Modeling the Impact of Exposure Reductions Using Multi-Stressor Epidemiology, Exposure Models and Synthetic Microdata:

A Case Study of Birthweight in Two Environmental Justice Communities

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CRESSH

The combined impact of environmental and built environment exposures on birthweight.

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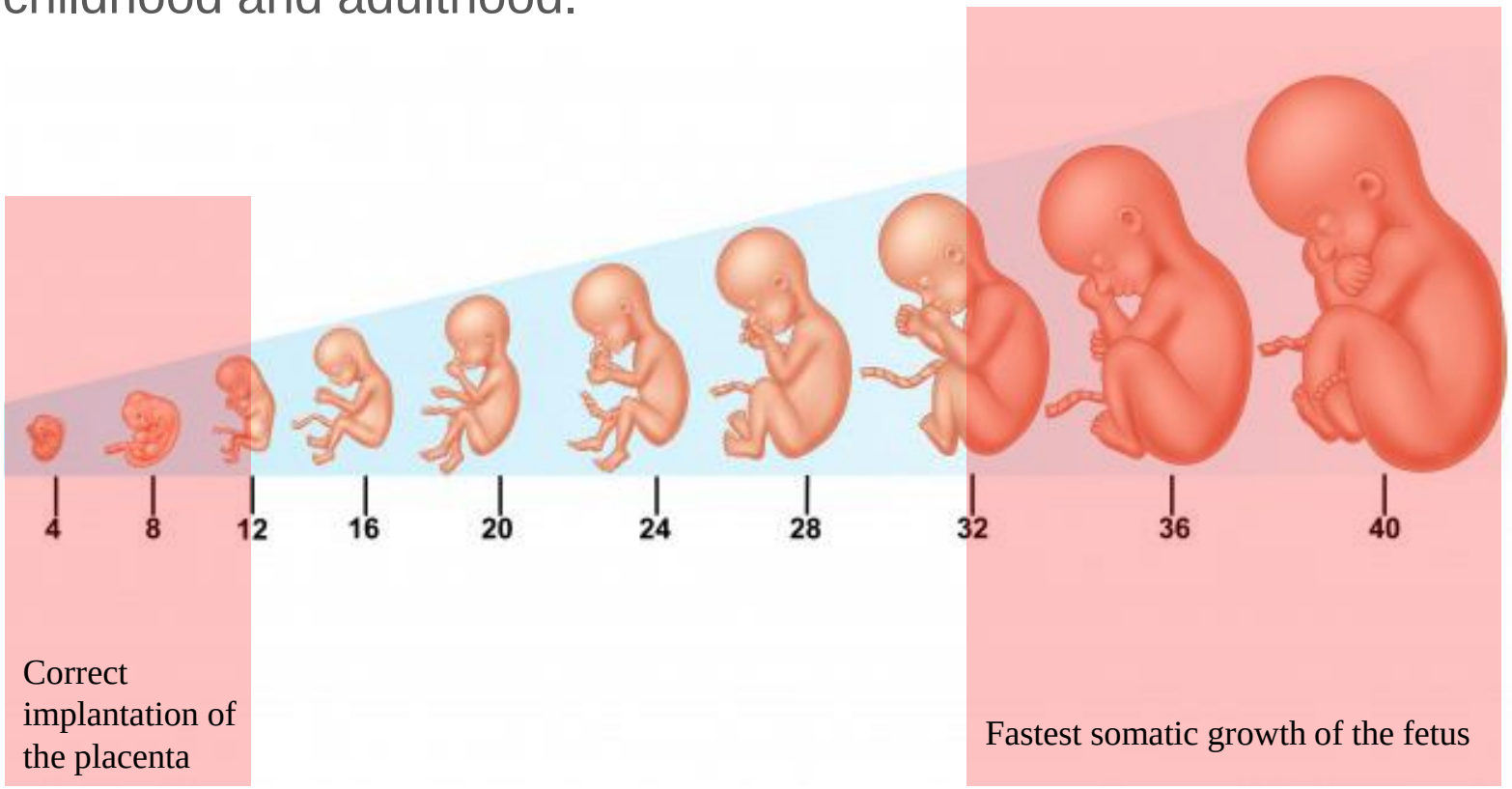
Background

- Low birthweight
  - A leading cause for perinatal morbidity and mortality.
  - A known risk factor for neurological and developmental adverse outcomes in childhood and adulthood.



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Background

- Extensive literature documenting the association between environmental exposures and birthweight, but most studies assessed the effect of a single exposure.
- The exposome concept: the focus has shifted, a more complete environmental exposure assessment in epidemiology studies.

- Challenges:
  - sample size and statistical power.
  - availability of exposure data.
  - multiple correlated exposures, *a priori* selection of predictors can be challenging.

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Study aims

- We applied a combination of variable selection, traditional and novel regression methods to identify the predictors of birthweight out of a set of:

Environmental exposures

Built environment characteristics

Socioeconomic indexes

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Methods

- Study population
  - Singleton live births
  - Urban neighborhoods, delivered in Massachusetts (2001-2011)

- We *a priori* defined potential environmental predictors of birthweight.
- Statistical analysis
  - Elastic-net model to select the important predictors of birthweight.
    - Multivariate regression
  - Weighted quantile sum (WQS) regression to assess the contribution of each exposure to birthweight changes.

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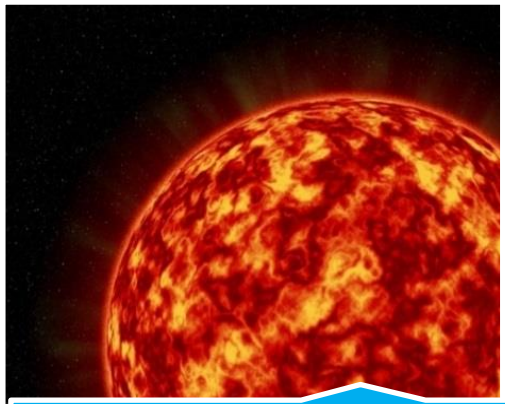
Exposures

Air pollution

Neighborhood greenness

Walkability



Temperature

Noise

Economic segregation

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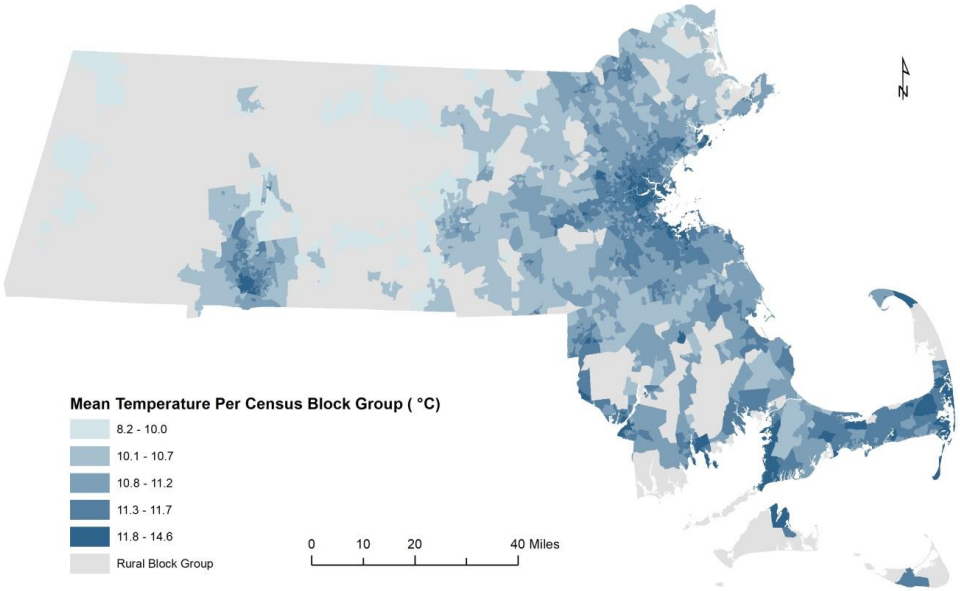
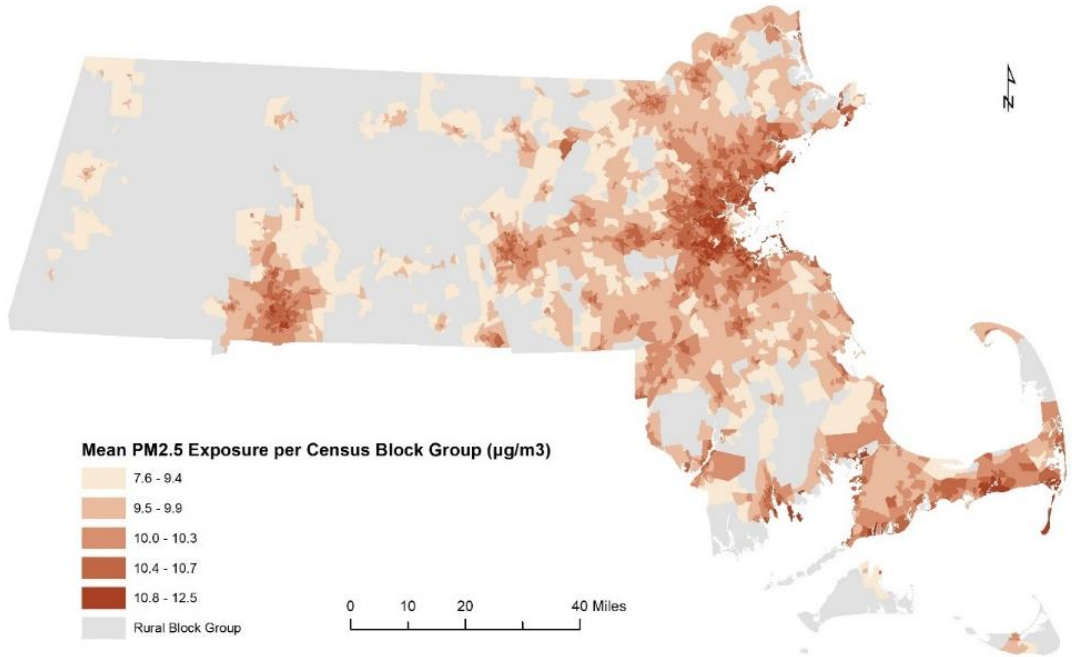
$PM_{2.5}$ and temperature exposures

- Daily average predictions from a model generating predictions at a 1x1 km spatial resolution using ground monitors, Moderate Resolution Imaging Spectroradiometer (MODIS) AOD measurements and LUR variables.
- Linked based on proximity to the residential address at birth.
- Averaged in each trimester of pregnancy.





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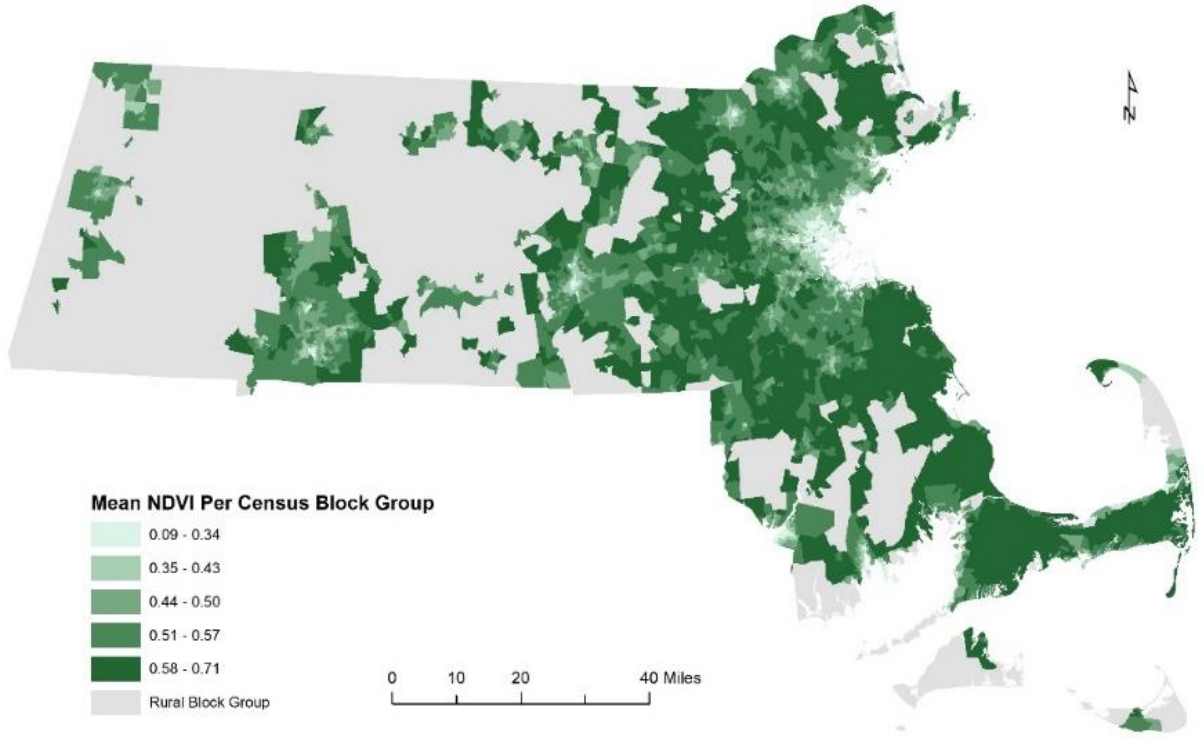
Source: PMID: 33260804

Neighborhood greenness

- Seasonal normalized difference vegetation index (NDVI).
- NDVI incorporates the plant absorption and reflection of light (range -1.0 to 1.0).
- 250 m buffer around each maternal residential address at birth.
- Mean exposure for each trimester of pregnancy.



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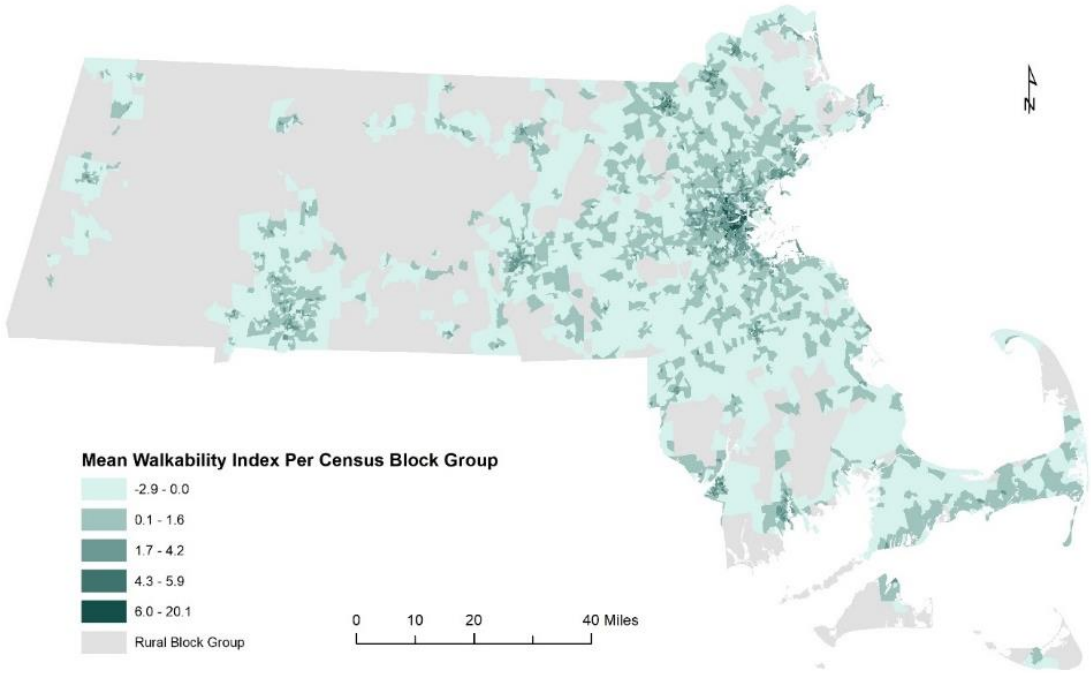
Walkability

- Index of built environment characteristics in the neighborhood.
- Comprised of 3 measures:
  - land use diversity (mix of retail, office, service, industrial, entertainment, education, healthcare, and public administration employment).
  - Population density
  - Street connectivity (intersection density)



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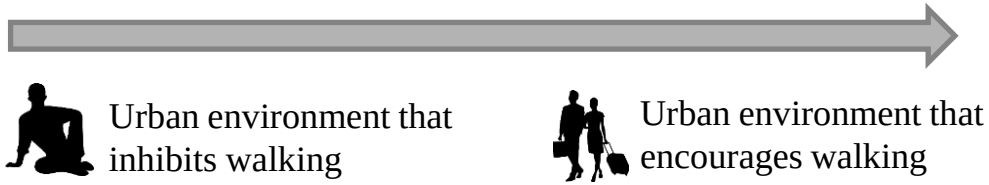

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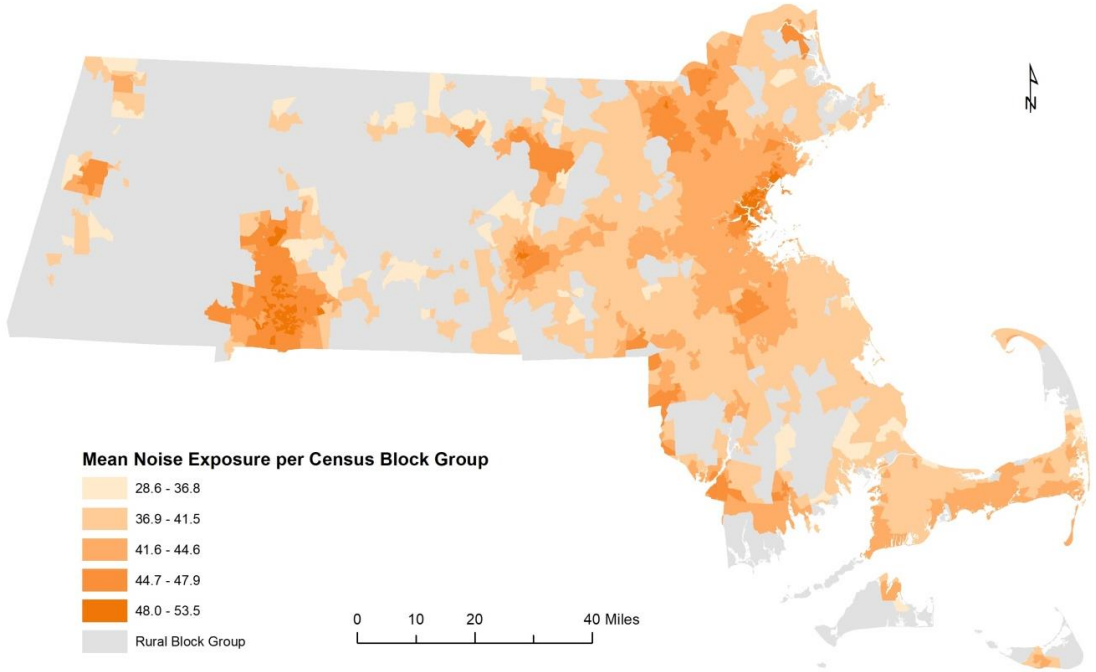
Noise

- Cross-sectional geospatial sound model that provides nighttime noise levels at a 270mx270m spatial resolution.
- Model incorporates geospatial features and empirical acoustical data sampled at 492 sites across the U.S. (2000-2014).
- Nighttime noise level at each residential address.



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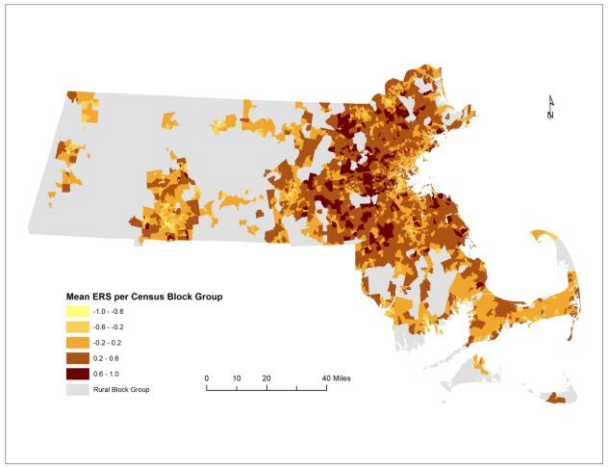
Economic residential segregation (ERS) and Index of Economic Dissimilarity (IED)

ERS: the uniformity of the % living in high income households vs the % living in low-income households.



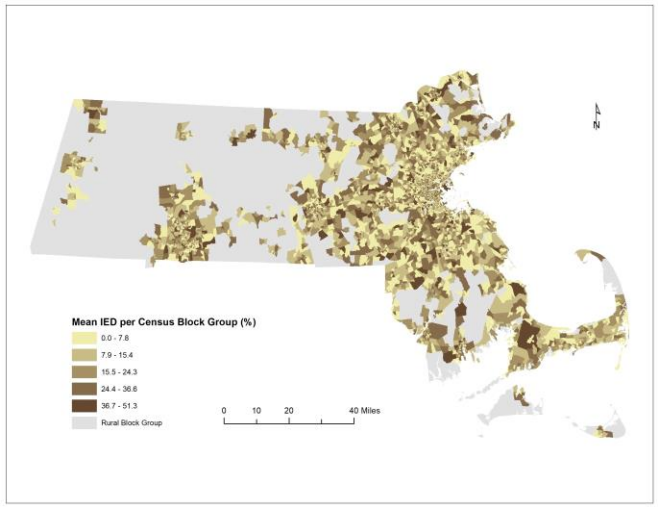
-1 to -0.6	-0.6 to -0.2	-0.2 to 0.2	0.2 to 0.6	0.6 to 1

-1
More ‘low income’
(<$25k/Y)

0
Equal
distribution

+1
More
‘high income’
(>=$100K/Y)

IED: Compare distributions of the two income groups at two spatial scales (the block group versus the census tracts).



0%

100%

Low
dissimilarity

High
dissimilarity

Source: PMID: 33260804

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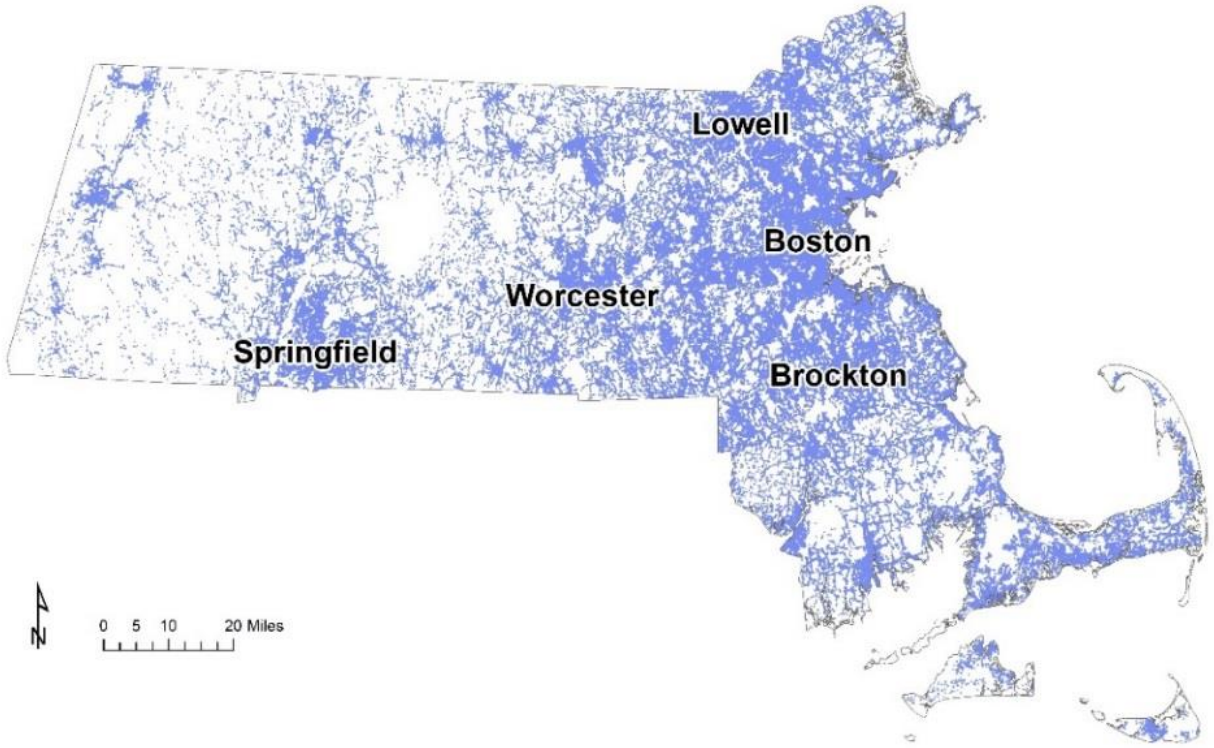
Results
Population characteristics

- 640,659 births
- 69.9% white, 8.3% black
- Mean age 30
- Mean birth weight 3.4 kg
- 49% of the newborns were female
- Mean gestational age: 39 weeks

Distribution of births in MA



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Elastic Net and Multivariate Regression

Exposures
$PM_{2.5}$, 1st trimester (µg/m3)
$PM_{2.5}$, 2nd trimester (µg/m3)
$PM_{2.5}$, 3rd trimester (µg/m3)
Temperature, 1st trimester (^{0}C)
Temperature, 2nd trimester (^{0}C)
Temperature, 3rd trimester (^{0}C)
NDVI, 1st trimester
NDVI, 2nd trimester
NDVI, 3rd trimester
Walkability
ERS -1 to -0.6
-0.6 to -0.2
-0.2 to 0.2
0.2 to 0.6
0.6+
IED
Noise levels, (dB)

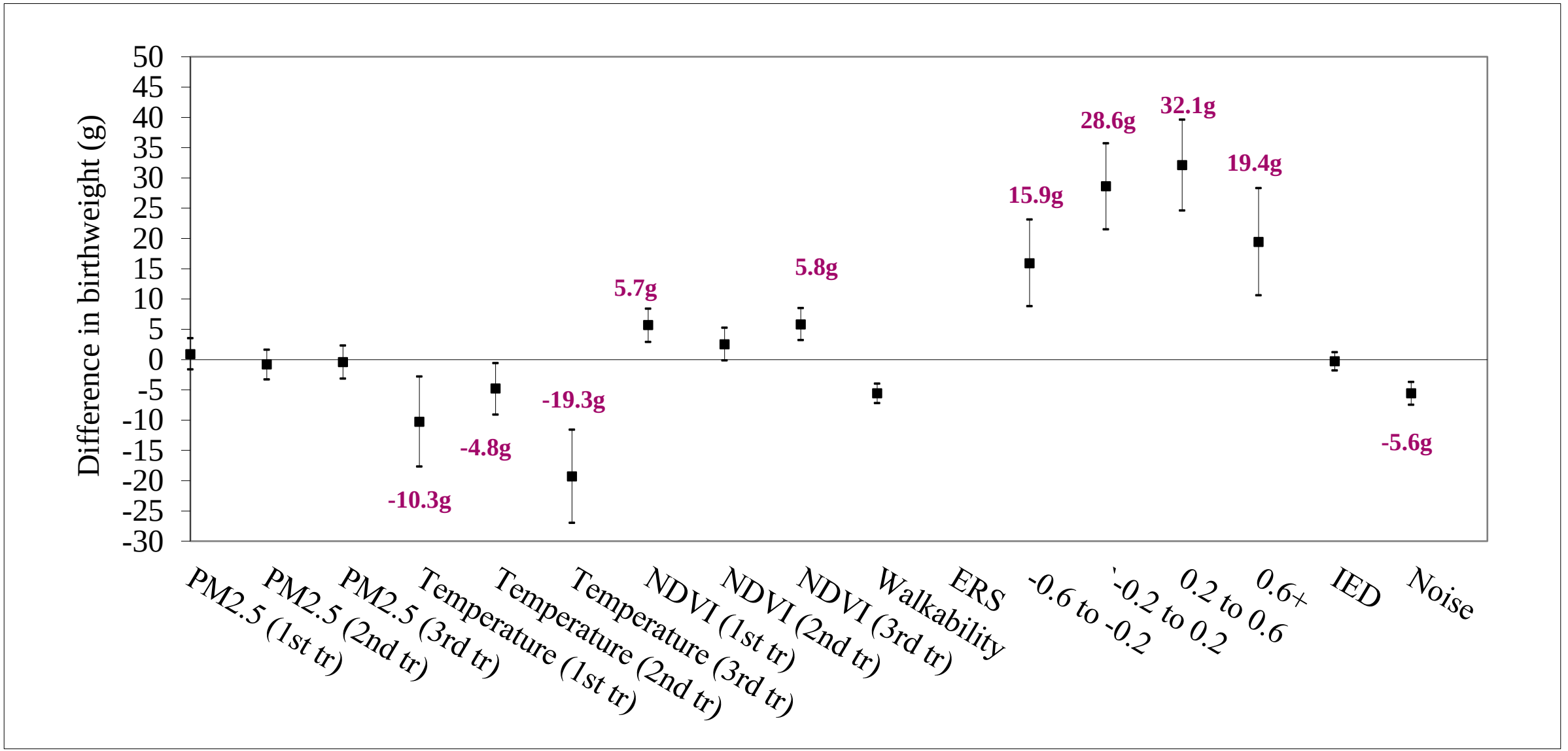
Basic model:

Season, year, government support for prenatal care, maternal education, race, age, parity, smoking, DM, HTN, and gestational age.

Multivariate model:

Selected exposures + basic model

Results



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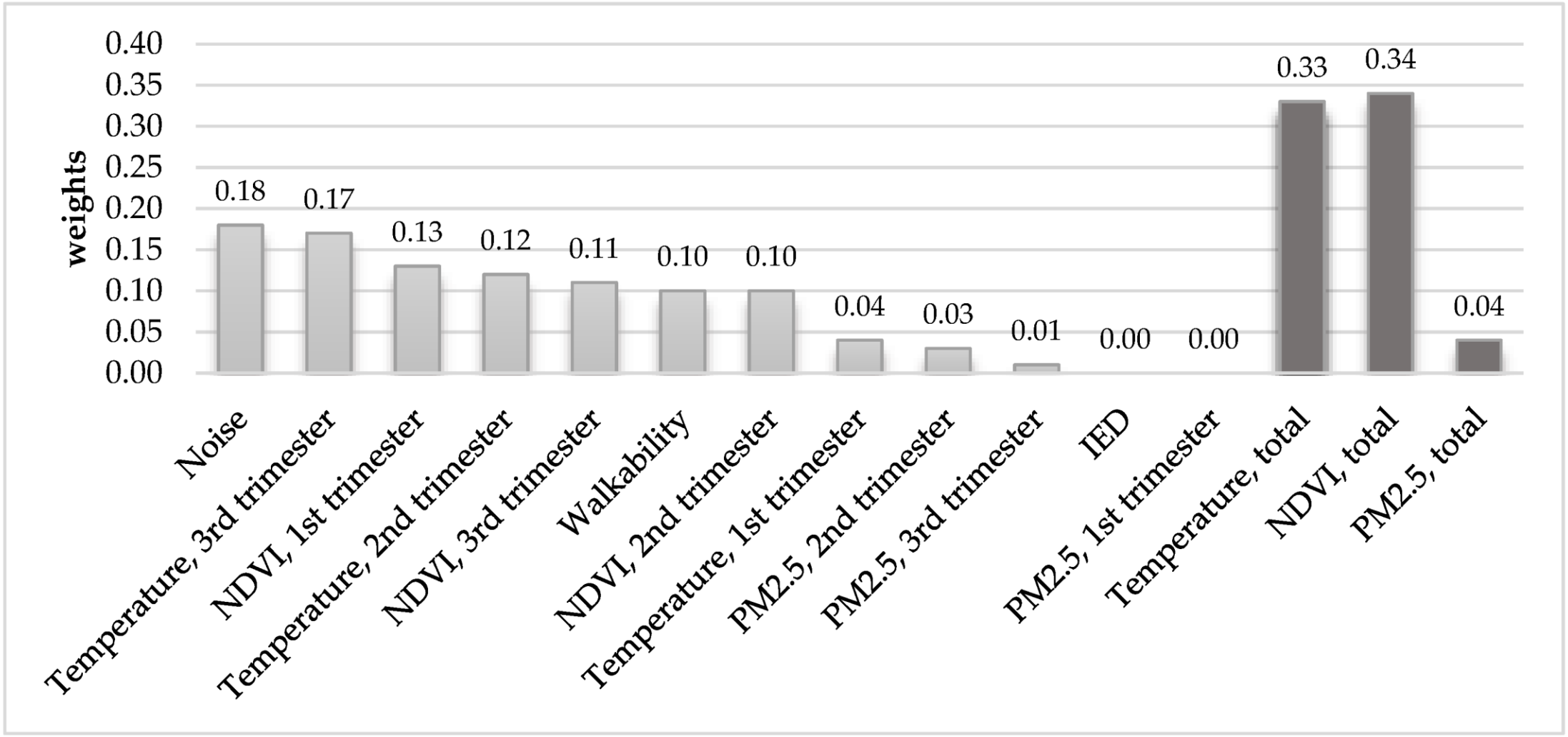
WQS results: the weighted contribution of each of the exposures to birthweight reduction



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Conclusion

- In conclusion, even after accounting for maternal and neonatal characteristics, **multiple built environment characteristics and environmental exposures during pregnancy were associated with birthweight changes, emphasizing the complex role of multiple exposures in fetal growth and development.**

- The inclusion of multiple exposures in the model provides avenues for intervention across different exposure dimensions.

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Acknowledgements

Center for Research on Environmental and Social Stressors in Housing Across the Life Course (CRESSH)

https://sites.sph.harvard.edu/cressh/

This work was supported by:

- National Institute of Minority Health and Health Disparities (grant P50MD010428)
- NIH/NIEHS (grants P30 ES000002 and RO1 ES024332)
- EPA grants (RD836156 and RD 835872)

We would like to thank Dr. Daniel J. Mennitt and Dr. Kurt M. Fristrup from the National Park Service, CO, USA, who contributed greatly to this work by providing the noise exposure model used in this analysis.

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Part II – Demonstration of model application

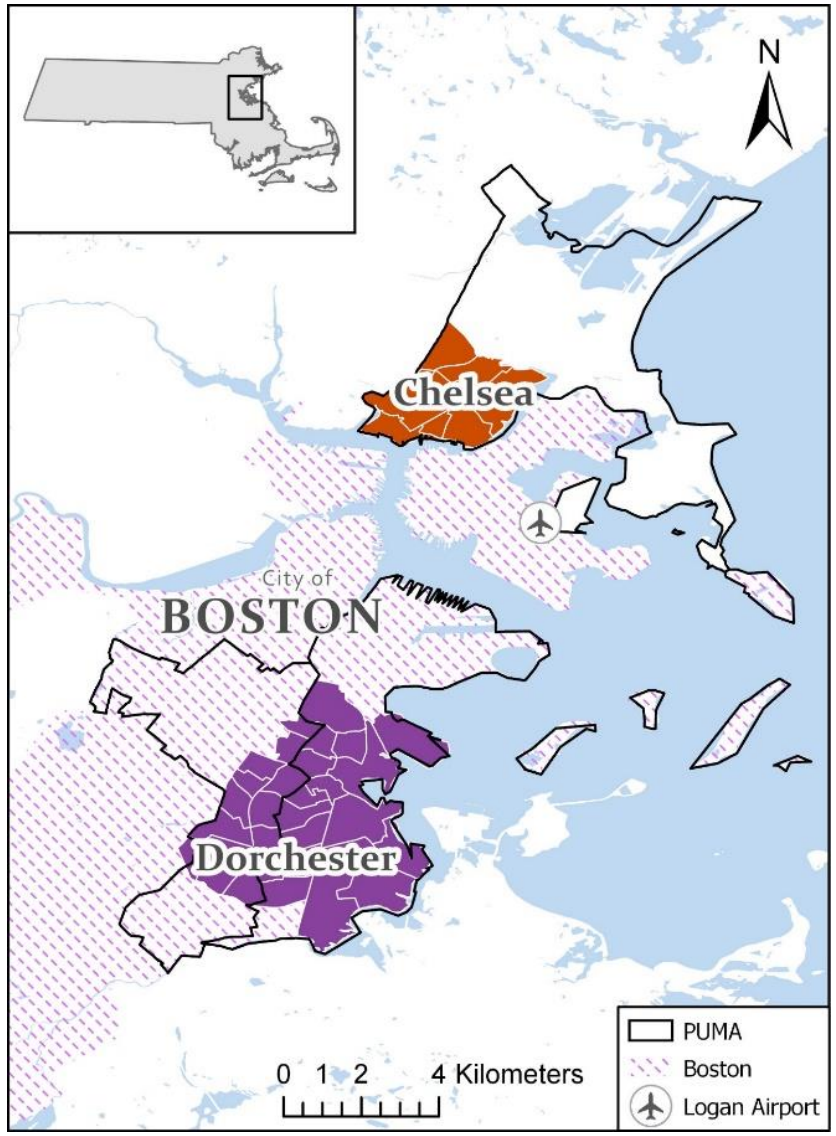
- Multi-stressor epidemiology can:
  - Inform decision-making
  - Test intervention alternatives
  - Motivate collection of local data

- What if: sensitive local population, but lack necessary health data

- Case study
  - Chelsea and Dorchester, two environmental justice communities partnered with CRESSH
  - Using the model coefficients and **public data only**
  - Predict changes in birthweight following improvements in:
    - noise,
    - greenness
    - temperature.

Chelsea and Dorchester

- In Massachusetts, environmental justice communities are those that meet any of the following criteria [22]:
  - annual median household income less than or equal to 65 percent of the statewide median ($62,072 in 2010);
  - at least 25% of residents identify as a race other than white;
  - or at least 25% of households have limited ability to communicate in English



Location of Chelsea and Dorchester in the Greater Boston Area, MA, the Boston Logan Airport, and the Public Use Microdata Areas (PUMAs) used in this study.

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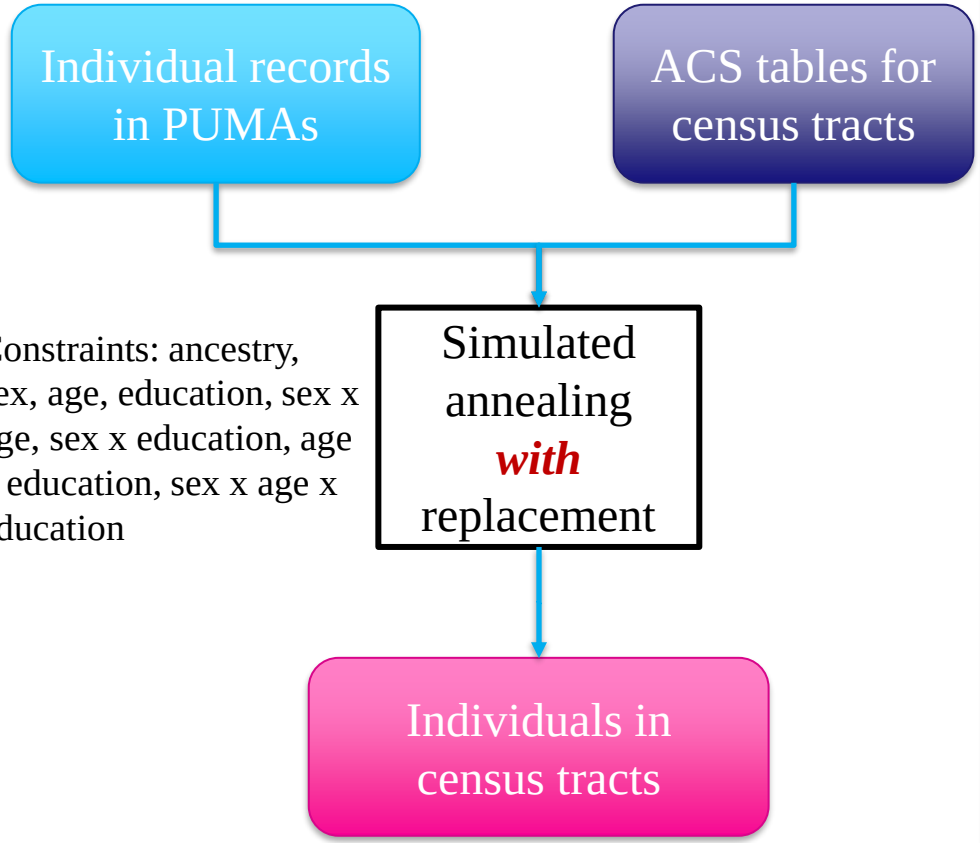
Creating synthetic microdata using public data (1/4)

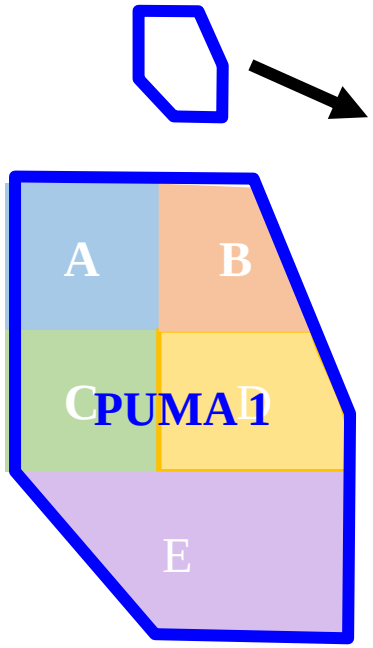


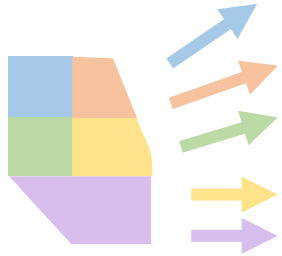
Constraints: ancestry, sex, age, education, sex x age, sex x education, age x education, sex x age x education

Result: total population of Chelsea and Dorchester

Desired: women who gave birth in 2010

Simulated annealing ***with*** replacement





PUMS data in this PUMA

Person ID	Household ID	Age	Sex
1	1	29	M
2	1	28	F
3	2	25	M
4	2	78	F
5	2	77	M
6	3	66	F
7	4	14	F
8	4	42	M

ACS Constraint tables

Census Tract A

	M	F
Age < 45	400	450
Age ≥ 45	500	550

Census Tract B

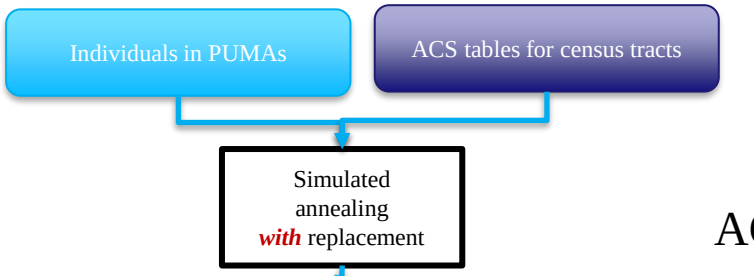
	M	F
Age < 45	300	350
Age ≥ 45	400	450

• • •

Result: Resampled PUMS data that matches ACS tract-level constraints

Tract	HH ID	P ID	Sex
A	1	1	M
A	1	2	F
A	1	1	M
A	1	2	F
A	3	6	F
A	3	6	F
A	3	6	F
A	4	1	M
A	4	2	F
B	2	3	M
B	2	4	F
B	2	5	M
B	2	3	M
B	2	4	F
B	2	5	M
…	…	…	…

Creating synthetic microdata using public data (2/4)



Census Tract A

	M	F
Age < 45	400	450
Age ≥ 45	500	550

ACS constraints: age, race

Table 4. Age-Specific and Crude Birth Rates, Massachusetts: 1990 and 2010

	1990		2010		
Mother's Age	Births[1]	Rate	Births	Rate[2]	Percent Change in Rate
10-14	124	1.3	39	0.2	-84.6%
15-19	7,259	35.1	3,907	17.1	-51.3%

Individuals in census tracts

ACS tables for census tracts

MA Births 2010 for state-wide births

MA Births 2010 constraints: Age and race-adjusted birth rates

Simulated annealing ***without*** replacement

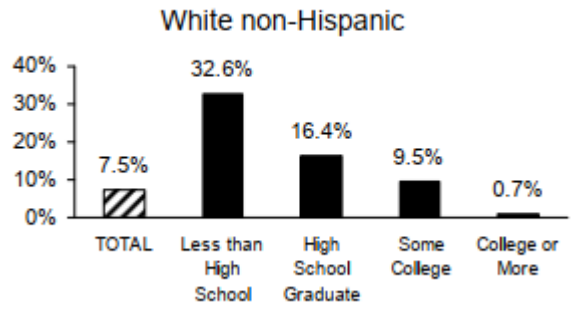
Without replacement means no duplicated individuals in the sample. This maintains constraint distributions from earlier step

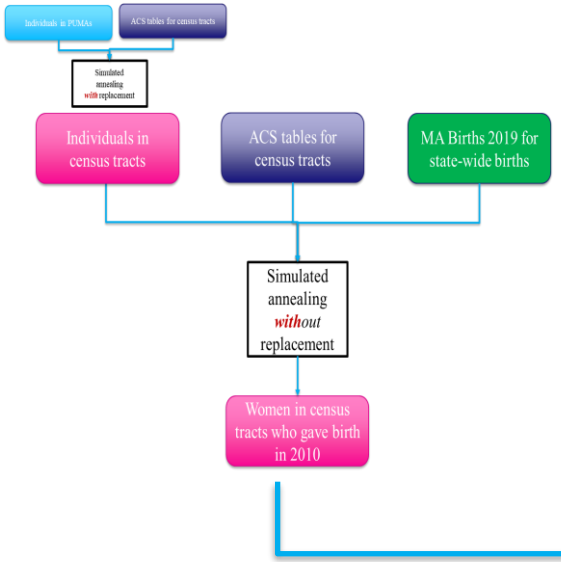
Women in census tracts who gave birth in 2010

Desired: women who gave birth in 2010, with distributions of gestational age, parity, smoking during pregnancy, use of government support and diabetes & hypertension

Creating synthetic microdata using public data (3/4)

Figure 10. Percent of Mothers who Reported Smoking during Pregnancy by Mother's Race/Hispanic Ethnicity and Educational Attainment, Massachusetts: 2010





MA Births 2010 for state-wide births

BRFSS 2011

Probabilistic sampling

Logistic regression

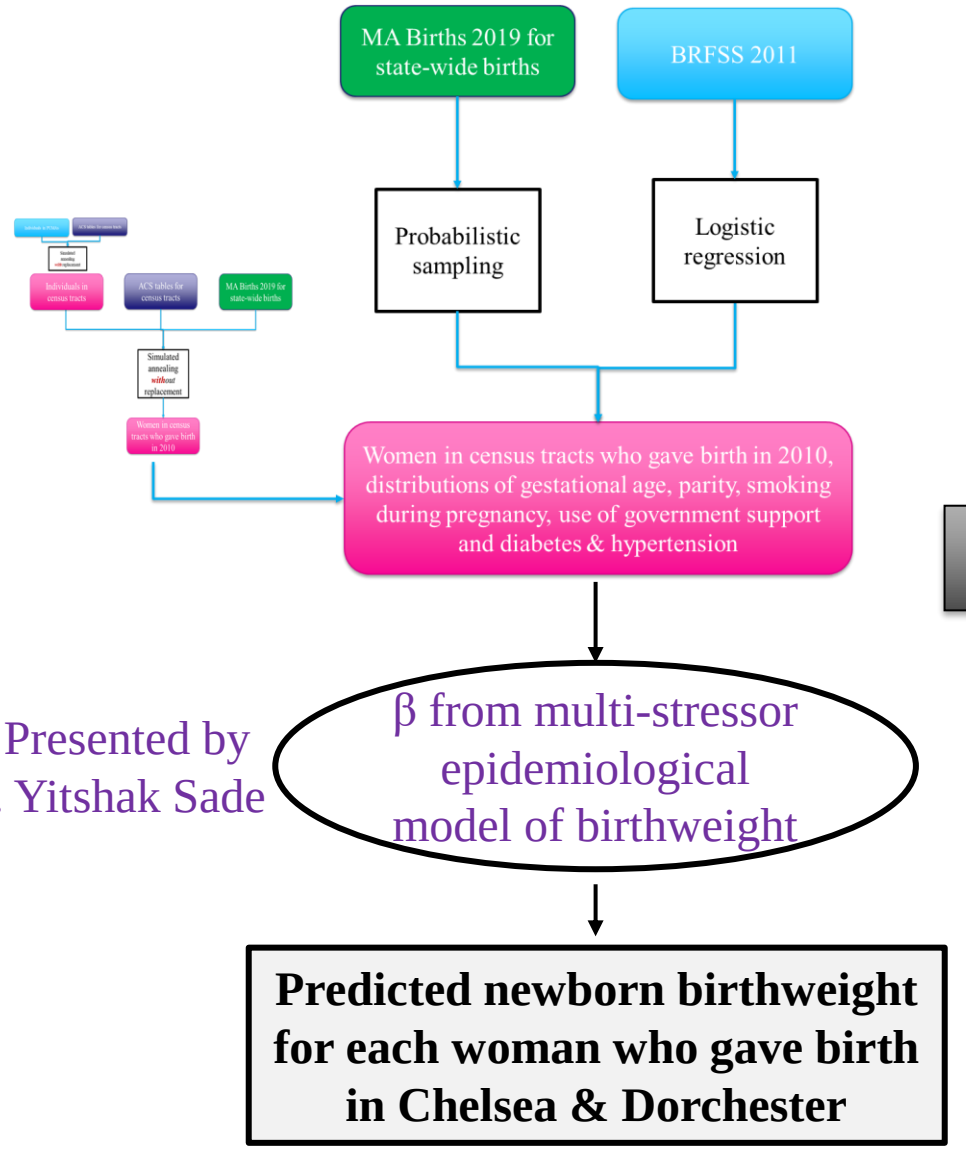
Women in census tracts who gave birth in 2010, distributions of gestational age, parity, smoking during pregnancy, use of government support and diabetes & hypertension

Behavioral Risk Factor Surveillance System, Massachusetts 2011

Self-reported risk factors (N women = 13,849), including diabetes & hypertension

$$\log\frac{P(X)}{1-P(X)} = \beta_0 + \beta_{1-5} \times \text{Maternal age} + \beta_{6-9} \times \text{Maternal race} + \beta_{10-13} \times \text{Maternal education} + \beta_{14} \times \text{Marital status}$$

Creating synthetic microdata using public data (4/4)

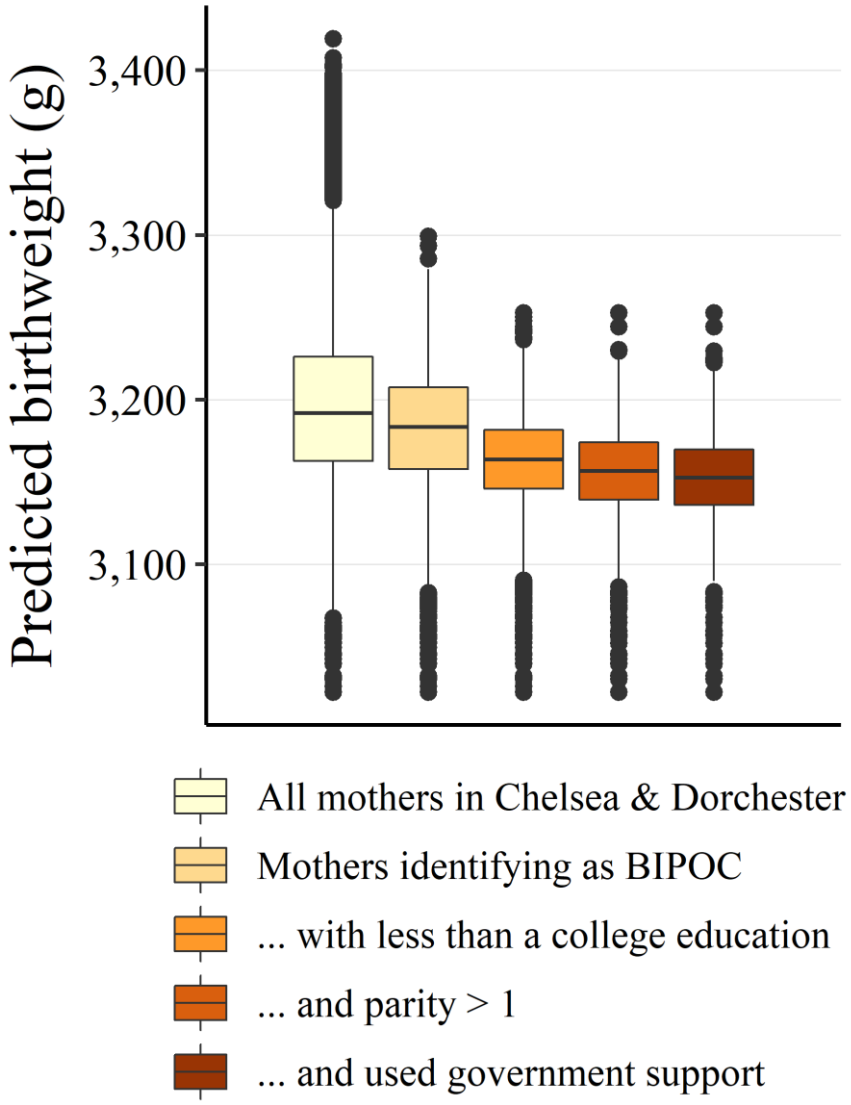


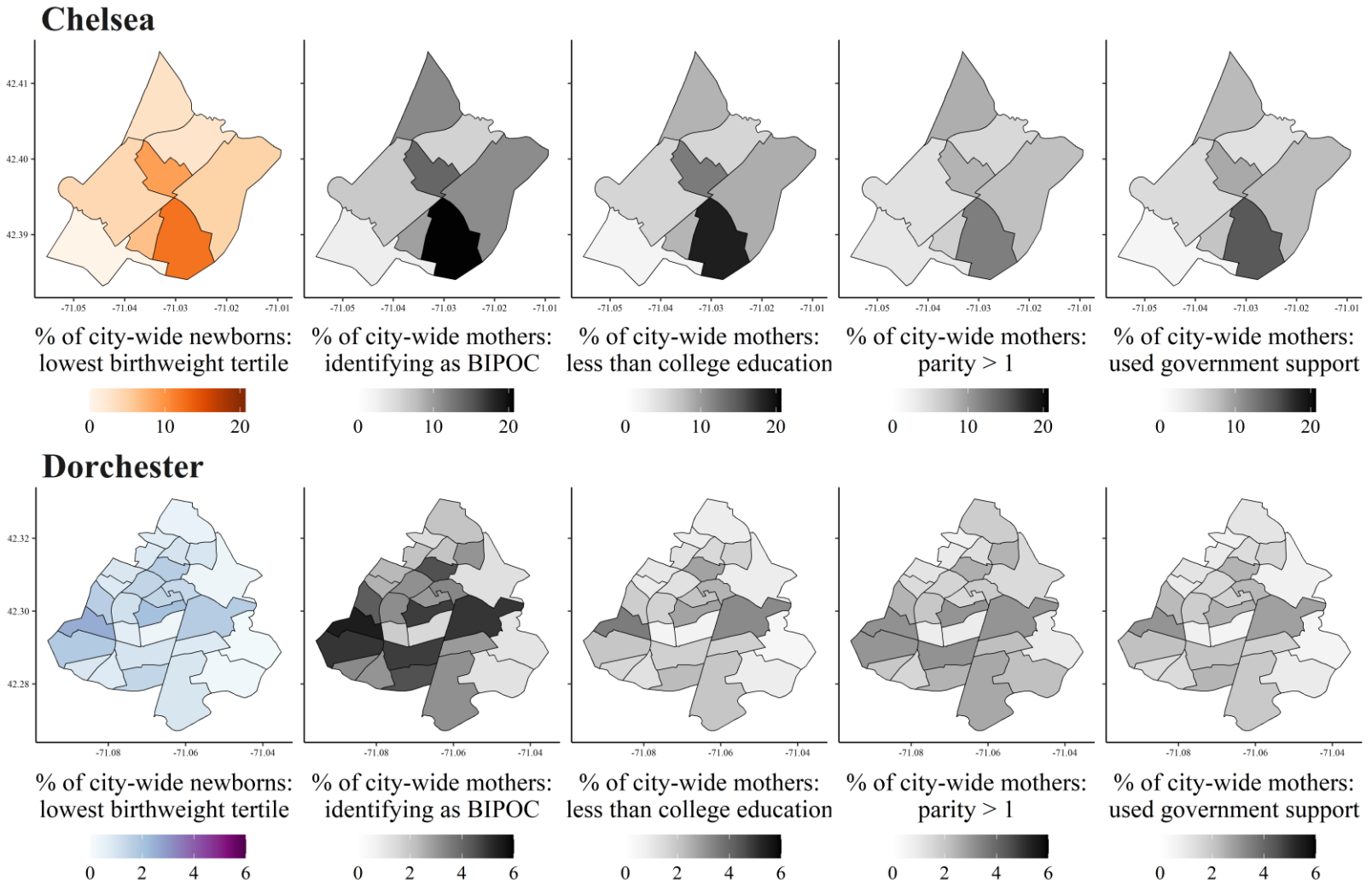
** Presented by Dr. Yitshak Sade

	MA Birth registry*	Chelsea Synthetic	Dorchester Synthetic
N	640,659	2,475	7,535
Birthweight, mean ± s.d. (grams)	3,379.3 ± 533.2	3,201.6 ± 67.9	3,208.6 ± 67.7
Socio-demographic risk factors			
Mother's age (years)	30.1	29.9	29.6
Maternal race:			
% Race = Black	8.5	4.4	50.0
% Race = Hispanic, Asian, Pacific Islander, Native American Indian, or others	21.6	77.6	35.7
% Race = White	69.9	18.0	14.3
Educational attainment:			
% Did not complete high school	11.3	33.7	18.4
% Completed high school	25.3	36.0	27.0
% Completed some college	21.5	11.2	24.7
% Completed college	26.0	15.2	23.1
% Completed more than college	15.9	3.8	6.8
Neonatal characteristics:			
Gestational age	39.0	38.6	38.6
Clinical risk factors			
% Newborn is not 1st child (parity > 1)	54.7	56.0	54.2
% Has diabetes mellitus	1.0	5.5	6.0
% Has high blood pressure	1.3	13.7	15.6
Socio-behavioral risk factors			
% Smoked prior or during pregnancy	14.2	5.8	4.7
% Used government support while pregnant	33.3	57.9	44.9

** Presented by Dr. Yitshak Sade

Trends in predicted birthweight





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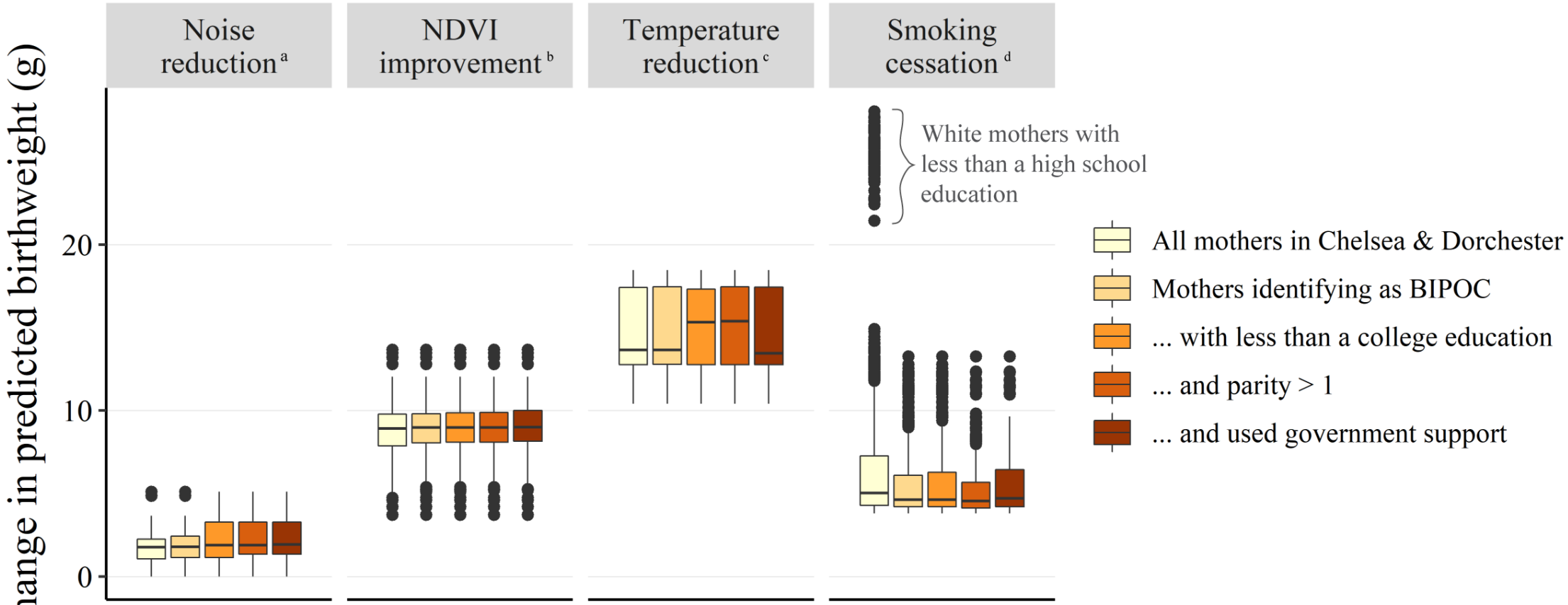
Impact of simulated interventions



[a] Reduced nighttime noise exposure to the 5th percentile

[b] Increased NDVI exposure to 95th percentile

[c] Reduced ambient temperature exposure to the 5th percentile

[d] Simulated smoking cessation for high-probability smokers

Source: PMID: 33824415

Conclusions

- Using synthetic data eases use of multi-stressor epidemiology in decision-making

- Can focus on vulnerable communities with historically less-available data (e.g., environmental justice)

Journal of Exposure Science & Environmental Epidemiology
https://doi.org/10.1038/s41370-021-00318-4

ARTICLE

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Received: 1 October 2020 / Revised: 25 February 2021 / Accepted: 12 March 2021

CRESSH MAP-EHD acknowledgements

- Francine Laden, co-director
- Jonathan Levy, co-director
- Gary Adamkiewicz
- Patricia Fabian
- Marty Alvarez
- Komal Basra, doctoral student
- Paige Brochu, doctoral student
- Leigh Evans, doctoral student
- Kelvin Fong, doctoral student
- Leila Heidari, doctoral student
- Shane Hennessy, master's student
- Raquel Jimenez, doctoral student

- Kevin Lane, postdoc & faculty
- Caitlin Matthews, master's student
- Zoe Petropoulos, doctoral student
- Jong Eun Rhee, postdoc
- Anna Rosofsky, doctoral student
- Claire Schollaert, master's student
- Madeleine Scammell
- Maayan Yitshak-Sade
- Antonella Zanobetti
- Yunke Zhang, master's student
- Fei Carnes

- BUSPH BEDAC
- BU Research Computing Services
- Children's HealthWatch
  - Stephanie Ettinger de Cuba
  - Megan Sandel
  - Sharon Coleman
  - Ana Poblacion
- CRESSH Community Partners
  - Green Roots
  - Health Resources in Action
- Communities of Chelsea & Dorchester
- Funding
  - National Institutes on Minority Health and Health Disparities, National Institutes of Health [grant number P50 MD010428]
  - U.S. Environmental Protection Agency [grant number 83615601]
  - NIEHS T32 (T32 ES014562)

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- Milando CW, **Yitshak-Sade M**, Zanobetti A, Levy JI, Laden F, Fabian MP. Modeling the impact of exposure reductions using multi-stressor epidemiology, exposure models, and synthetic microdata: an application to birthweight in two environmental justice communities. J Expo Sci Environ Epidemiol. 2021 Apr 6. doi: 10.1038/s41370-021-00318-4. Epub ahead of print. PMID: 33824415.

- **Yitshak-Sade M**, Fabian MP, Lane KJ, Hart JE, Schwartz JD, Levy L, Laden F, James P, Fong K, Kloog I, Zanobetti A. Estimating the Combined Effects of Natural and Built Environmental Exposures on Birthweight among Urban Residents in Massachusetts. J Environ Res Public Health. 17.23 (2020): 8805. PMID: 33260804.