

# MODELING AND UNDERSTANDING MORTALITY DISPARITIES

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# Outline

- 1 Aims, motivation and challenges
  - Monitoring neonatal mortality in countries worldwide (poor-quality data)
  - Racial disparities in the US opioid epidemic (noisy data)
- 2 Methodological approach
- 3 Spatial patterns of racial disparities in the opioid epidemic
- 4 Summary

## Aims and motivation

# Aims of research

To assess and interpret **health and mortality disparities across populations** and understand how **underlying demographic processes** affect these disparities and **drive changes over time**.

# Motivation

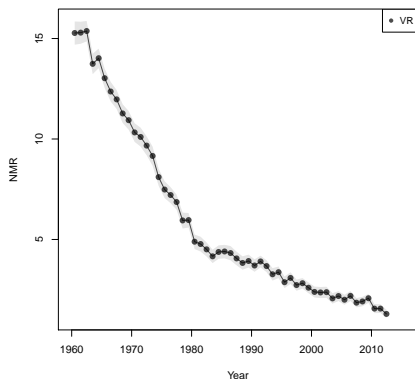
- In order to understand disparities, need to be able to monitor changes over time
- In many situations, trends may be unclear because of data issues
- Need to develop statistical methods in order to understand underlying processes

# Motivating example 1: What is the progress in decreasing neonatal mortality in countries worldwide?

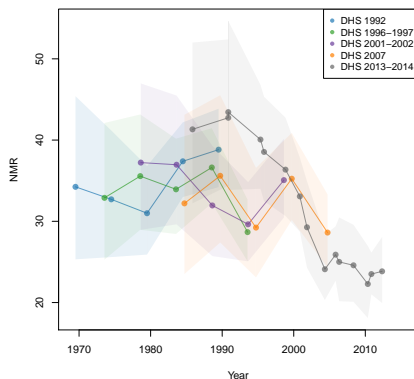
- Deaths in the first month of life
- Important health and development indicator (SDG 3)
- How are countries tracking toward reaching this goal?
- Issue: many countries only have poor-quality data available



# Motivating example 1



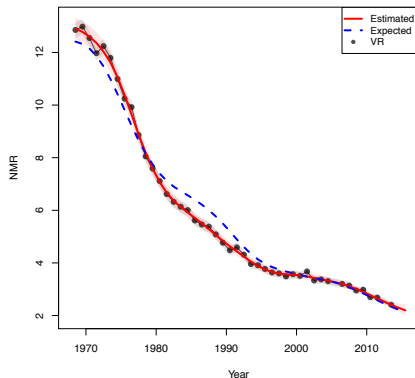
(a) Australia



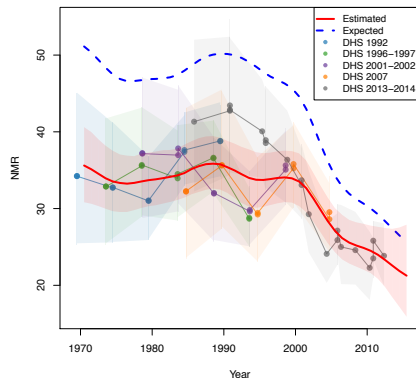
(b) Zambia

Figure: Data on neonatal mortality rates (deaths per 1,000 births)

# Motivating example 1



(a) Australia



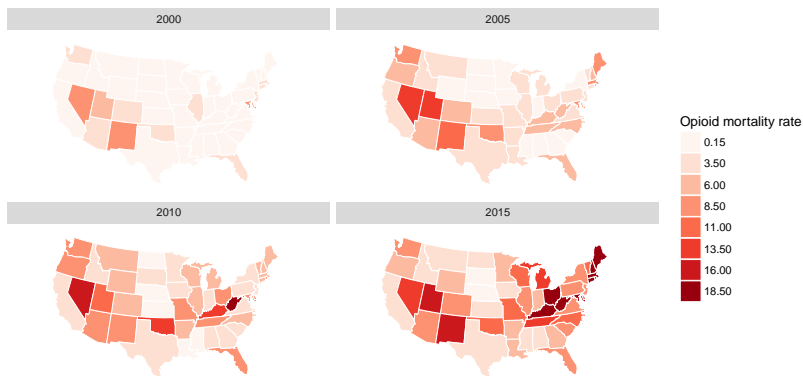
(b) Zambia

**Figure:** Data and estimates of neonatal mortality rates (deaths per 1,000 births) (Alexander and Alkema, 2017).

Full results: [childmortality.org](http://childmortality.org)



# Motivating example 2: What are the racial differences in the opioid epidemic?



# Motivating example 2

Investigating spatial patterns in racial disparities in the opioid epidemic. Issues:

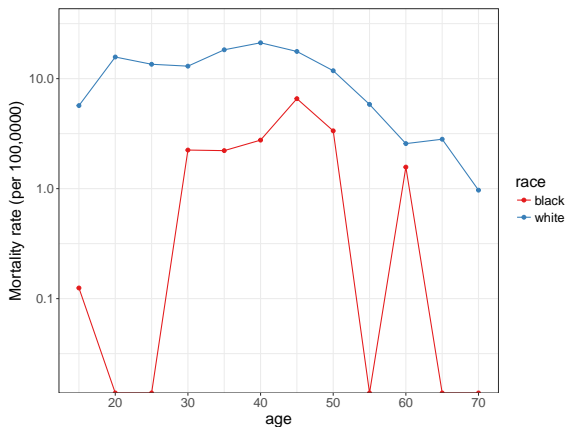
- Deaths are a relatively rare event
- Observed data suffer from high stochastic (random) variation
- Difficult to understand underlying processes from observed data

# Motivating example 2

Why are rare events an issue? Consider a coin which has a probability of a head turning up equal to 1%.

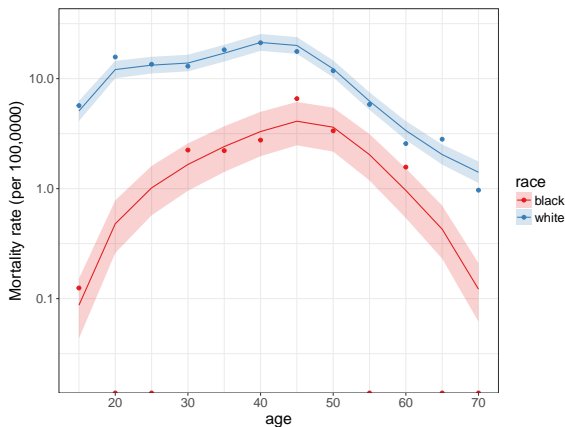
- In 100 tosses, expect to get 1 head
- Small variations in number of heads result in large variations in the observed probability

# Motivating example 2



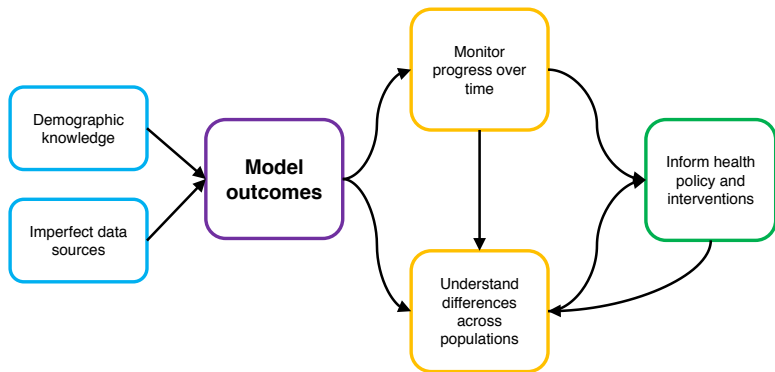
**Figure:** Observed opioid mortality rate by age and race, North Carolina, 2004

# Motivating example 2



**Figure:** Observed and estimated opioid mortality rate by age and race, North Carolina, 2004

# Overview of research



## Methodological approach

# Methodological approach

## Motivation:

- Differences in underlying age structures affect disparities
- Human populations display strong regularities in age patterns of death

## Use this demographic knowledge and incorporate information:

- about geographic patterns in mortality
- about trends in mortality over time



# Methodological approach

Bayesian hierarchical framework to model mortality rates, with three components:

- 1 Model of underlying age structure
- 2 Spatial model
- 3 Temporal model

# Modeling subnational mortality rates

$$D_{x,a,t} \sim \text{Poisson}(P_{x,a,t} \cdot m_{x,a,t})$$

where

- $D_{x,a,t}$  = deaths in age group  $x$ , area  $a$ , at time  $t$ .
- $P_{x,a,t}$  = population in age group  $x$ , area  $a$ , at time  $t$ .

We are trying to estimate mortality rate  $m_{x,a,t}$ .

# 1. Model underlying structure

- Data may be noisy or sparse at the subnational level or for particular subgroups
- Model age patterns based on observed patterns at higher levels
- Creates underlying structure, which can be flexibly shifted based on available data

# 1. Model underlying structure

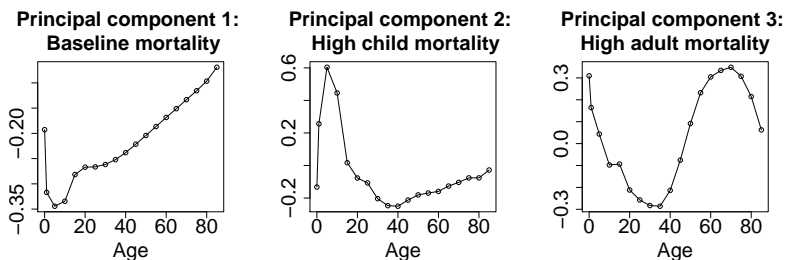
Parametric model to express overall shape of mortality curve:

$$\log(m_{x,a,t}) = \beta_{1,a,t} \cdot Y_{1x} + \beta_{2,a,t} \cdot Y_{2x} + \beta_{3,a,t} \cdot Y_{3x}$$

- $Y_{1x}$ ,  $Y_{2x}$  and  $Y_{3x}$  are principal components of a standard set of log-mortality curves.

# 1. Model underlying structure

Represent age-specific mortality curve as a combination of three components:



**Figure:** Principal components of (logged) US state mortality schedules, Males, 1980–2010 (Alexander et al. 2017).

## 2. Spatial model

### Motivation:

- Different regions/populations often have different amounts of available data
- Can share information about mortality across geographic space
- Patterns in areas with less information are partially informed by mortality patterns in similar data-rich areas

## 2. Spatial model

$\beta_{p,a,t}$  are assumed to be drawn from a common distribution for each state (or other group of areas).

$$\log(m_{x,a,t}) = \beta_{1,a,t} \cdot Y_{1x} + \beta_{2,a,t} \cdot Y_{2x} + \beta_{3,a,t} \cdot Y_{3x}$$

$$\beta_{p,a,t} \sim N(\mu_{\beta_{p,t}}, \sigma_{\beta_{p,t}}^2)$$

Average level  
across all areas

Variation across  
areas

### 3. Temporal model

- Mortality changes gradually and in a relatively regular pattern over time
- Allow for autocorrelation: estimates today are related to what happened in the past
- Provide a mechanism for projecting trends into the future



### 3. Temporal model

$$\log(m_{x,a,t}) = \beta_{1,a,t} \cdot Y_{1x} + \beta_{2,a,t} \cdot Y_{2x} + \beta_{3,a,t} \cdot Y_{3x}$$

Age patterns

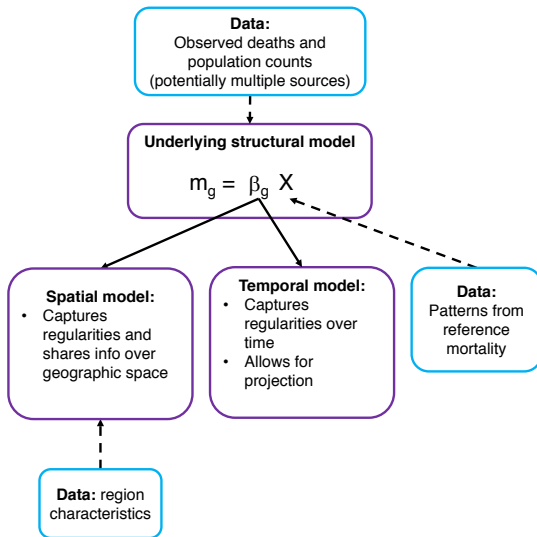
Spatial patterns

$$\beta_{p,a,t} \sim N(\mu_{\beta_{p,t}}, \sigma_{\beta_{p,t}}^2)$$

Temporal patterns

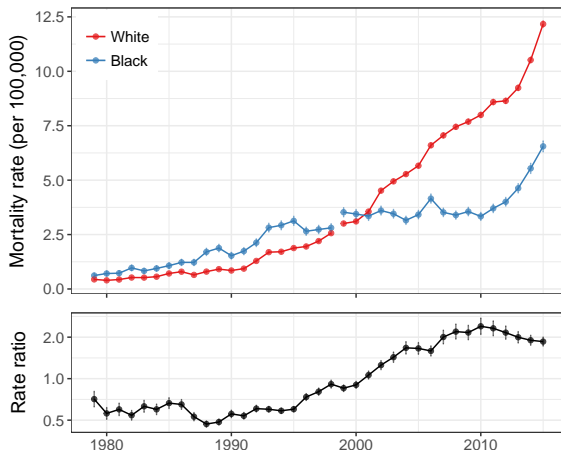
$$\mu_{\beta_{p,t}} = \mu_{\beta_{p,t-1}} + \varepsilon_{\beta_{p,t}}$$

# Summary of methodology



What are the spatial patterns by race in the opioid epidemic?

# Opioid mortality by race, 1979–2015



**Figure:** Top: Opioid mortality rate for white and black populations. Bottom: Rate ratio (white / black) of opioid mortality rates. (Alexander et al. 2017).

# The US opioid epidemic by race

- Opioid epidemic has shifted from prescription opioids to heroin/fentanyl
- Reversal of usual racial inequality observed in mortality
  - Low opioid prescription rates in black population (Frenck et al. 2015)
  - Lower access to healthcare; differing attitudes of patients and doctors (Pletcher et al. 2008; Singhal et al. 2016)
- However, epidemic is increasingly affecting the black population
  - Increased supply, affordability, potency of heroin

# Why has the opioid epidemic changed?

Three potential mechanisms:

- 1 Substitution effect painkillers to heroin (concentration) (Alpert et al. 2017)
- 2 New users (diffusion) (Cicero et al. 2017)
- 3 New effects on existing users (concentration) (CDC 2015; Slavova et al. 2017)

# Racial disparities by state

- How do racial patterns in opioid mortality vary by state?
- How have they evolved over time?
- Evidence for potential mechanisms of change?

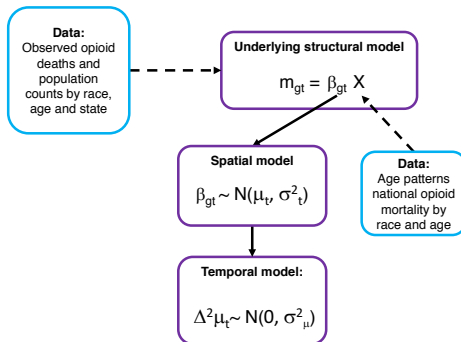
# Data

- NCHS multiple cause of death microdata from 1999–2015 (ICD-10)
- Restrict to non-hispanic white and black populations
- Opioid deaths defined as a combination of
  - underlying cause of X40-X44, X60-X64, X85 and Y10-Y14.
  - drug poisoning code of T40.0-4, T40.6
- Age-specific mortality for five-year age groups between ages 15–75
- Death rates standardized using 2000 US Census population



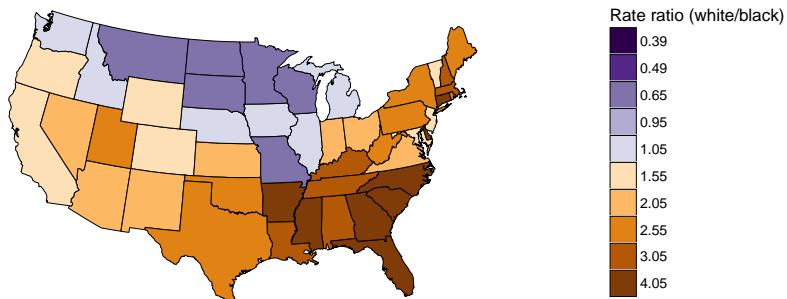
# Modeling approach

- Model underlying age structure based on race-specific age-specific mortality curves at the national level
- Pool information by geographic space
- Smooth parameter trajectories over time

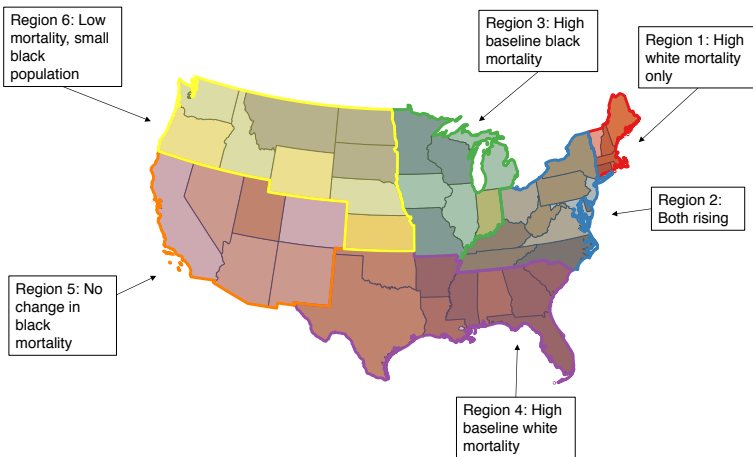


# Results: opioid mortality rate ratio

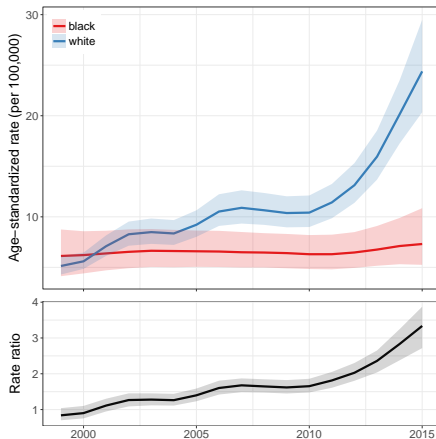
Opioid mortality rate ratio (white/black), 2015



# Regions of similar racial patterns

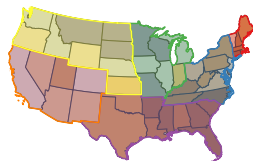


# Region 1: white only



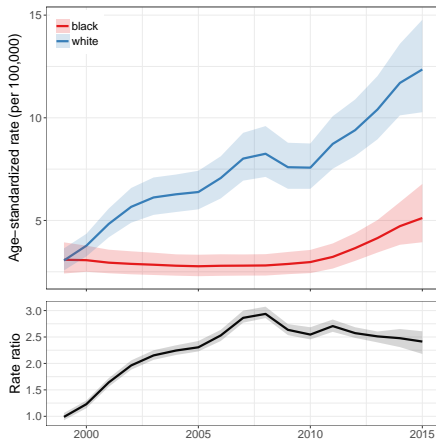
## Region 1: white mortality only

- New England states
- Increasing white mortality
- Acceleration in 2010
- Substitution, concentration



**Figure:** Opioid mortality rates by race and ratio ratio (white/black) for Massachusetts.

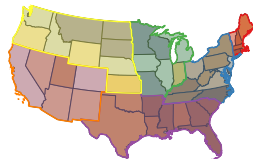
## Region 2: both races rising



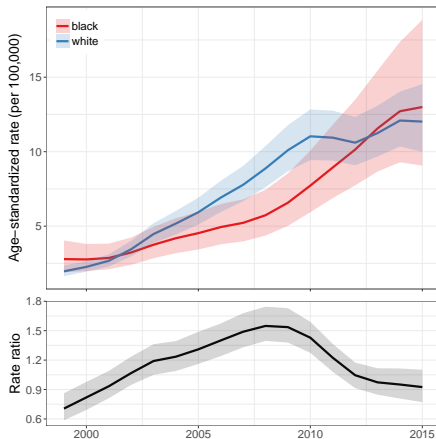
**Figure:** Opioid mortality rates by race and ratio ratio (white/black) for **Virginia**.

Region 2: mortality rising in both races

- mid-Atlantic, Appalachia states
- Higher for white but increasing for both
- New users, diffusion



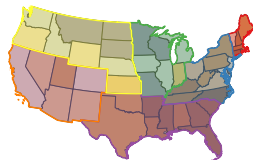
## Region 3: higher black mortality



**Figure:** Opioid mortality rates by race and ratio ratio (white/black) for **Missouri**.

### Region 3: higher black mortality

- Midwest states
- Higher relative black mortality
- Ratios closer to 1
- New effects on existing users



# Summary of findings

- Distinct spatial patterns in opioid mortality by race
- Evidence of both diffusion and concentration of epidemic
- Implications for how to think about effective policy:
  - Treatment in affected communities versus prevention across communities
  - Restricting access to prescriptions versus focusing on pathways to heroin addition
  - Education about drug use versus dangers of new drugs

## Summary



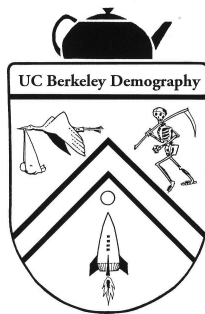
# Summary

- Important to be able to assess and interpret health and mortality outcomes across populations
- In many cases, data to study such inequalities are limited
- Build on demographic knowledge about underlying population processes
- Flexible hierarchical modeling frameworks which incorporate patterns across space and time

# Future directions

- 1 How are health and mortality inequalities across socioeconomic status evolving?
- 2 How do subnational differences in developing countries affect progress towards health goals?

Thanks!



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## Extra Slides