Separate And Unequal:
The relationship between residential segregation, air toxics and associated cancer risks

Photos: David Woo, Dallas Morning News & GreenAction
Overview

- Previous EJ work and methodological approaches
- Understanding segregation and how it’s measured
- Conceptual Framework
- Materials & Methods
  - Segregation
  - National Air Toxics Assessment
- Results
- Limitations
- Implications for research and policy
Air Toxics and Segregation in CA: Background

- Racial/ethnic and income disparities in exposure to air pollutants is well documented.
- Few environmental justice studies have elucidated pathways that *explain* how social context shapes these disparities in environmental hazard exposures.
- In this study, we examine links between social inequality—in particular, residential segregation—with estimated cancer risks from ambient air pollutants.
Basics of Segregation

- Describes spatial separation of people by race and (less often) by class
- Concentrates poverty and other psycho-social stressors
- Applies to various contexts
  - Residential
  - Occupational
  - Educational
- Measurement
  - Used to characterize racial inequality within a metro area or region
  - Often focuses on dyadic comparisons (e.g. Black v. White)
  - Can also be considered in context of racial diversity
Examining Links Between Segregation, Environmental Inequality

- Health literature points to persistent association between segregation and mortality/morbidity
- Suggests spatially-mediated power distributions across racial and economic lines
- This may shape disparities in pollutant exposures across demographic groups.
- Spatially-mediated differences in environmental regulation and land use policy may impact community environmental health.

Source: Gilbert Gee, University of Michigan
Dissimilarity of Ethnic Minorities to Whites, United States 1980-2000

Source: Gilbert Gee, University of Michigan
Segregation and Environmental Health Inequality

- Segregation and mortality/morbidity
  - Adult and infant mortality
  - Tuberculosis
  - Exposure to violence & homicide

- Segregation and environmental health disparities
  - Disparities in exposure
    - Hazardous waste
    - Air pollution
  - Regulatory and land use inequities
    - Unequal enforcement
    - Locally unwanted land uses
  - Concentration of stressors that enhance individual and community vulnerability to environmental hazard exposures.
    - Food Insecurity (lack of commercial markets)
    - Lack of access to health care and other services
Dimensions of Segregation

- Unevenness
  - Most common measure
  - Dissimilarity Index

- Isolation / Exposure
  - Probability of “interaction” with same or majority racial group
  - Good measure of segregation experience

- Neighborhood racial composition
  - *often used as (inappropriate) surrogate*
“Spatial” Dimensions of Segregation

- **Concentration** - density of racial group in metro area

  - Dispersed
  - Concentrated

- **Clustering** – are racial groups in “ethnic enclaves?”

  - Not Clustered
  - Clustered

- **Centralization** – are racial groups in city centers?

  - Not Centralized
  - Centralized

Central Business District
Segregation and Environmental Justice

- Highlights links between segregation and political economy of environmental health by asking:
  - How do legacies of discrimination shape current spatial distributions of pollution sources among diverse communities?
  - Are observed pollution – health outcome relationships mediated by segregation?
  - Do segregation patterns affect diverse communities differently?

- Promotes a regional perspective for assessing dynamics of environmental health disparities:
  - Decisions about economic development, land use, transportation planning, and industrial clusters tend to be regional in nature
  - Zoning, siting, and urban planning decisions also tend to be more local
Structural Mechanisms of Discrimination
- Political Disenfranchisement
- Economic/Financial System
- Legal System
- Social Inequality
- Government & Industrial Investment Patterns

Residential Segregation & Uneven Regional Development

Community-level
- Built Environment
  - Land Use/Zoning
  - Traffic Density
  - Housing Quality
- Social Environment
  - Civic Engagement
  - Poverty Concentration
  - Access to Services
  - Food Security
  - Regulatory Enforcement Activities
  - Neighborhood Quality

Individual-level
- Social support
- Income
- Poverty
- Working Conditions
- Educational Status
- Marital Status
- Diet/Nutritional Status
- Psycho-social Stress
- Health Behaviors

Sources
- Industrial Facility/Transportation Corridor
- Chemicals Emitted

Emissions/Contamination
- Indoor/Outdoor Pollution Levels

Exposure
- Chemical Body Burden

Internal Dose
- Detoxification Capacity

Response & Resilience
- Birth Outcome

Health Effect
- Co-Morbidity/Mortality

Ability to Recover

Community-level Measures

Community-level Measures

Individual-level Measures
Segregation Measure: Generalized Index of Dissimilarity

Extent of segregation across several demographic groups within a metropolitan statistical area (MSA).

\[ D_m = \frac{\frac{1}{2} \sum_i \sum_j |N_{i,j} - E_{i,j}|}{N \sum_j P_j (1 - P_j)} \]

- \( D_m \) = multi-racial index of dissimilarity.
- \( N_{i,j} \) = number of people in racial/ethnic subgroup \( j \) in census tract \( i \).
  - racial/ethnic subgroups: White, African American, Latino, Asian, Native American.
- \( E_{i,j} \) = expected number of people in subgroup \( j \) in census tract \( i \), under the assumption of no segregation (\( N_i \times N_j / N \)).
- \( P_j \) = proportion of people in subgroup \( j \) in the whole MSA population (\( N_j / N \)).
Dissimilarity Index Cont.

\[ D_m = \frac{\frac{1}{2} \sum_i \sum_j |N_{i,j} - E_{i,j}|}{N \sum_j P_j (1 - P_j)} \]

Numerator = number of people who would have to move from one census tract to another to attain racial/ethnic balance in every census tract within an MSA.

Denominator = maximum possible value of the numerator if each racial/ethnic group were completely segregated from one another in separate neighborhoods.

Index varies from 0 (no segregation) to 1 (completely segregated).
U.S. EPA's National Air Toxics Assessment (NATA)

Gaussian dispersion modeling estimates long-term annual average outdoor concentrations for 1996 of 36 air toxics and diesel particulates for each census tract. The model includes mobile and stationary emissions sources:

Manufacturing (point and area)
  e.g., refineries, small fabricators, chemical manufacturers
Non-Manufacturing (point and area)
  e.g., utilities, hospitals, dry cleaners
Mobile (on road and off road)
  e.g., cars, trucks, air craft, agricultural equipment
Air pollutant concentration estimates allocated to census tract centroids.
Estimating Cancer Risk

- Lifetime cancer risk calculated for each pollutant with toxicity information:

\[ R_{ij} = C_{ij} \times IUR_j \]

- \( R_{ij} \) = individual lifetime cancer risk from pollutant \( j \) in census tract \( i \).
- \( C_{ij} \) = concentration of HAP \( j \) in \( \text{ug}/\text{m}^3 \) in census tract \( i \).
- IUR = Inhalation Unit Risk: cancer potency associated with continuous lifetime exposure to pollutant \( j \) in \((\text{ug}/\text{m}^3)^{-1}\).

- Risks summed across pollutants
Key Science Policy Assumptions

- Methods based on U.S. EPA’s and California’s Risk Guidelines for carcinogenic risk assessment
- Air toxics classified by US EPA as known, probable or possible human carcinogens were evaluated
- Cancer potency information for pollutants compiled by US-EPA and Cal-EPA
- Assumes exposures are chronic over a lifetime
- Cancer risks are additive across pollutants
cancer risk-weighted air toxics exposures (all sources), metropolitan statistical areas of the continental United States

Estimated lifetime cancer risk (per million inhabitants)

- 0 - 1
- 1 - 10
- 10 - 100
- 100 - 1000
- 1000 - 10000
- 10000 - 50000
Estimated Cancer Risks Associated with Air Toxics in California Metro Areas – NATA 1996
Multi-Group Segregation
In California Metro Areas
1990 Census

- Extremely Segregated
- Highly Segregated
- Moderately Segregated
### Breakdown of Counties by Segregation Level

<table>
<thead>
<tr>
<th>Metro Area</th>
<th>Dm</th>
<th>Counties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redding</td>
<td>16%</td>
<td>Shasta</td>
</tr>
<tr>
<td>Yuba City</td>
<td>24%</td>
<td>Sutter, Yuba</td>
</tr>
<tr>
<td>Santa Rosa</td>
<td>26%</td>
<td>Sonoma</td>
</tr>
<tr>
<td>Yolo</td>
<td>29%</td>
<td>Yolo</td>
</tr>
<tr>
<td>San Luis Obispo-Atascadero-Paso Robles</td>
<td>29%</td>
<td>San Luis Obispo</td>
</tr>
<tr>
<td>Merced</td>
<td>31%</td>
<td>Merced</td>
</tr>
<tr>
<td>Vallejo-Fairfield-Napa</td>
<td>32%</td>
<td>Napa, Solano</td>
</tr>
<tr>
<td>Chico-Paradise</td>
<td>32%</td>
<td>Butte</td>
</tr>
<tr>
<td>Modesto</td>
<td>33%</td>
<td>Stanislaus</td>
</tr>
<tr>
<td>Riverside-San Bernardino</td>
<td>35%</td>
<td>Riverside, San Bernardino</td>
</tr>
<tr>
<td>Stockton-Lodi</td>
<td>38%</td>
<td>San Joaquin</td>
</tr>
<tr>
<td>Visalia-Tulare-Porterville</td>
<td>38%</td>
<td>Tulare</td>
</tr>
<tr>
<td>Santa Barbara-Santa Maria-Lompoc</td>
<td>39%</td>
<td>Santa Barbara</td>
</tr>
<tr>
<td>San Jose</td>
<td>41%</td>
<td>Santa Clara</td>
</tr>
<tr>
<td>Sacramento</td>
<td>42%</td>
<td>El Dorado, Placer, Sacramento</td>
</tr>
<tr>
<td>San Diego</td>
<td>44%</td>
<td>San Diego</td>
</tr>
<tr>
<td>Fresno</td>
<td>44%</td>
<td>Fresno, Madera</td>
</tr>
<tr>
<td>Orange County</td>
<td>45%</td>
<td>Orange</td>
</tr>
<tr>
<td>Oakland</td>
<td>47%</td>
<td>Alameda, Contra Costa</td>
</tr>
<tr>
<td>San Francisco</td>
<td>49%</td>
<td>Marin, San Francisco, San Mateo</td>
</tr>
<tr>
<td>Ventura</td>
<td>49%</td>
<td>Ventura</td>
</tr>
<tr>
<td>Bakersfield</td>
<td>51%</td>
<td>Kern</td>
</tr>
<tr>
<td>Salinas</td>
<td>51%</td>
<td>Monterey</td>
</tr>
<tr>
<td>Santa Cruz-Watsonville</td>
<td>52%</td>
<td>Santa Cruz</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>56%</td>
<td>Los Angeles</td>
</tr>
</tbody>
</table>
metropolitan areas, census tracts, and population (by race/ethnicity)
by racial/ethnic segregation (multi-group dissimilarity index, $D_m$)

metropolitan areas (n=25)
census tracts (n=5,424)
people (n=28,798,718)
Hispanics (n=7,507,545)
non-Hispanic Whites (n=16,308,925)
non-Hispanic Blacks (n=2,072,152)
non-Hispanic American Indians (n=158,684)
non-Hispanic Asians and Pacific Islanders (n=2,696,590)
estimated cancer risk by pollutant, all sources, California metropolitan areas
estimated cancer risk by source, and by racial/ethnic residential segregation

estimated lifetime cancer risk from air pollution, 1996 NATA estimates (per million inhabitants)

<table>
<thead>
<tr>
<th>Segregation (multi-group dissimilarity index, Dm)</th>
<th>Non-road mobile sources</th>
<th>On road mobile sources</th>
<th>Area sources</th>
<th>Point sources</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>All metro areas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.15 to 0.34 (n=4,787,179)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.35 to 0.44 (n=9,663,896)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.45 to 0.56 (n=14,347,643)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Population Risk Index

- PRI displays inequities in estimated cancer risks associated with air toxics across income and racial/ethnic categories.
- Weighted average of census level individual lifetime cancer risks:
  \[ \text{PRI}_S = \sum R_c n_{c_S}/N_{C_S} \]
- \( R_c \) = individual lifetime cancer risk estimate in census tract \( c \)
- \( n_{c_S} \) = number of people in sub-population \( S \) in census tract \( c \)
- \( C \) = set of all census tracts considered in the analysis \( (C = \sum c) \)
- \( N_{C_S} \) = total number of people in sub-population \( S \) who reside in all tracts \( C \)
cancer risk by race/ethnicity, and racial/ethnic residential segregation

estimated lifetime cancer risk from air pollutants, 1996 NATA estimates (per million residents)

- All metro areas: 0.15 to 0.34 (n=4,787,179)
- 0.35 to 0.44 (n=9,663,896)
- 0.45 to 0.56 (n=14,347,643)

- All residents: (n=28,798,718)
- non-Hispanic Whites: (n=16,308,925)
- non-Hispanic Blacks: (n=2,072,152)
- Hispanics: (n=7,507,545)
- non-Hispanic American Indians: (n=158,684)
- non-Hispanic Asians & Pacific Islanders: (n=2,696,590)
cancer risk by race/ethnicity, and poverty status

estimated lifetime cancer risk from air pollutants, 1996 NATA estimates (per million residents)

- Poor (n=3,490,435)
- Near poor (n=4,820,472)
- Not poor (n=19,708,365)

- All residents (n=28,798,718)
- Non-Hispanic Whites (n=16,308,925)
- Non-Hispanic Blacks (n=2,072,152)
- Hispanics (n=7,507,545)
- American Indians & Alaska Natives (n=213,998)
- Asians & Pacific Islanders (n=2,830,574)
cancer risk by poverty status, race/ethnicity, and racial/ethnic residential segregation

Estimated lifetime cancer risk from air pollutants, 1996 NATA estimates (per million residents)

- All residents (n=28,798,718)
- Non-Hispanic Whites (n=16,308,925)
- Non-Hispanic Blacks (n=2,072,152)
- Hispanics (n=7,507,545)
- American Indians & Alaska Natives (n=213,998)
- Asians & Pacific Islanders (n=2,830,574)

Income categories:
- Poor: income < poverty
- Near poor: poverty < income < 2xpoverty
- Not poor: 2xpoverty < income
Covariates

- Segregation (MSA):
  - low (17 to 30%)
  - moderate (30 to 45%)
  - high (45 to 60%)
  - extreme (60 to 80%)
- Population Density (Tract)
- Townsend Index (Tract): sum of four z-scores /4:
  - crowding
  - unemployment
  - home ownership
  - car ownership
- Sprawl (MSA):
  - mixed use index
  - street connectivity index
- Eligible Voters (Tract)
- Average commute time (County)
estimated cancer risk ratios relative to lower segregation levels (0.16 to 0.34) by race/ethnicity, California metropolitan areas (n=25)
crude, $R^2=15\%$

<table>
<thead>
<tr>
<th></th>
<th>(0.45 &lt;=Dm&lt; 0.57)</th>
<th>(0.35 &lt;=Dm&lt; 0.45)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>hazard</td>
<td>95% conf.</td>
</tr>
<tr>
<td>Total</td>
<td>2.41 ( 2.27 - 2.55 )</td>
<td>3.18 ( 3.01 - 3.37 )</td>
</tr>
<tr>
<td>non-Hispanic White</td>
<td>2.56 ( 2.38 - 2.76 )</td>
<td>3.12 ( 2.90 - 3.36 )</td>
</tr>
<tr>
<td>non-Hispanic Blacks</td>
<td>1.69 ( 1.30 - 2.19 )</td>
<td>2.96 ( 2.35 - 3.73 )</td>
</tr>
<tr>
<td>Hispanics</td>
<td>2.11 ( 1.87 - 2.38 )</td>
<td>2.81 ( 2.51 - 3.15 )</td>
</tr>
<tr>
<td>non-Hispanic Asians &amp; Pacific Islanders</td>
<td>2.44 ( 1.88 - 3.17 )</td>
<td>3.81 ( 2.96 - 4.91 )</td>
</tr>
<tr>
<td>non-Hispanic American Indians &amp; Alaska Natives</td>
<td>2.17 ( 1.06 - 4.43 )</td>
<td>3.35 ( 1.69 - 6.62 )</td>
</tr>
</tbody>
</table>
Estimated cancer risk ratios relative to lower segregation levels (0.16 to 0.34) by race/ethnicity, California metropolitan areas (n=25) adjusted for tract population density, poverty rate, and material deprivation (Townsend index); county voter turnout; and metropolitan area population size, $R^2=38\%$

<table>
<thead>
<tr>
<th></th>
<th>16 to 34</th>
<th>35 to 44</th>
<th>45 to 57</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>2.15 (1.99 - 2.31)</td>
<td>2.29 (2.13 - 2.47)</td>
<td></td>
</tr>
<tr>
<td>non-Hispanic White</td>
<td>2.24 (2.05 - 2.44)</td>
<td>2.27 (2.08 - 2.47)</td>
<td></td>
</tr>
<tr>
<td>non-Hispanic Blacks</td>
<td>2.06 (1.57 - 2.68)</td>
<td>2.38 (1.88 - 3.01)</td>
<td></td>
</tr>
<tr>
<td>Hispanics</td>
<td>2.00 (1.76 - 2.27)</td>
<td>2.14 (1.89 - 2.43)</td>
<td></td>
</tr>
<tr>
<td>non-Hispanic Asians &amp; Pacific Islanders</td>
<td>2.04 (1.57 - 2.65)</td>
<td>2.64 (2.04 - 3.41)</td>
<td></td>
</tr>
<tr>
<td>non-Hispanic American Indians &amp; Alaska Natives</td>
<td>2.10 (1.03 - 4.30)</td>
<td>2.29 (1.15 - 4.53)</td>
<td></td>
</tr>
</tbody>
</table>
estimated cancer risk ratios relative to lower segregation levels (0.16 to 0.34) by race/ethnicity, California metropolitan areas (n=25) adjusted for tract population density, poverty rate, and material deprivation (Townsend index); county voter turnout; and metropolitan area average commuting time, population size, $R^2=42$

<table>
<thead>
<tr>
<th>Total</th>
<th>1.70 ( 1.55 - 1.86 )</th>
<th>1.83 ( 1.69 - 1.99 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>non-Hispanic White</td>
<td>1.76 ( 1.59 - 1.95 )</td>
<td>1.81 ( 1.65 - 1.99 )</td>
</tr>
<tr>
<td>non-Hispanic Blacks</td>
<td>1.68 ( 1.28 - 2.21 )</td>
<td>1.92 ( 1.51 - 2.44 )</td>
</tr>
<tr>
<td>Hispanics</td>
<td>1.57 ( 1.37 - 1.81 )</td>
<td>1.71 ( 1.50 - 1.95 )</td>
</tr>
<tr>
<td>non-Hispanic Asians &amp; Pacific Islanders</td>
<td>1.69 ( 1.29 - 2.21 )</td>
<td>2.09 ( 1.61 - 2.70 )</td>
</tr>
<tr>
<td>non-Hispanic American Indians &amp; Alaska Natives</td>
<td>1.71 ( 0.83 - 3.50 )</td>
<td>1.86 ( 0.94 - 3.69 )</td>
</tr>
</tbody>
</table>
Racial segregation can play an important role in the differential distribution of air pollution exposures across demographic groups.

Stratifying by segregation shows air pollution burdens are higher for all demographic groups within the most segregated areas.

Demographic disparities are higher in the more segregated areas.

Multivariate models show these relationships persist even after controlling for population density, material deprivation (Townsend Index), political empowerment, and commuting time.
Limitations

- Ambient air concentrations are not reflective of personal exposures and do not include indoor exposures.

- Concentration estimates from 1996 that may have changed significantly over time.

- Several pollutants could not be included in this analysis due to limited cancer toxicity data.

- Dispersion model underestimates concentrations of certain pollutants.

- Potential for mis-interpretation of ecological risk as individual risk
Methodological Challenges

- Measuring multiple exposures, cumulative risks and health impacts across segregation levels and between demographic groups over varying geographic scales.

- How segregation interacts with:
  - Community social factors (e.g. area level poverty)
  - And individual factors (e.g. genetics, age, stress) that could enhance vulnerability to the health effects of environmental hazards.