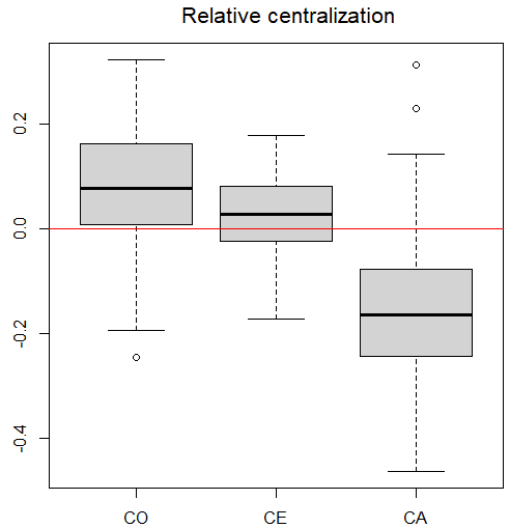
- **CO** (Cadres vs. Ouvriers) : **executives vs workers**
- **CE** (Cadres vs. Employés) : **executives vs employees**
- **CA** (Cadres vs. Autres) : **executives vs unemployed**

Empirical evidence: zoom

Segregation patterns

- High **dissimilarity** between executives and unemployed (median = 40%), and between executives and workers (median = 33%)
- Spatial interactions reduce the dissimilarity, but the general pattern remains
- Very **central locations** for unemployed, while executives are close to center, and workers and employees more in periphery

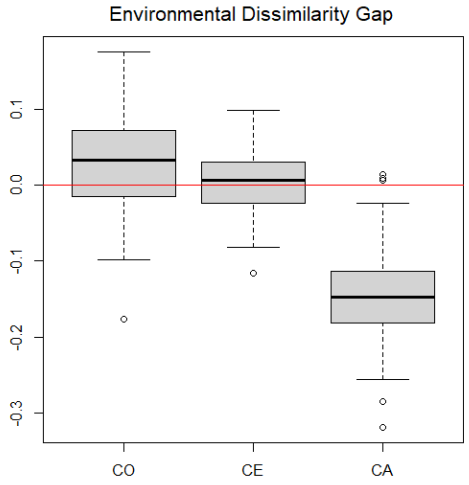




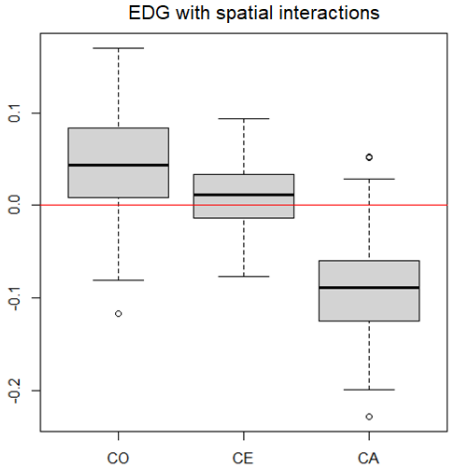
Empirical evidence: zoom

Environmental Dissimilarity Gap (tree canopy cover)

- Significant positive EDG for CO (executives vs workers)
- Significant negative EDG for CA (executives vs unemployed)



	T-test	P-value	
1	CO	2.339072e-05	***
2	CE	8.454388e-01	
3	CA	6.071732e-43	***



	T-test	P-value	Sign
1	CO	8.245255e-11	***
2	CE	9.649902e-03	**
3	CA	7.661921e-28	***

Inequalities not structured by income in an obvious way:

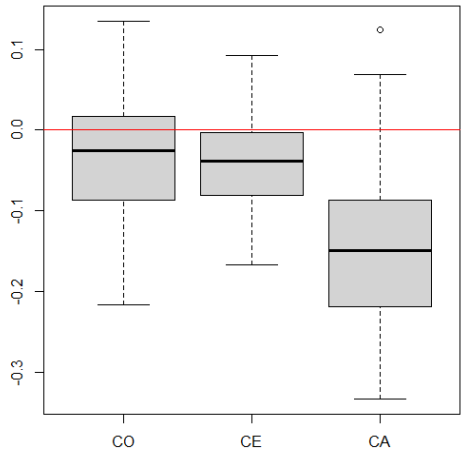
⇒ **unemployed much more segregated from tree cover than executives**

⇒ (but) **workers less segregated from tree cover than executives**

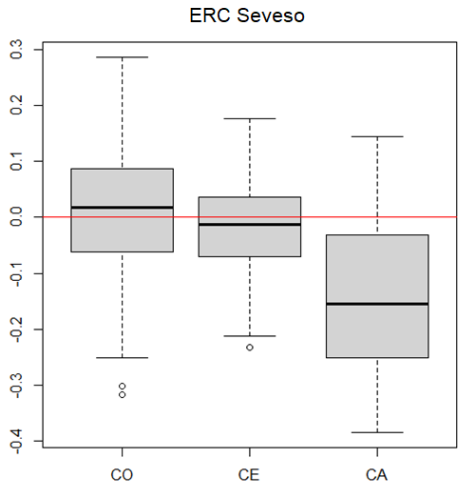
Empirical evidence: zoom

Environmental Relative Centralization (industrial sites)

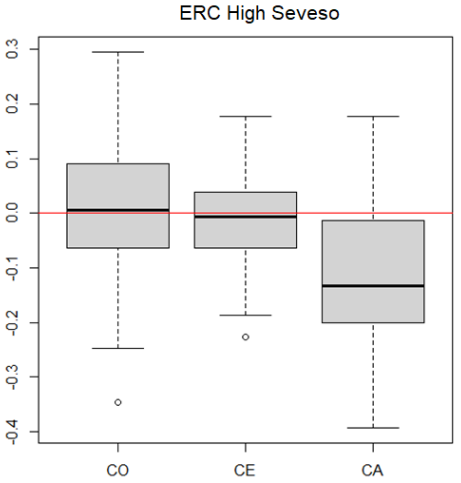
- All sites: significant negative ERC for CO, CE, CA
- Dangerous and very dangerous: significant negative ERC only for CA



	T-test	P-value	Sign
1	CO	4.245190e-05	***
2	CE	2.157437e-11	***
3	CA	1.543244e-29	***



	T-test	P-value	Sign
1	CO	7.632525e-01	
2	CE	1.642088e-02	*
3	CA	8.013576e-18	***



	T-test	P-value	Sign
1	CO	3.786987e-01	
2	CE	1.028578e-01	
3	CA	4.153838e-13	***

⇒ **unemployed more centralized than executives relative to all & dangerous sites**

⇒ **executives less centralized than others relative to all (but not dangerous) sites**

Conclusions

- Based on methodology of Schaeffer and Tivadar (2019) we bring mathematical proof and empirical evidence of the links between social segregation and environmental inequalities
- Environmental inequalities are bounded by social segregation, as a consequence:
  - Social segregation is a necessary but insufficient condition for environmental inequalities
  - Positive and significant (but not perfect) correlation between segregation
  - Heteroscedastic distribution of environmental inequalities
- On environmental inequalities by income:
  - Unemployed/student group more segregated from tree canopy cover and more centralized relative to dangerous industrial sites
  - Inequalities not always against low-income groups (e.g. blue-collar workers appear less segregated from tree canopy cover and no more centralized relative to dangerous sites than executives), but these results should be checked at a finer spatial scale