A Complex Systems Theory of Disease

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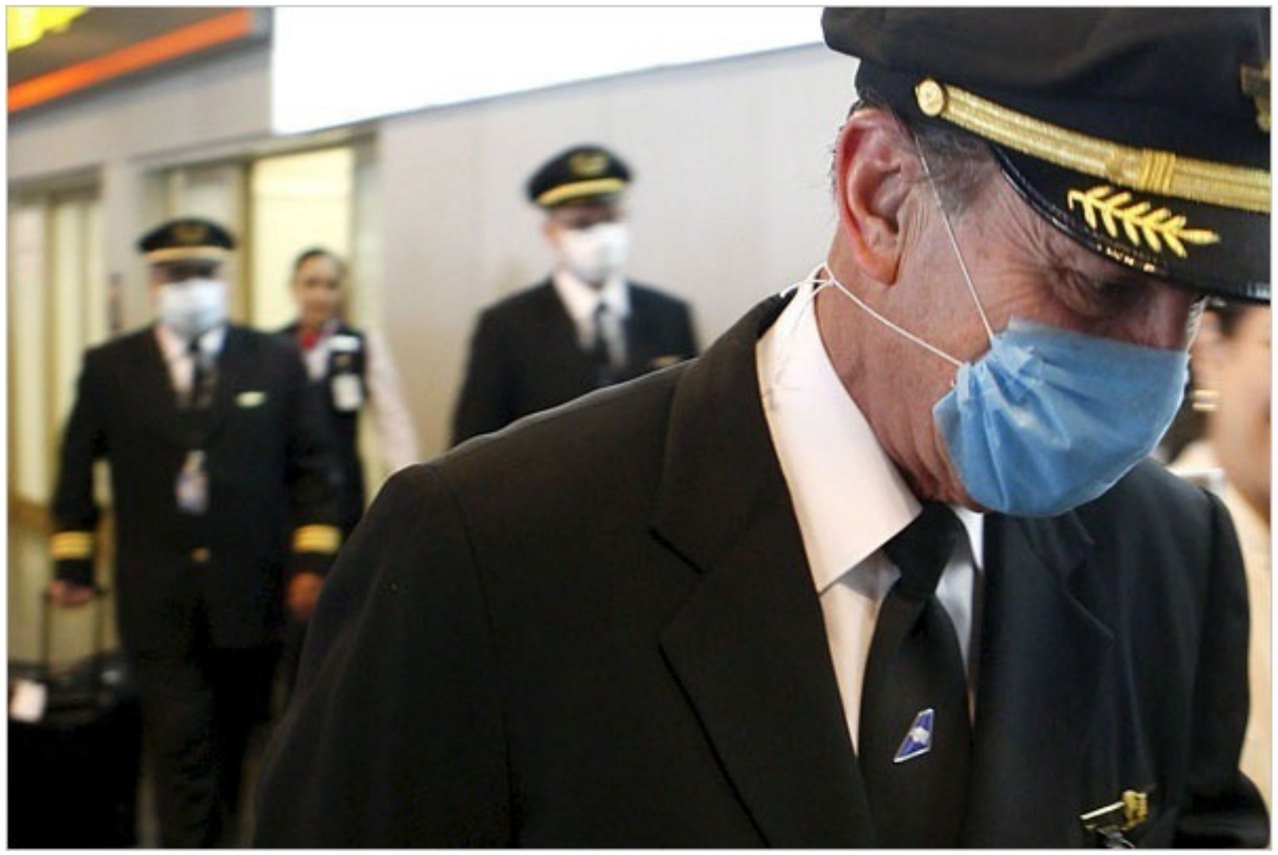
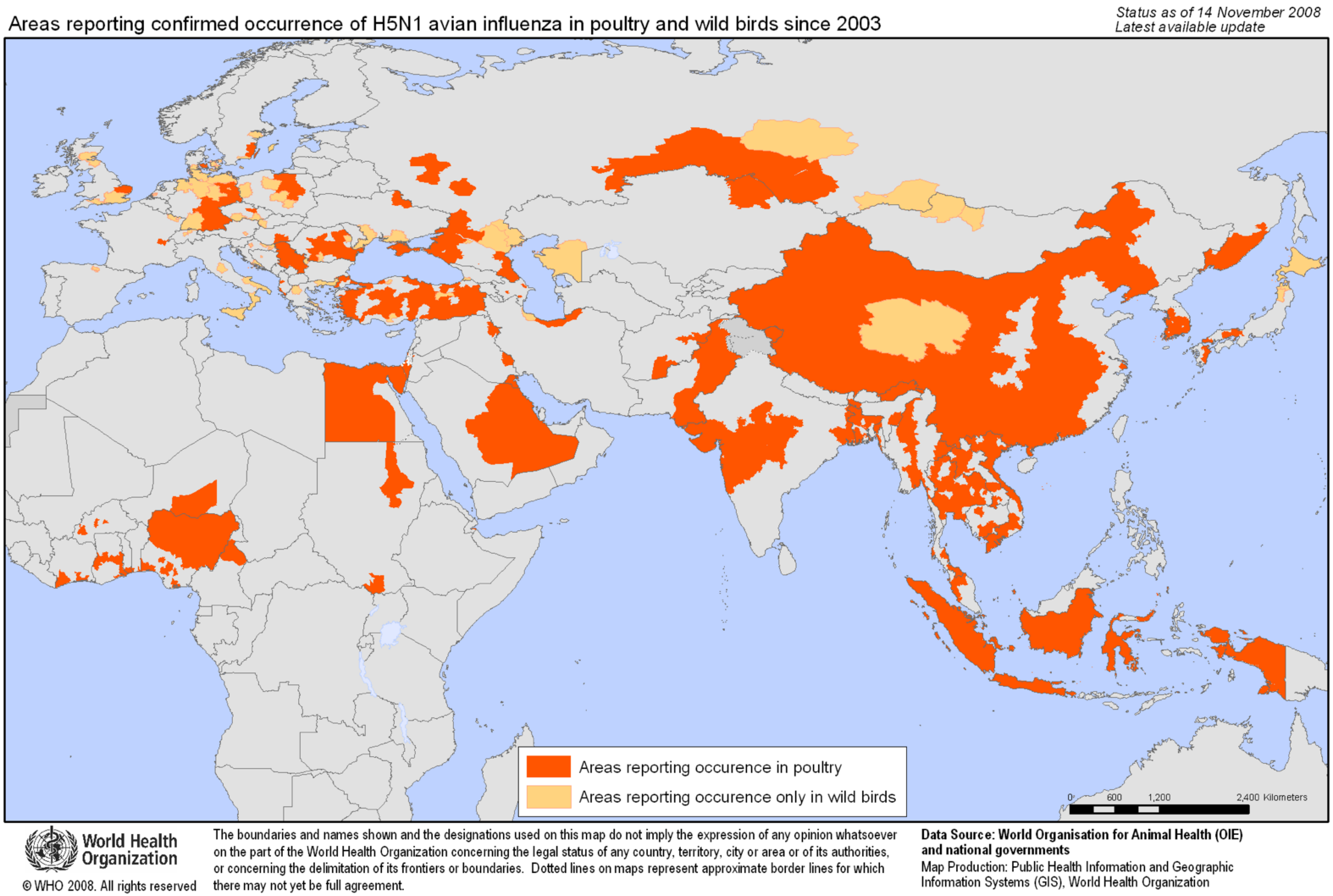
Juan Genoves

Where will the next pandemic emerge?



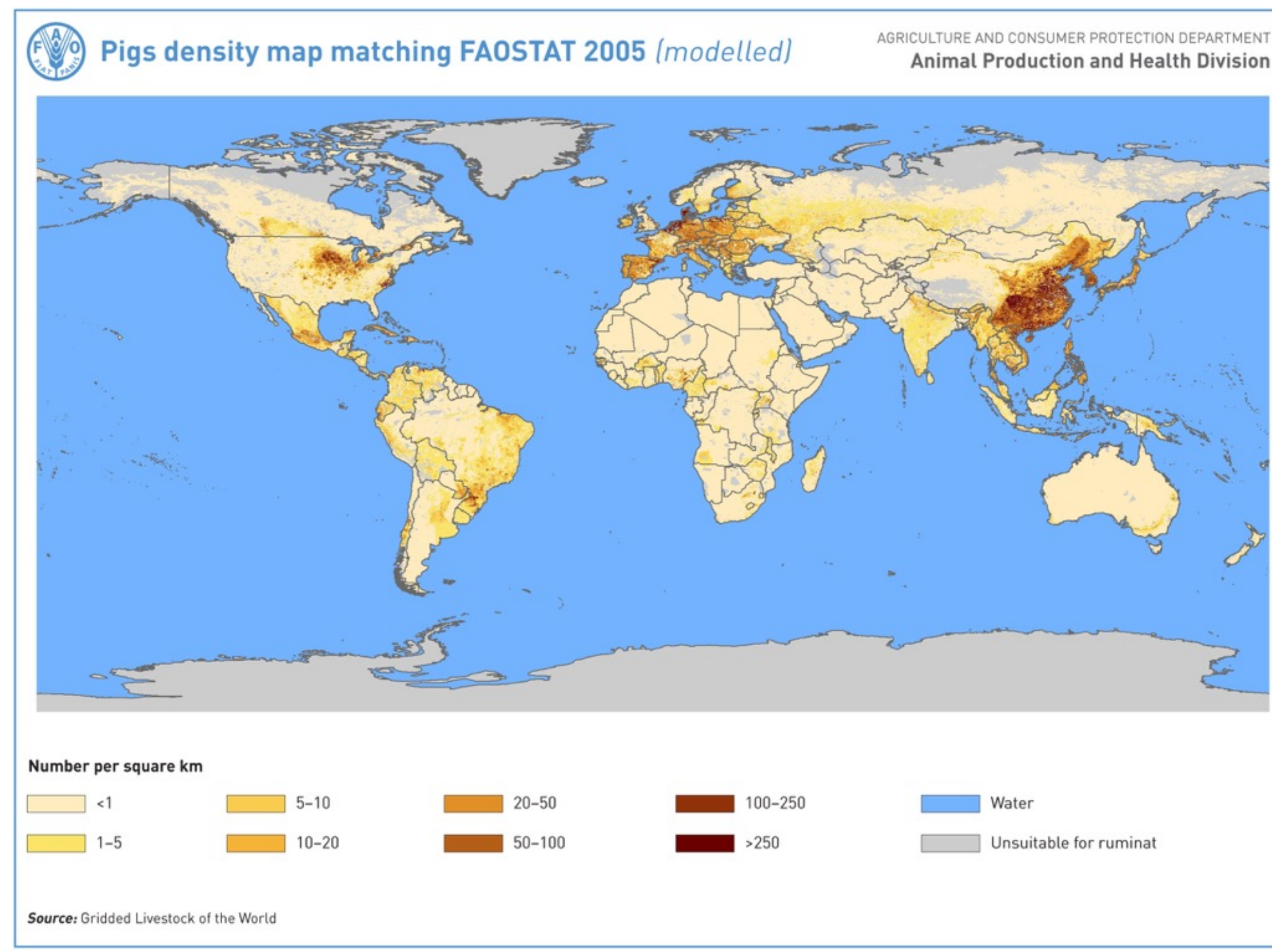
Where will the next **influenza** pandemic emerge?



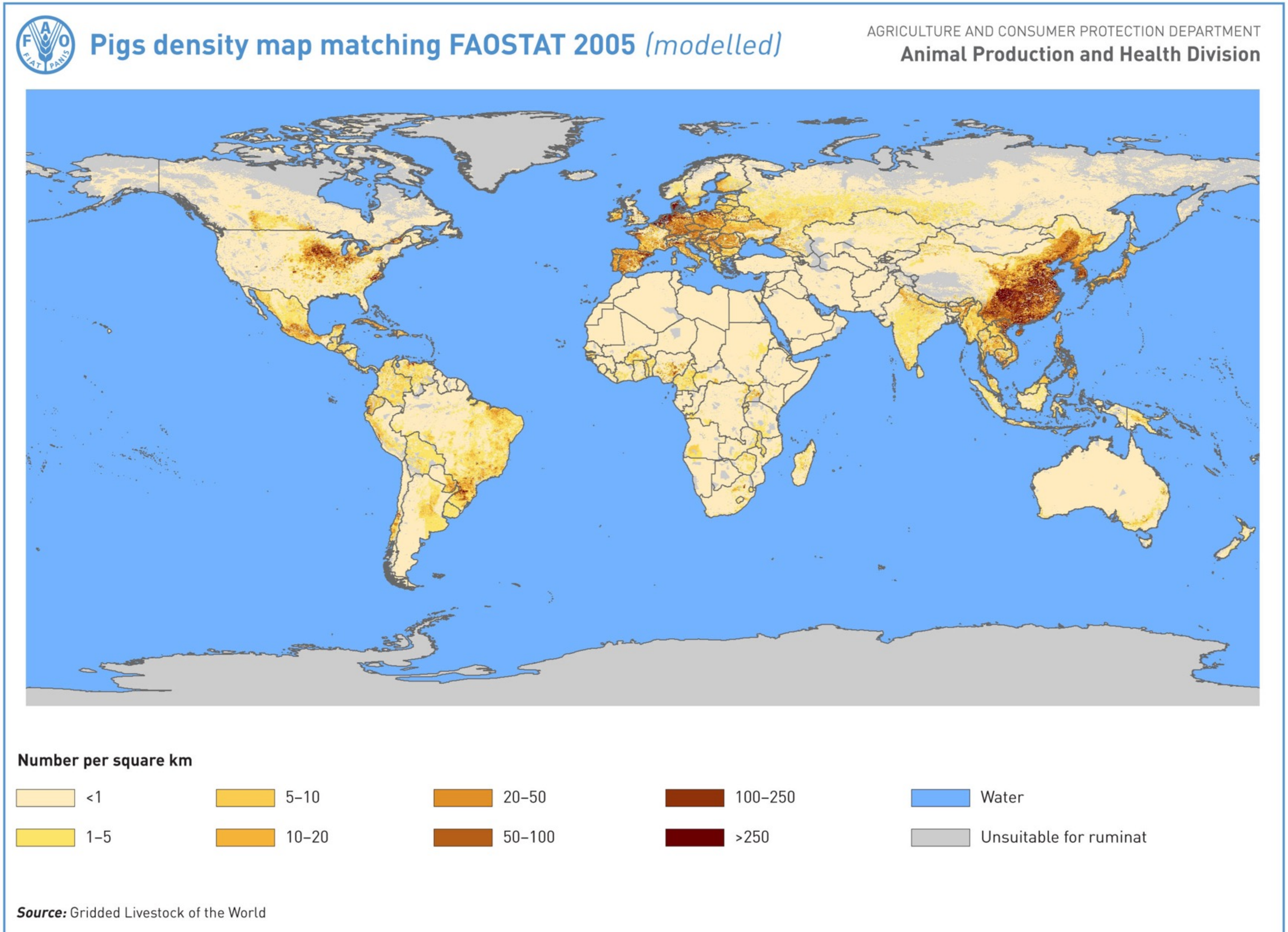
What factors are important for pandemic flu?

Air travel

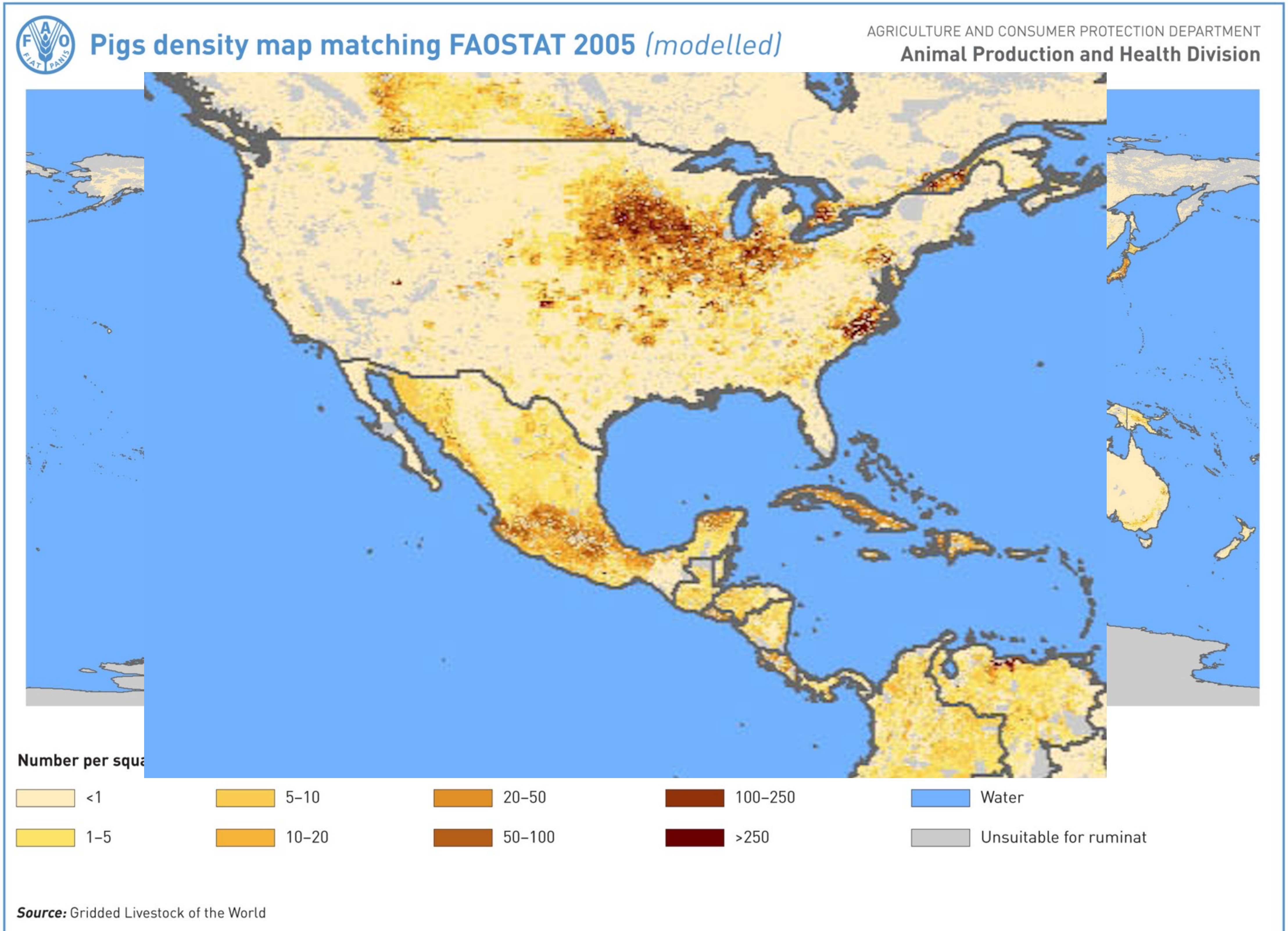
Density of pig farms



Worldwide pig density



Worldwide pig density



and it happened again with Ebola

and it happened again with Ebola

TABLE I. — **Age distribution of persons positive for either Lassa (LAS), Ebola (EBO) or Marburg (MAR) virus antibodies.**

Age (years)	Nb tested	LAS-positive (prevalence %)	EBO-positive (prevalence %)	MAR-positive (prevalence %)
0-9	49	5 (10 %)	2 (4 %)	0
10-19	68	11 (16 %)	5 (7 %)	0
20-29	108	21 (19 %)	6 (6 %)	1
30-39	94	16 (17 %)	5 (5 %)	1
40-59	88	9 (10 %)	6 (7 %)	1
60 plus	26	5 (16 %)	2 (8 %)	2
Total	433	67 (16 %)	26 (6 %)	5 (1 %)

Knobloch et al. 1982

and it may happened again with Chagas

Brumpt et al. 1912
Salazar et al. 2015

and it may happened again with Chagas

Brumpt et al. 1912
Salazar et al. 2015

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  Modeling infectious diseases

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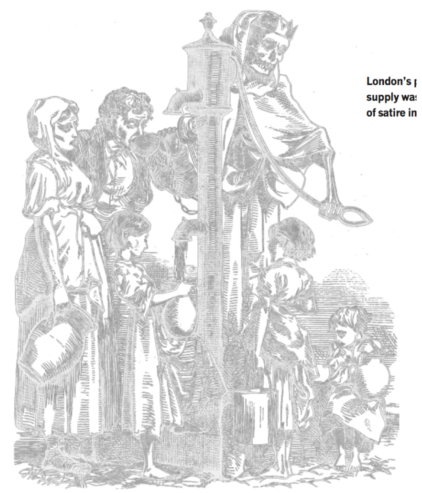
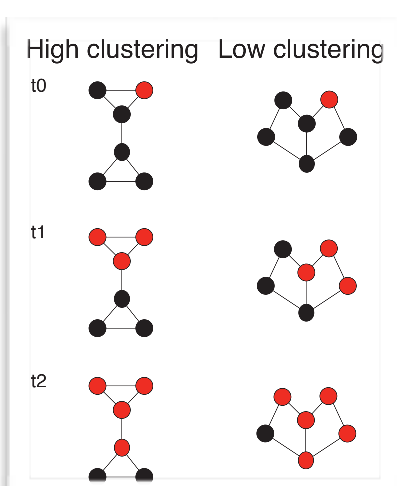
  

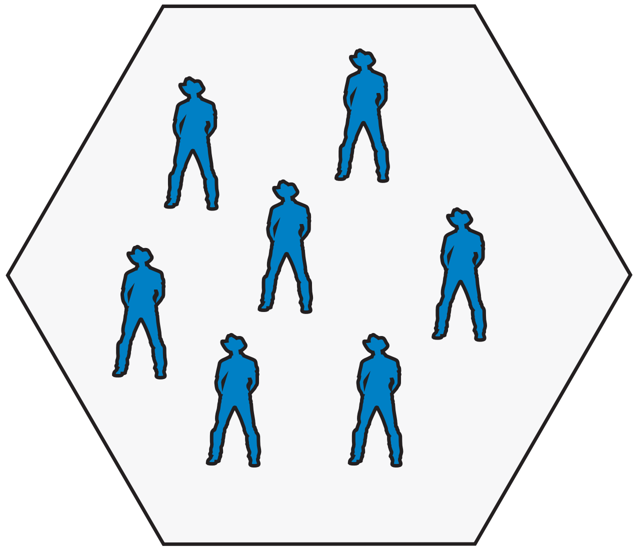
  Inequality & disease

- 

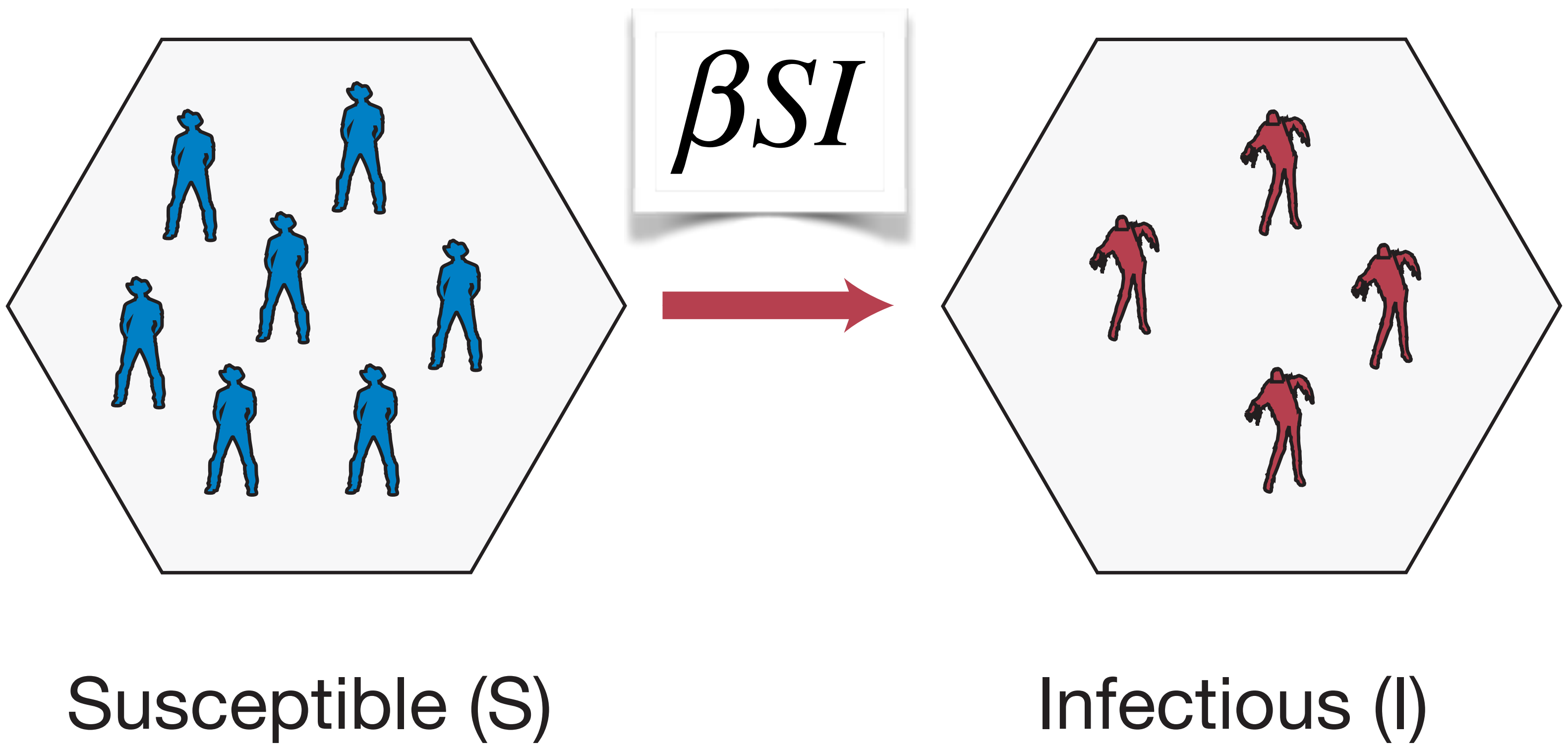
  Social clustering & Ebola

Compartmental models

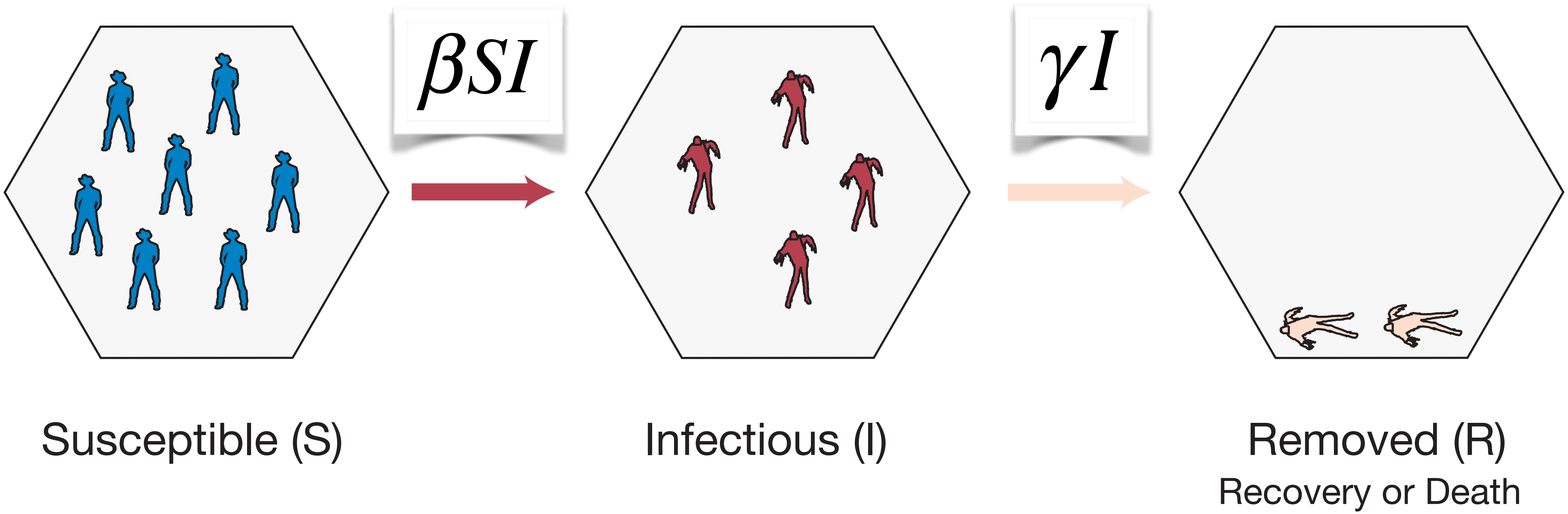


Susceptible (S)

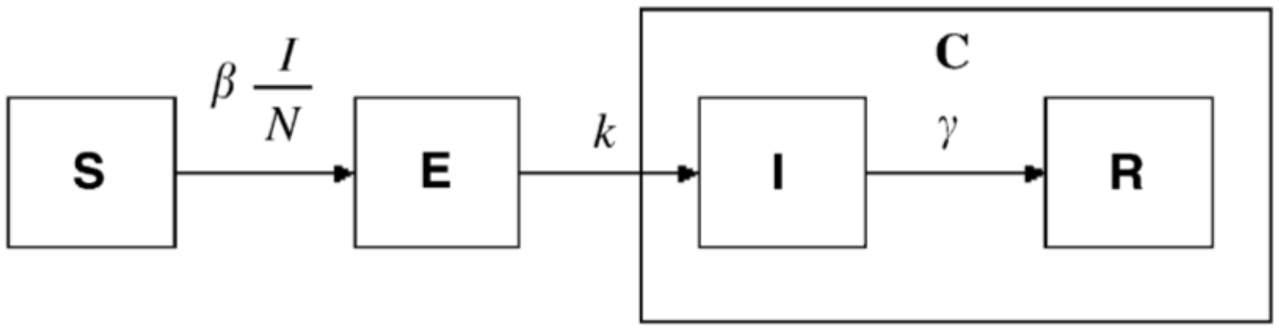
Compartmental models - Mass Action Assumption



Compartmental models



Lions, Tigers, and Boxes … oh my



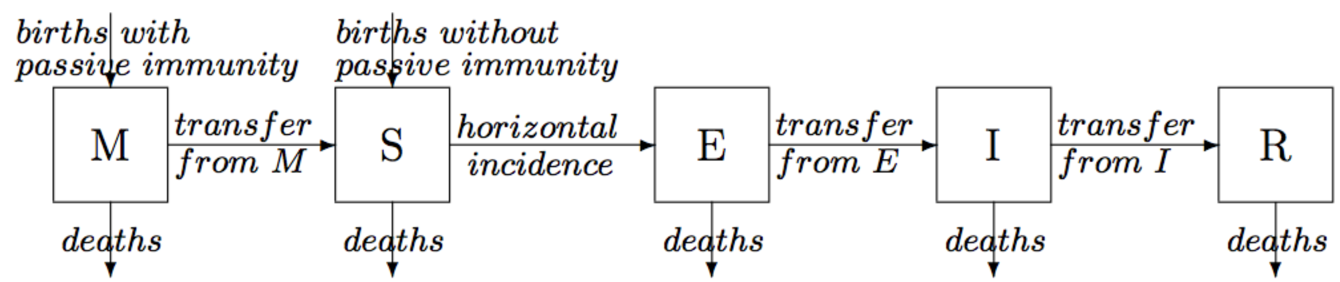
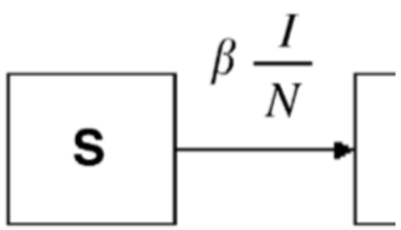


Fig. 1 *The general transfer diagram for the MSEIR model with the passively immune class M, the susceptible class S, the exposed class E, the infective class I, and the recovered class R.*

$$
\begin{aligned}
S'(t) &= \mu \cdot (1 - wP - aP) - \beta[I_s(t) + I_a(t)]S(t) - \nu S(t) && (1)\\
I_s'(t) &= \beta\sigma[I_s(t) + I_a(t)]S(t) - \gamma_s I_s(t) - \nu I_s(t) && (2)\\
I_a'(t) &= \beta(1-\sigma)[I_s(t) + I_a(t)]S(t) + \beta[I_s(t) + I_a(t)]V(t) - \gamma_a I_a(t) - \nu I_a(t) && (3)\\
V'(t) &= \mu \cdot aP - \beta[I_s(t) + I_a(t)]V(t) - \nu V(t) && (4)\\
R'(t) &= \mu \cdot wP + \gamma_s I_s(t) + \gamma_a I_a(t) - \nu R(t) && (5)
\end{aligned}
$$

Lions, Tigers, and Boxes … oh my



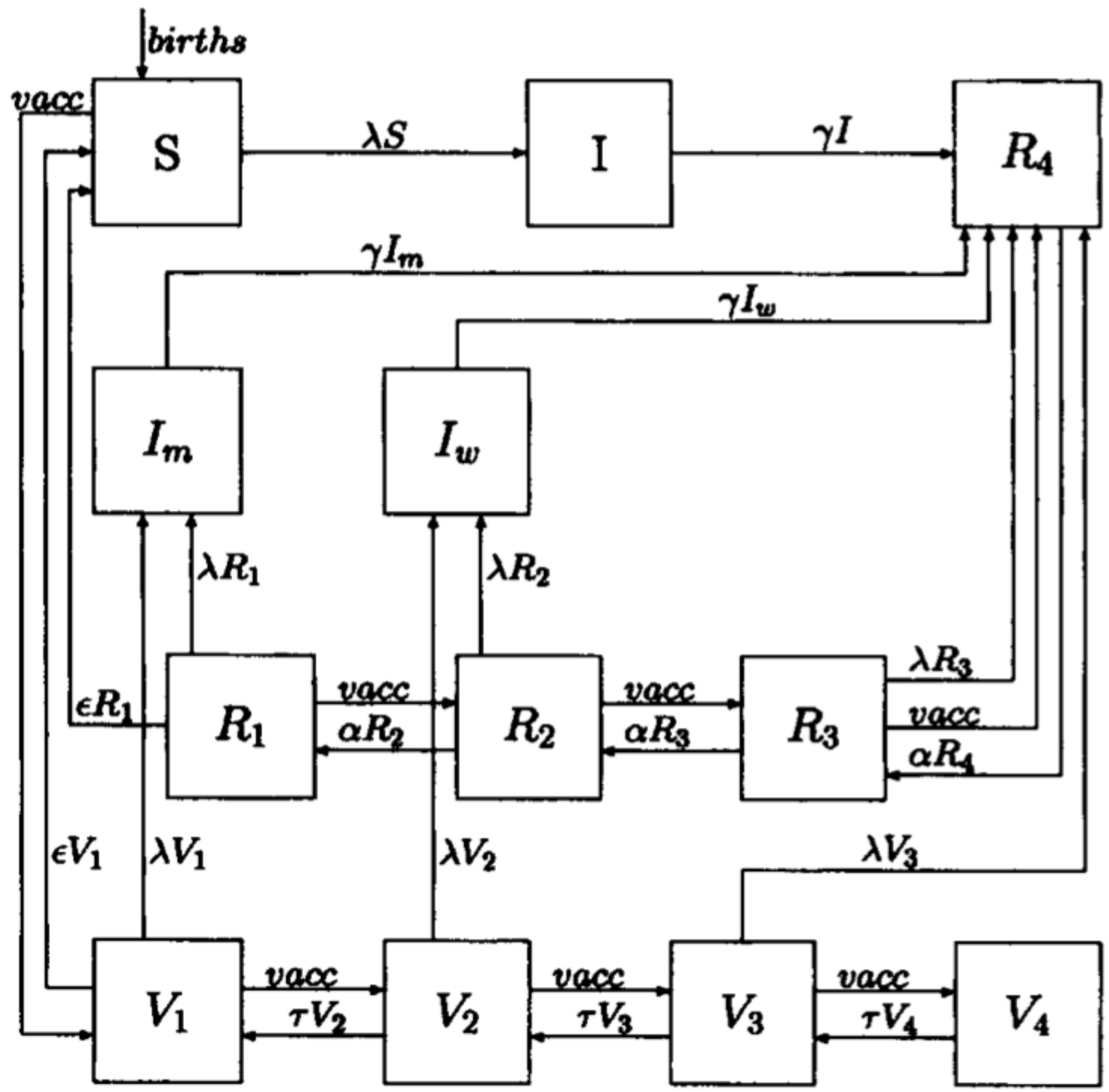
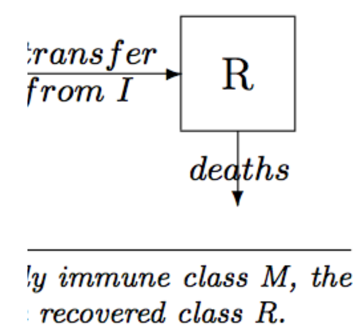
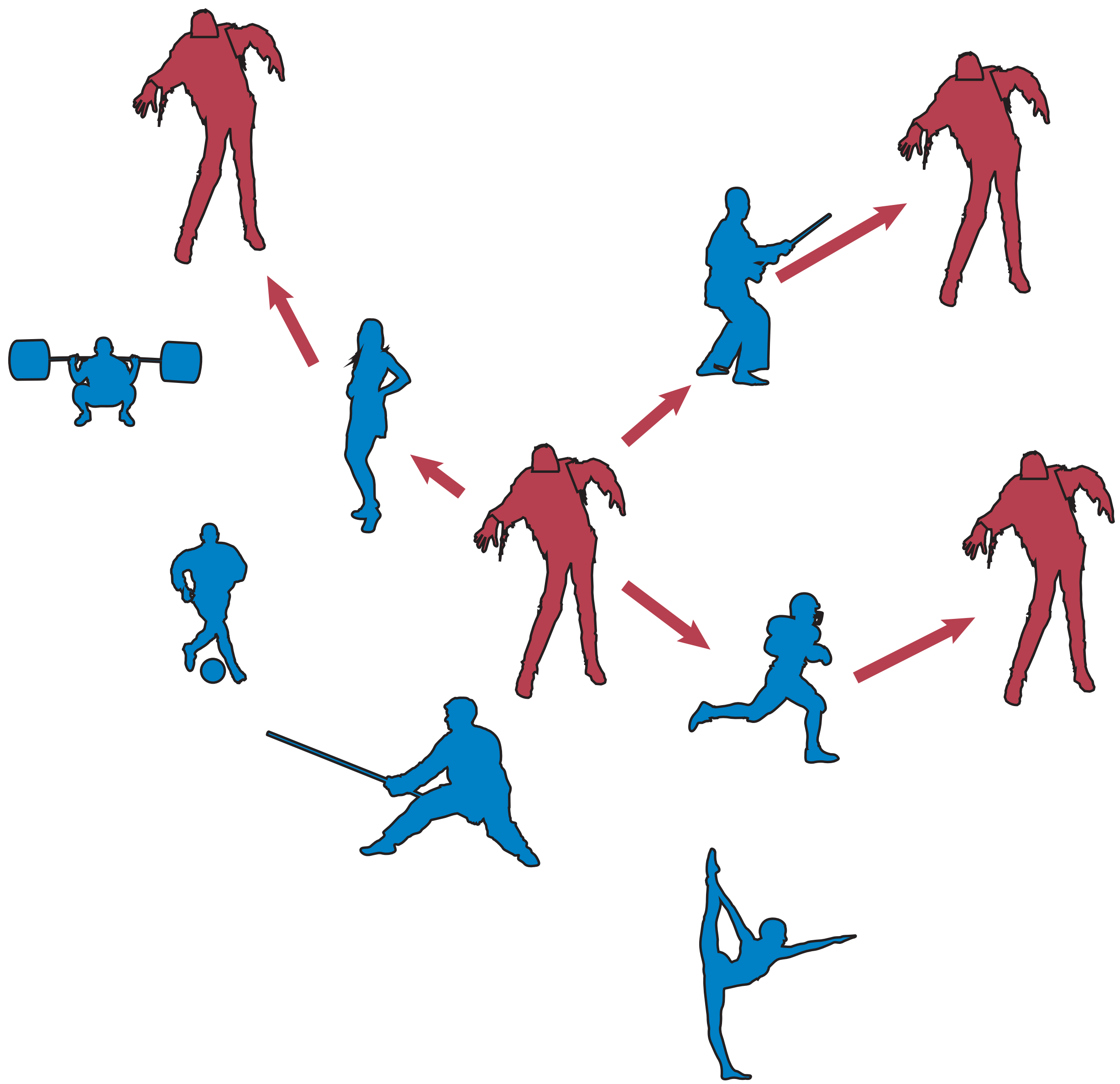


FIG. 3. Transfer diagram for the pertussis model with vaccination.



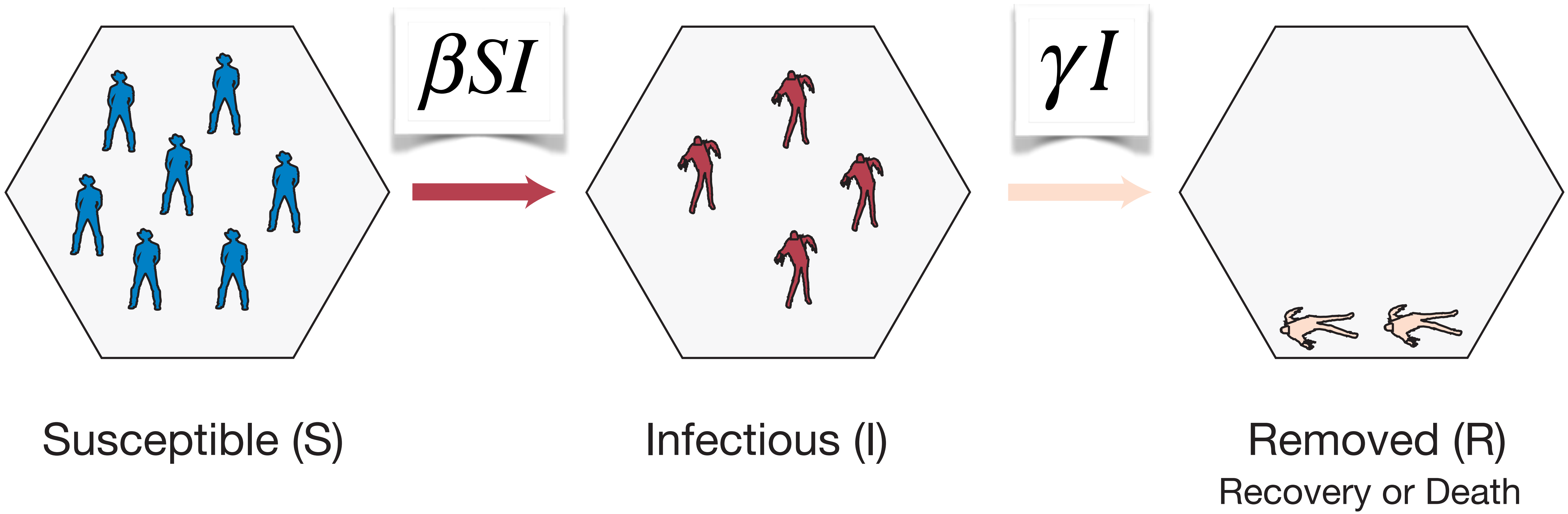
$$
\begin{aligned}
S'(t) &= \mu \cdot (1 - \\
I_s'(t) &= \beta\sigma[I_s(t \\
I_a'(t) &= \beta(1 - \\
V'(t) &= \mu \cdot aP \\
R'(t) &= \mu \cdot wP
\end{aligned}
$$

Reproduction Number



Expected number of secondary cases
in the begining of an outbreak

Compartmental models



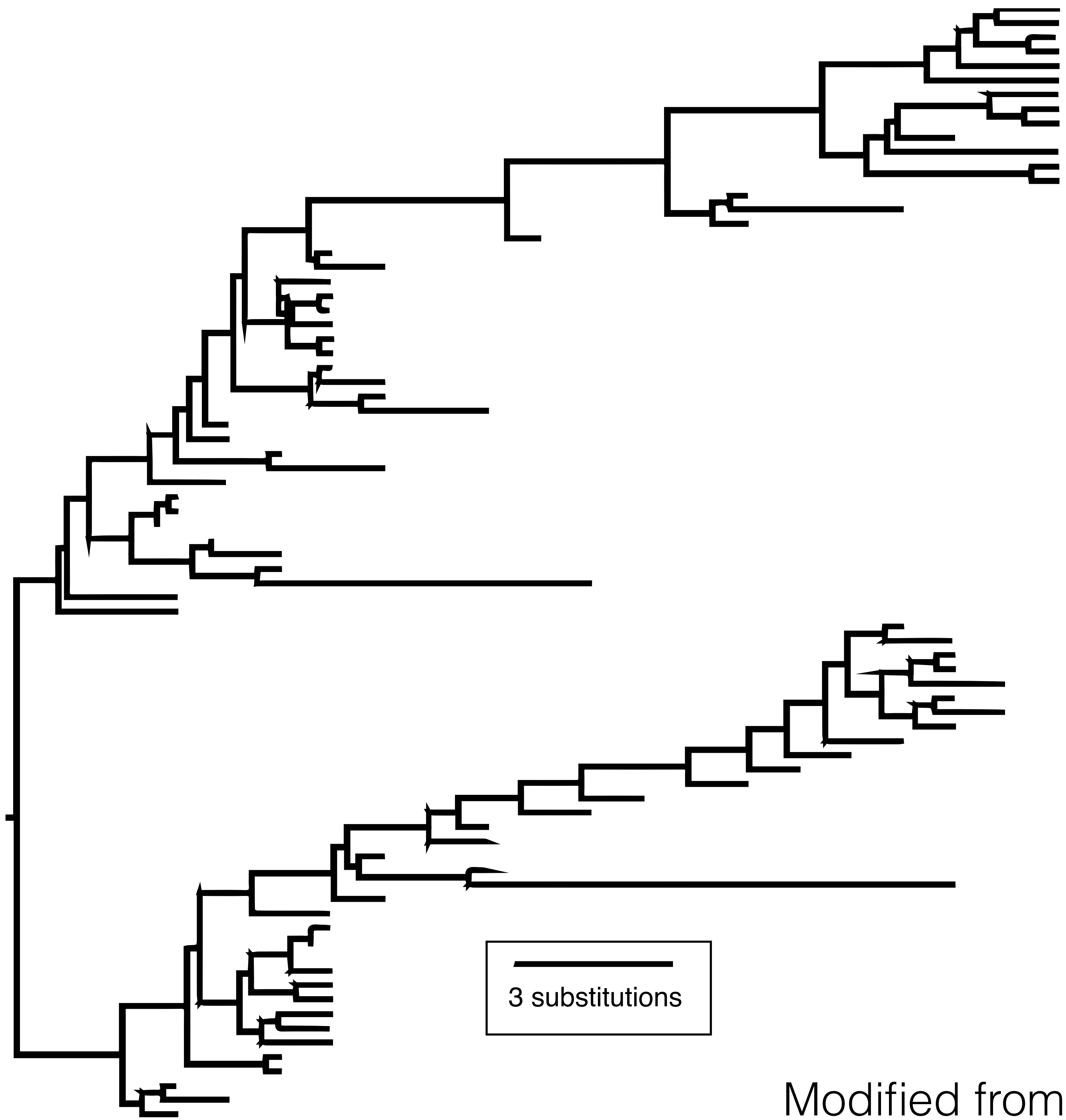
$$R_0 = \frac{\text{Infection rate}}{\text{Recovery rate}} = \frac{\beta S}{\gamma}$$

Reproduction Numbers

Disease	R_0
Measles & Whooping Cough	5 - 18
Chicken Pox	7 - 12
Polio	5 - 7
Smallpox	1.5 - 20+
Seasonal flu	1.1 - 1.5
Ebola	1.1 - 3

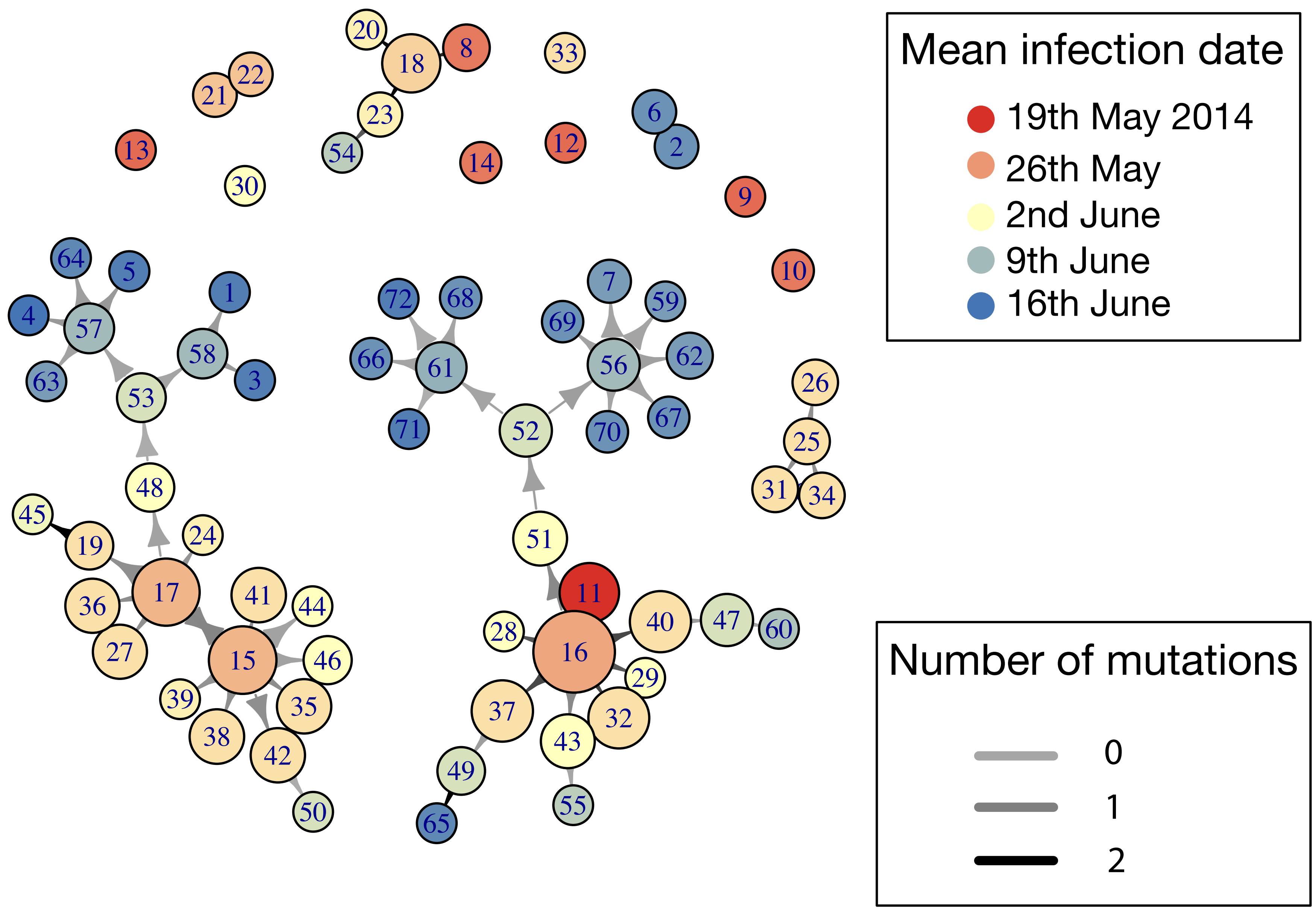
Problems with the Reproduction Number

Ebola virus genomic data

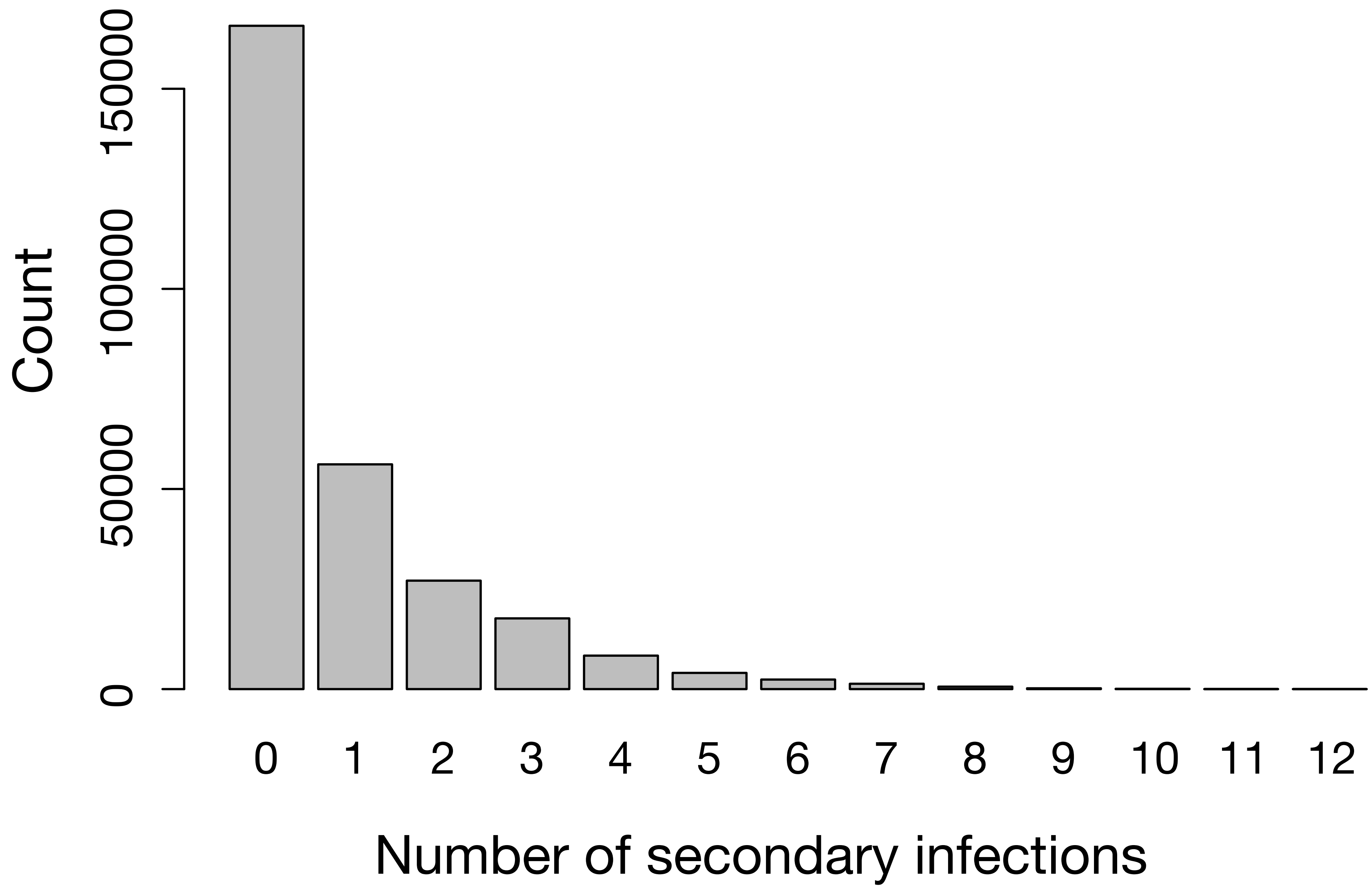


Modified from Gire et al. 2014

Reconstructed transmission network



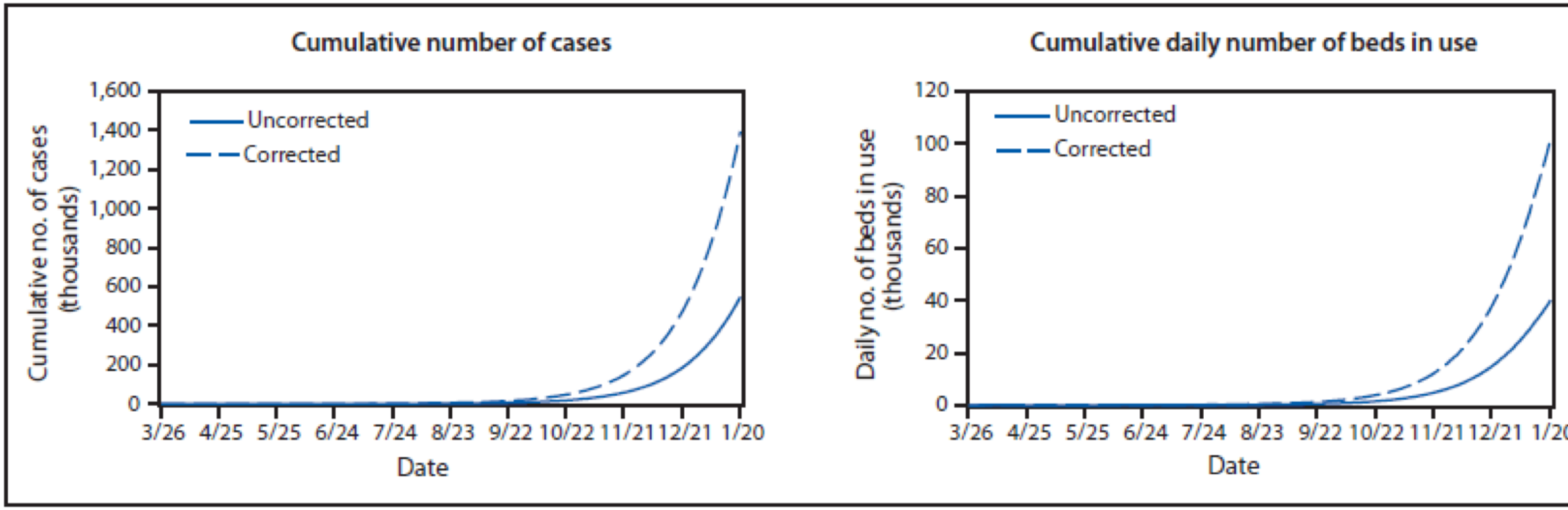
Posterior number of secondary infections



Problems with the Reproduction Number

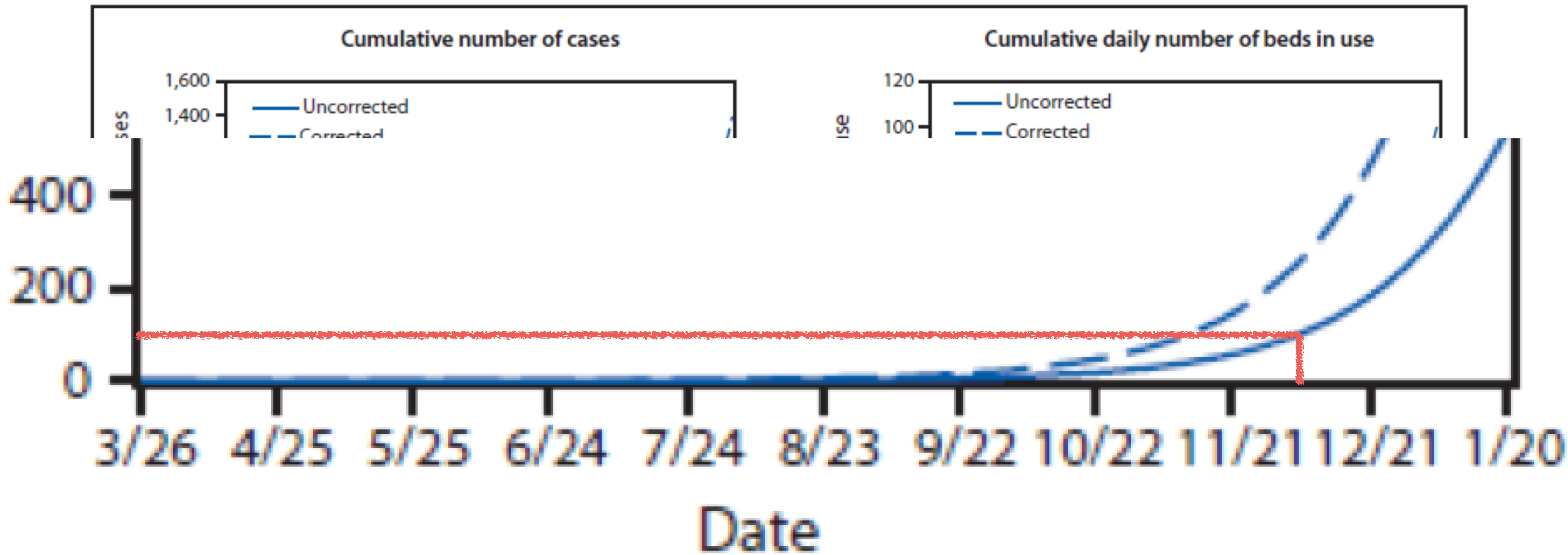
Contact Patterns Vary

Ebola Predictions from mass-action models



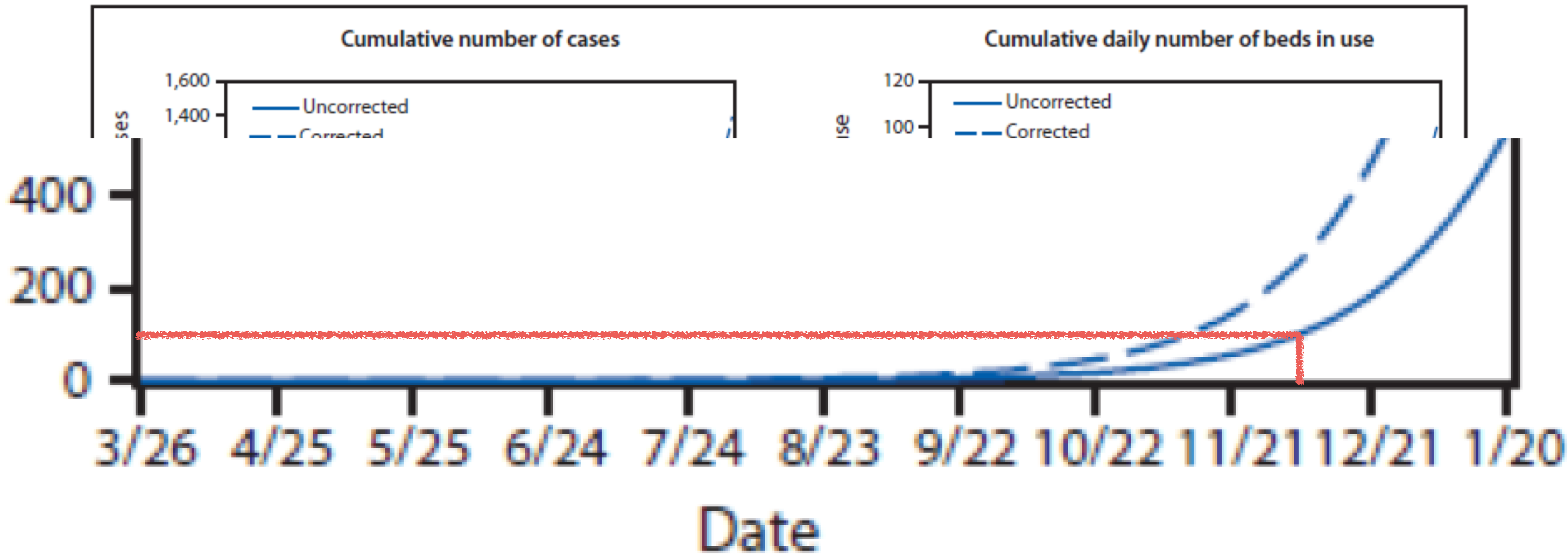
Meltzer et al. 2014

Ebola Predictions from mass-action models



Meltzer et al. 2014

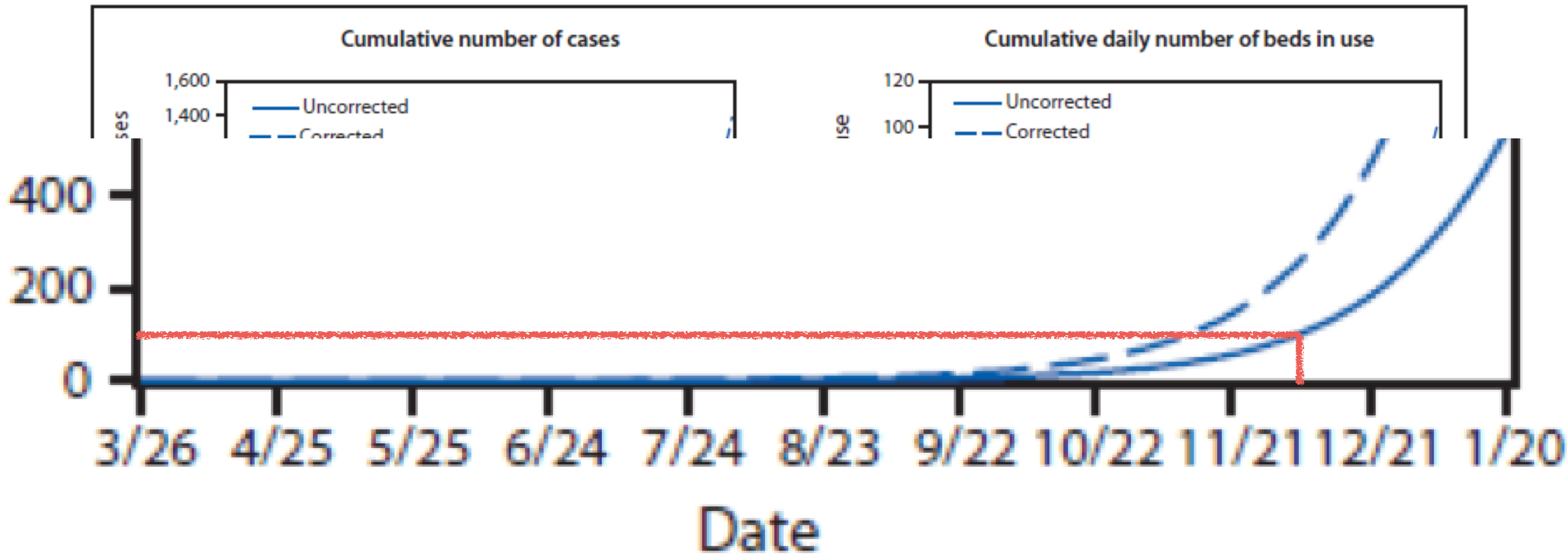
Ebola Predictions from mass-action models



Estimated - 100,000

Meltzer et al. 2014

Ebola Predictions from mass-action models



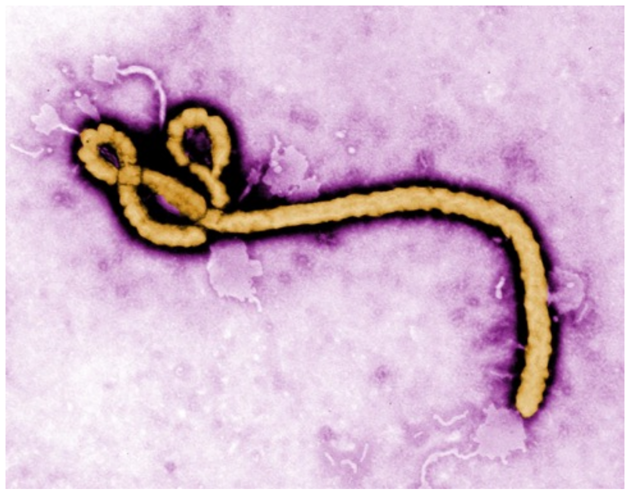
Estimated - 100,000

Observed - 10,000

Meltzer et al. 2014

Why do these problems exist?

Why do these problems exist?

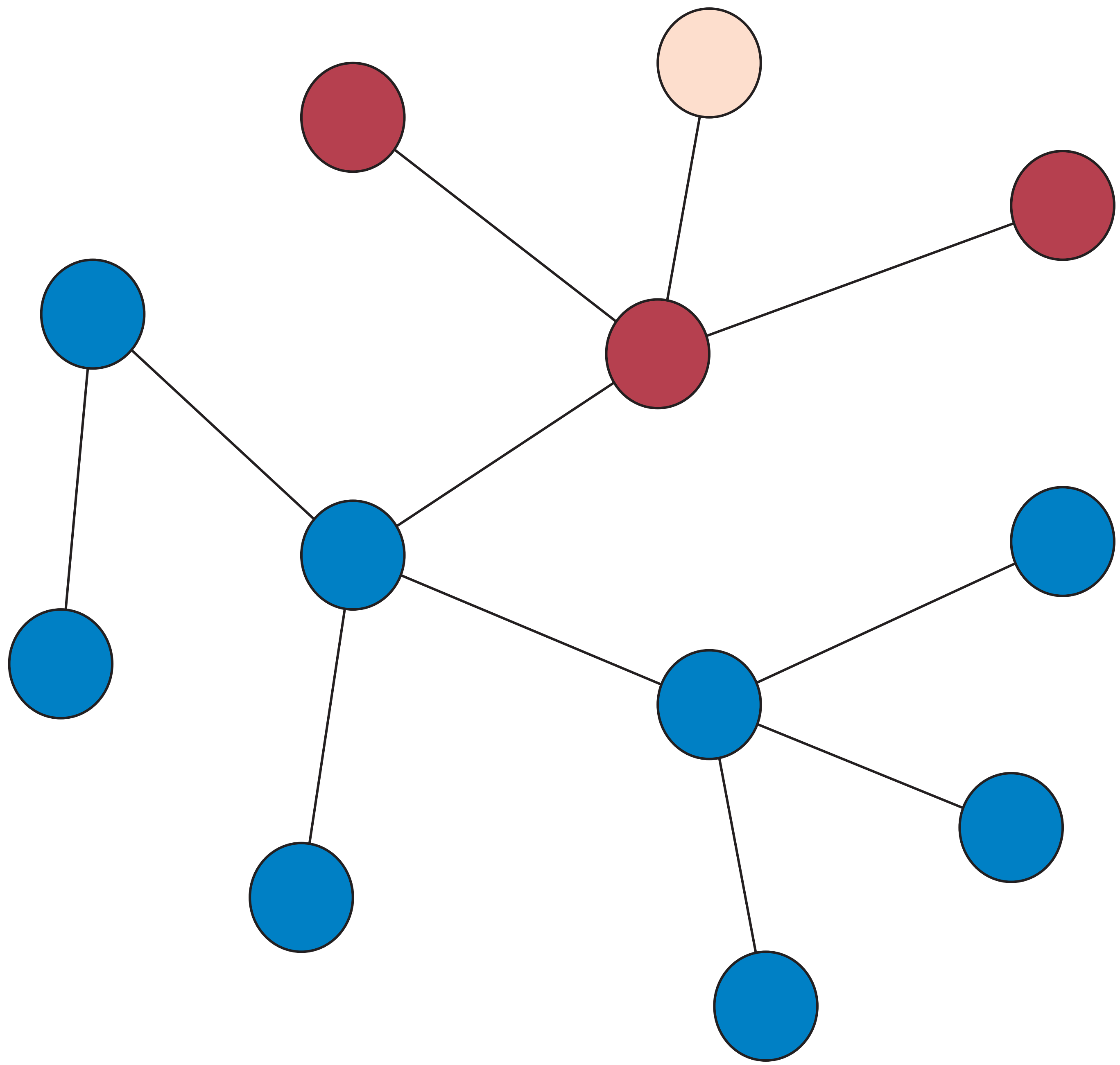
1. 

Intrinsic properties of the pathogen

2. 

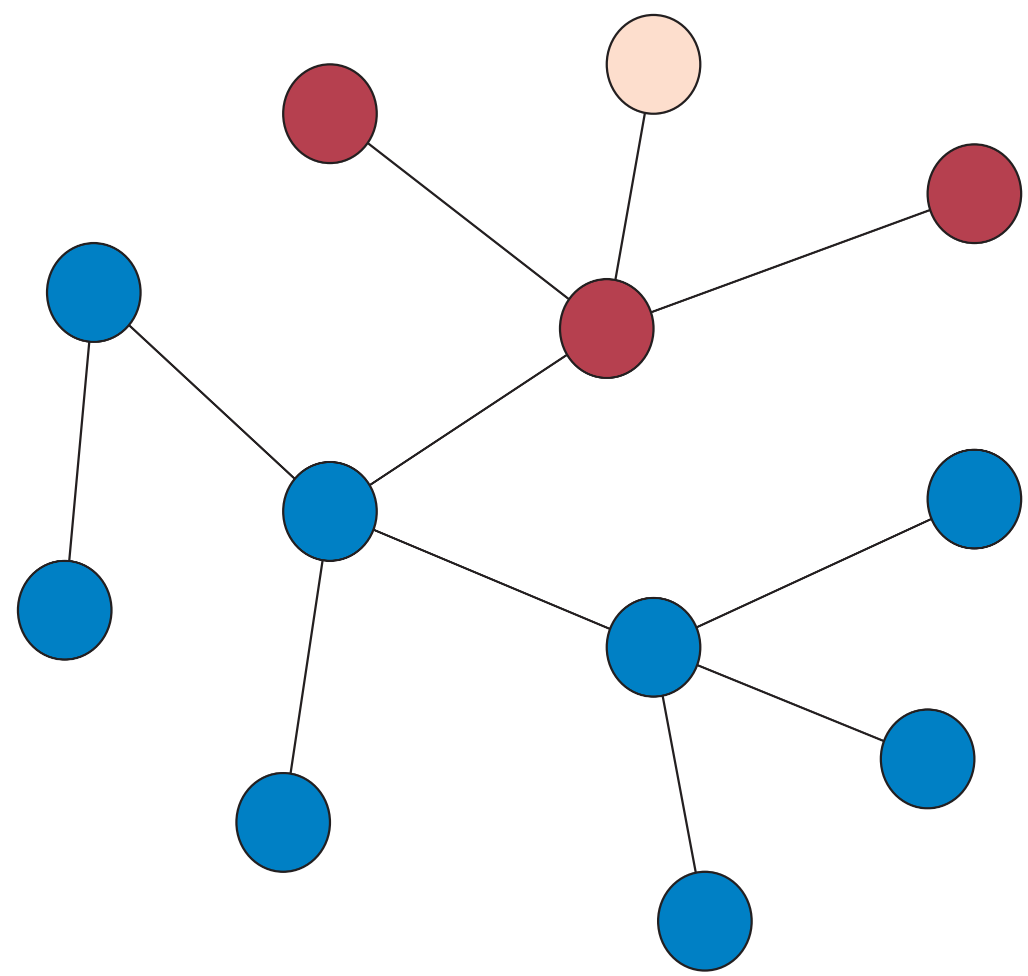
Contact patterns of the host

Network Epidemiology



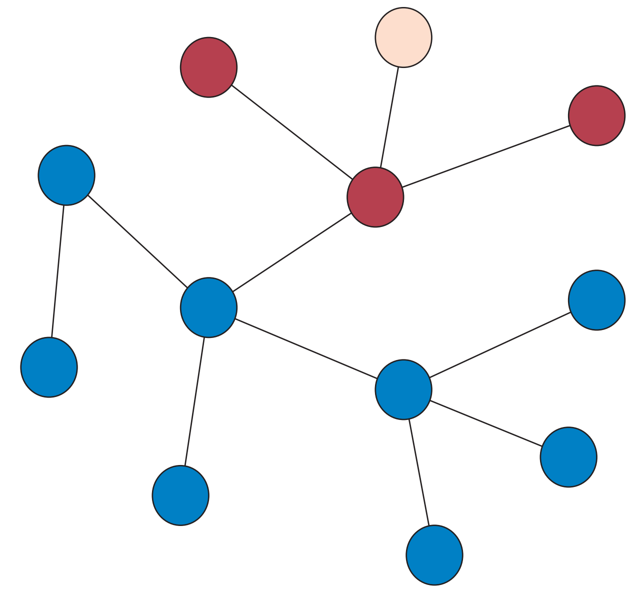
Network Epidemiology

$$R_0 = T\left(\frac{\langle K^2\rangle - \langle K\rangle}{\langle K\rangle}\right)$$



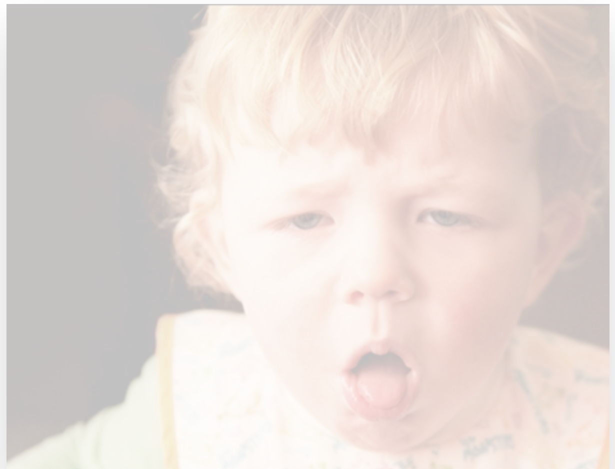
Network Epidemiology Vs. Standard Calculation

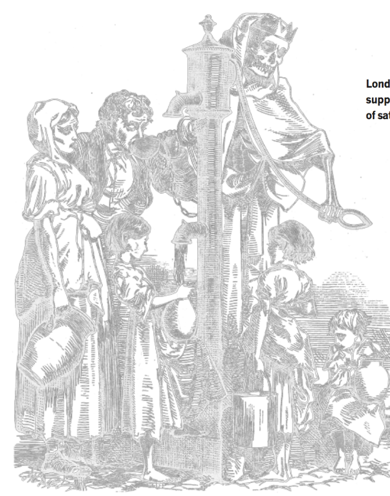
$$R_0 = T\left(\frac{\langle K^2\rangle - \langle K\rangle}{\langle K\rangle}\right)$$



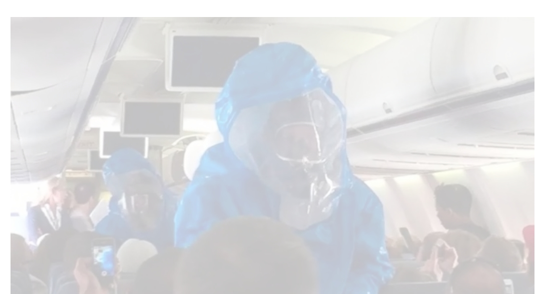
$$R_0 = \frac{\beta S}{\gamma}$$

Model complexity

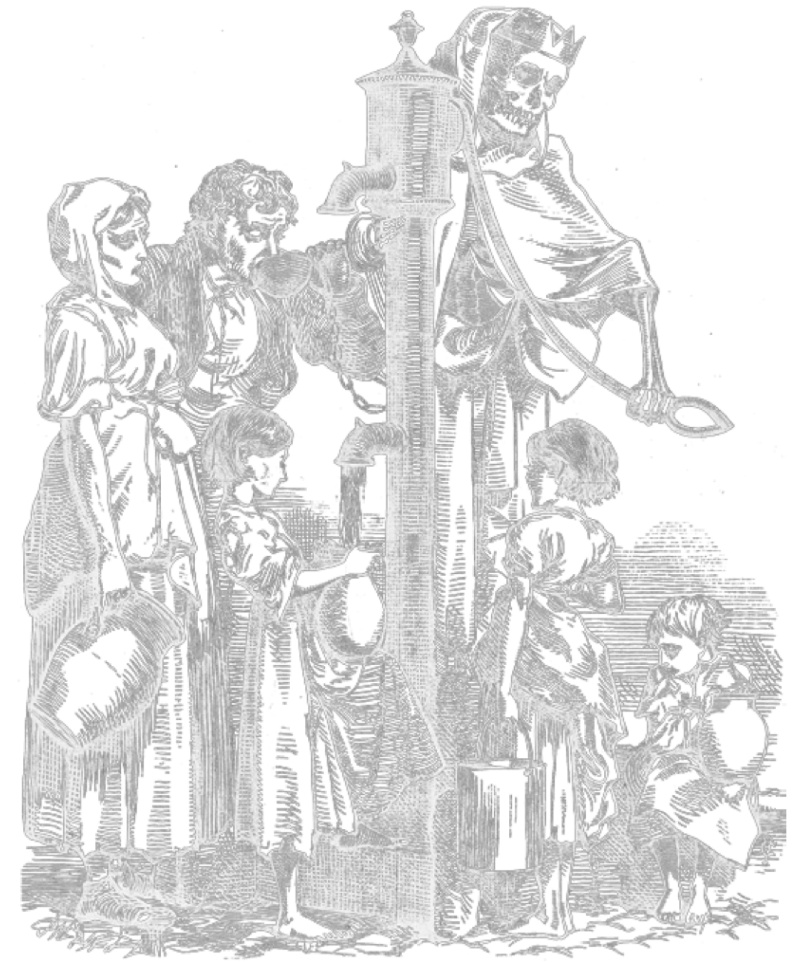
-  Modeling infectious diseases

-   Inequality & disease

-

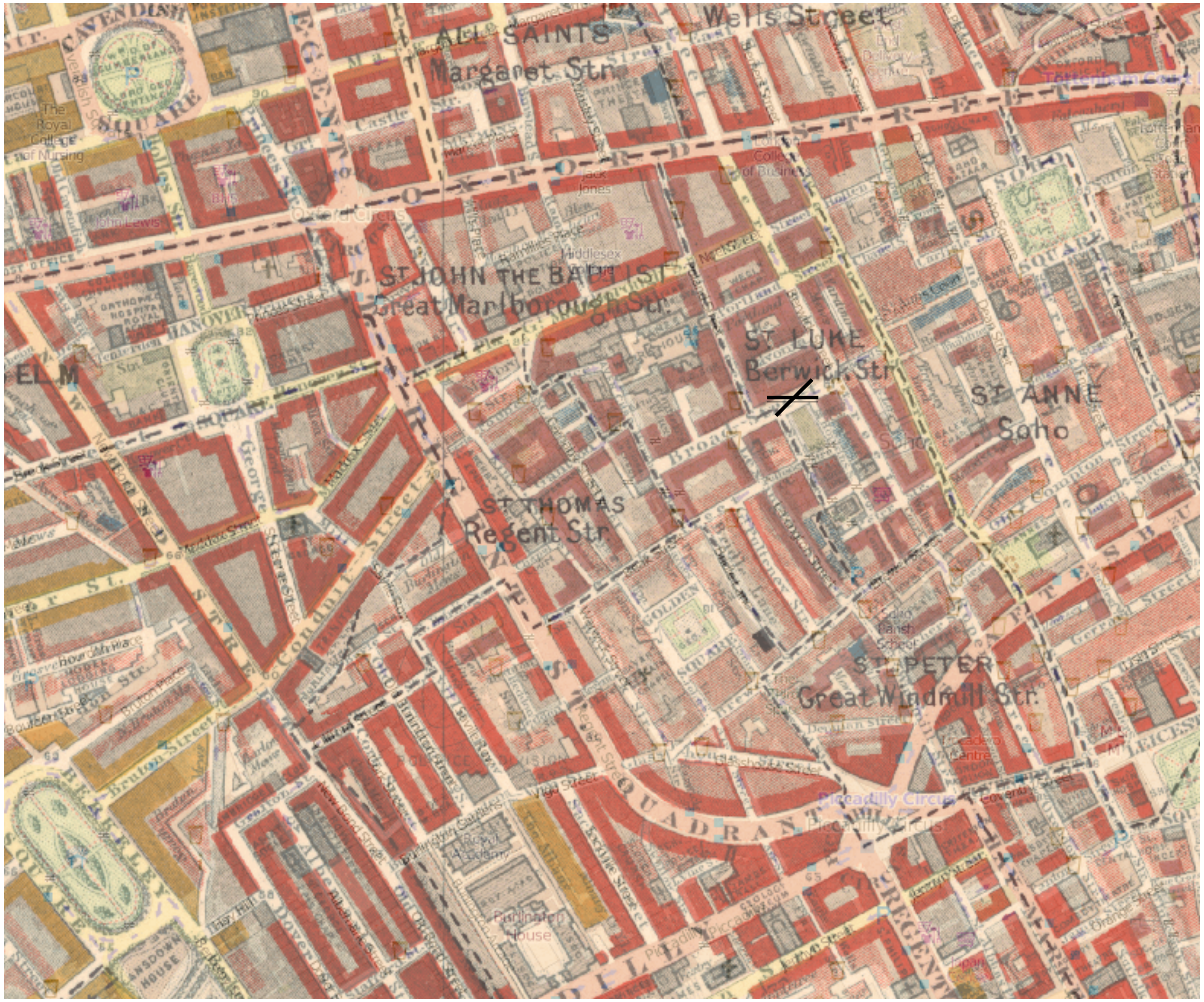
 Social clustering & Ebola

The Cholera Outbreak of 1854



Snow 1855

Poverty and the Cholera Outbreak of 1854



Booth 1898

Modern Inequality and health

Life Expectancy

↑

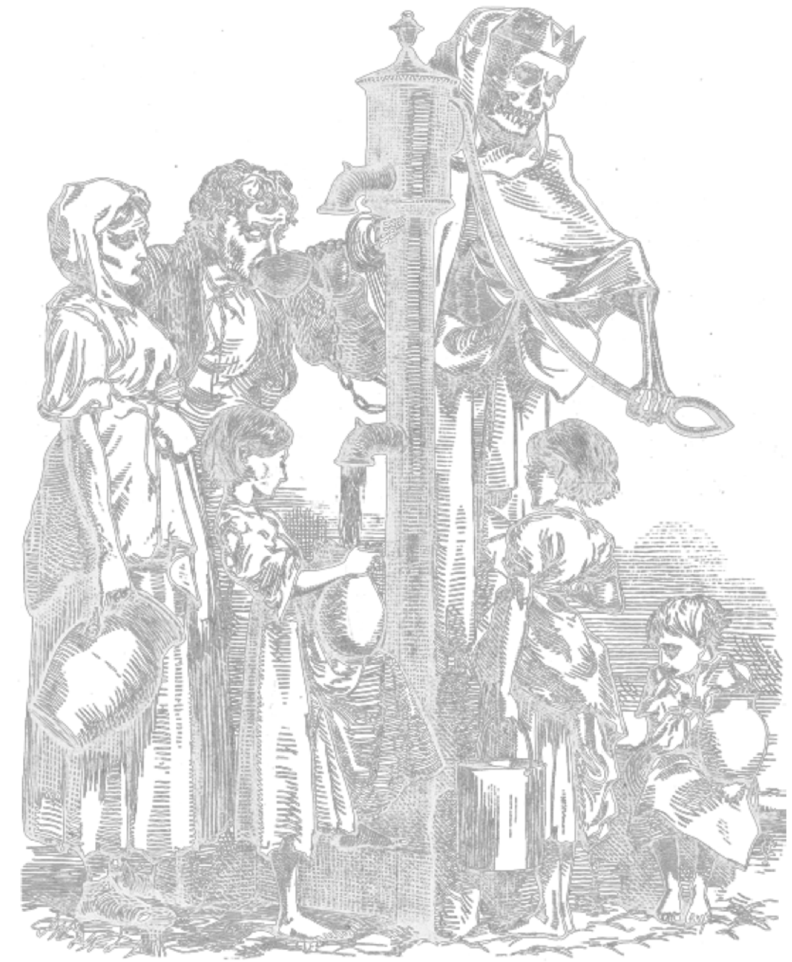
Income Inequality

↓

Primary Care

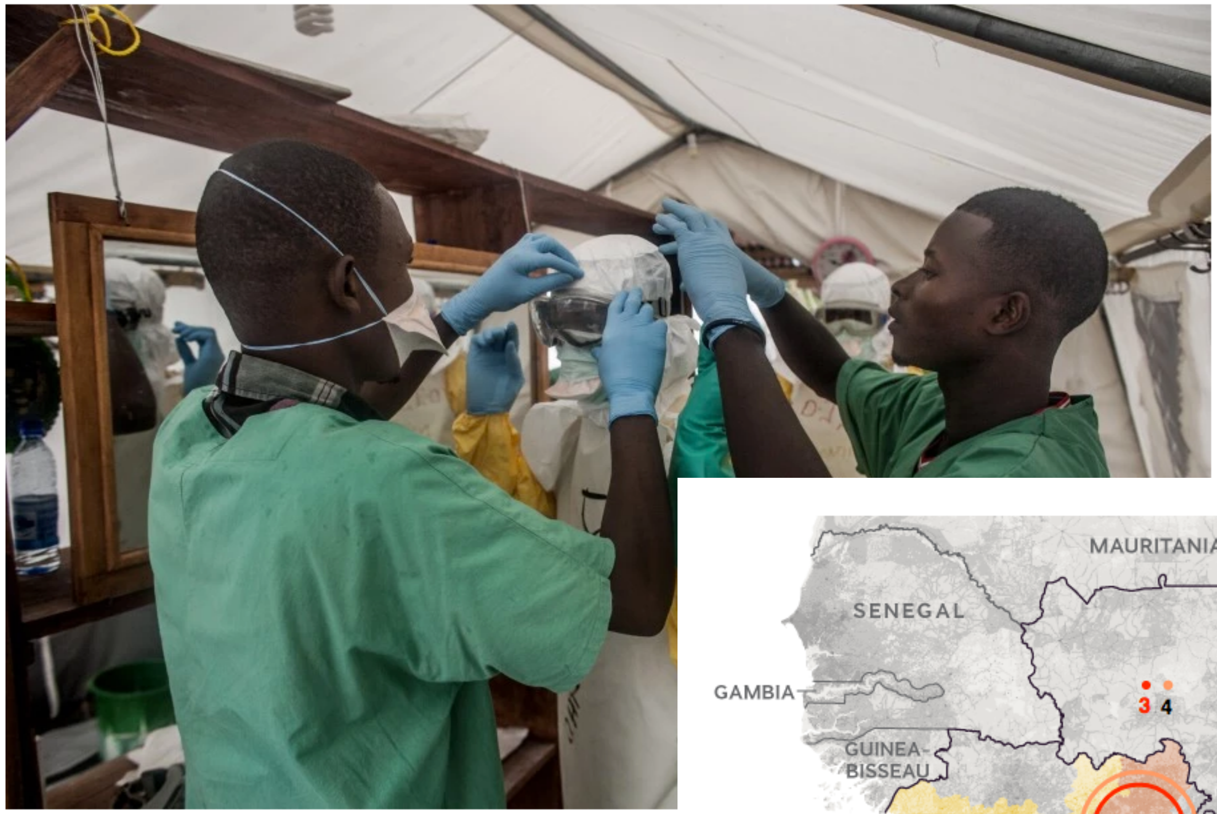
↓

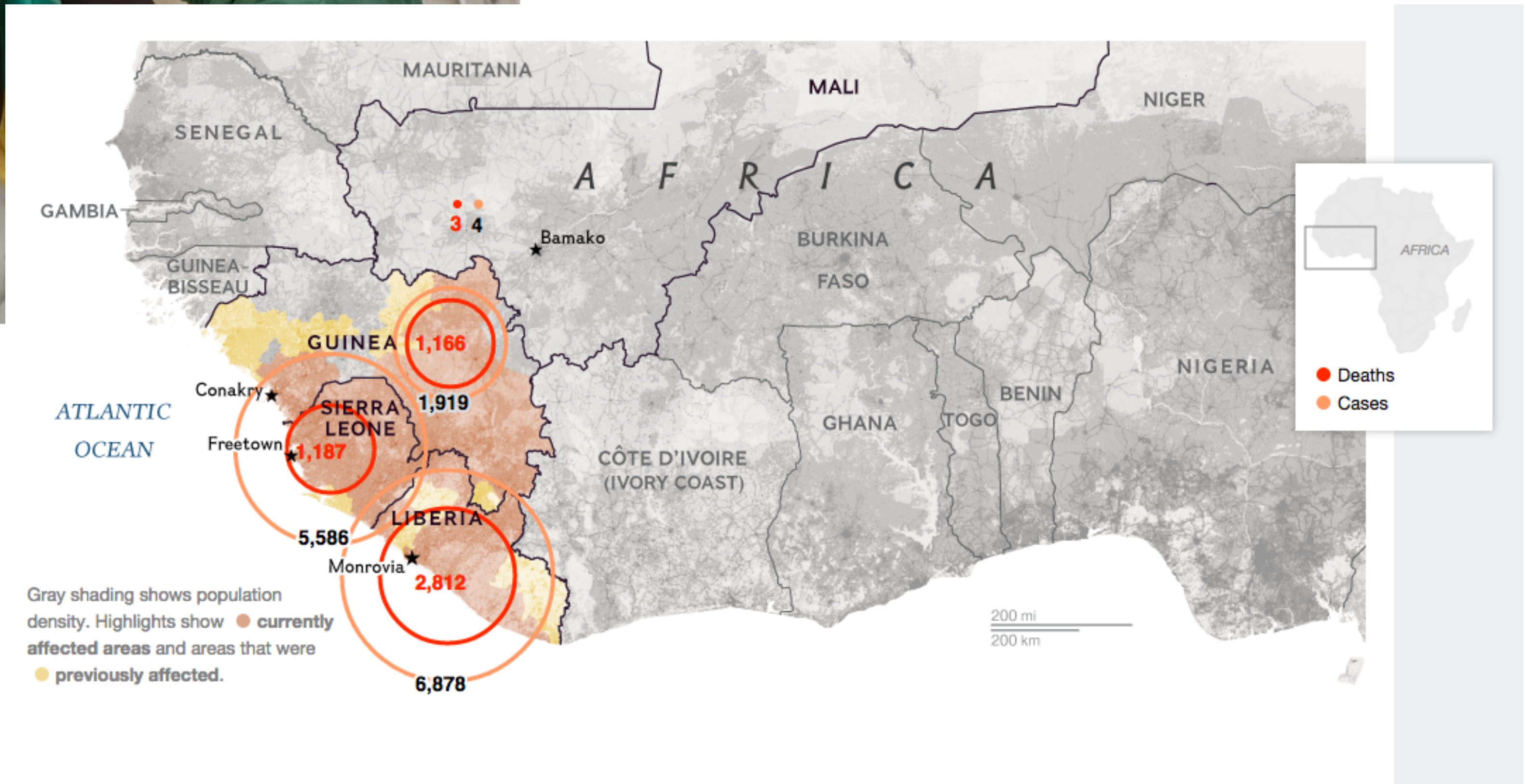
Life Expectancy



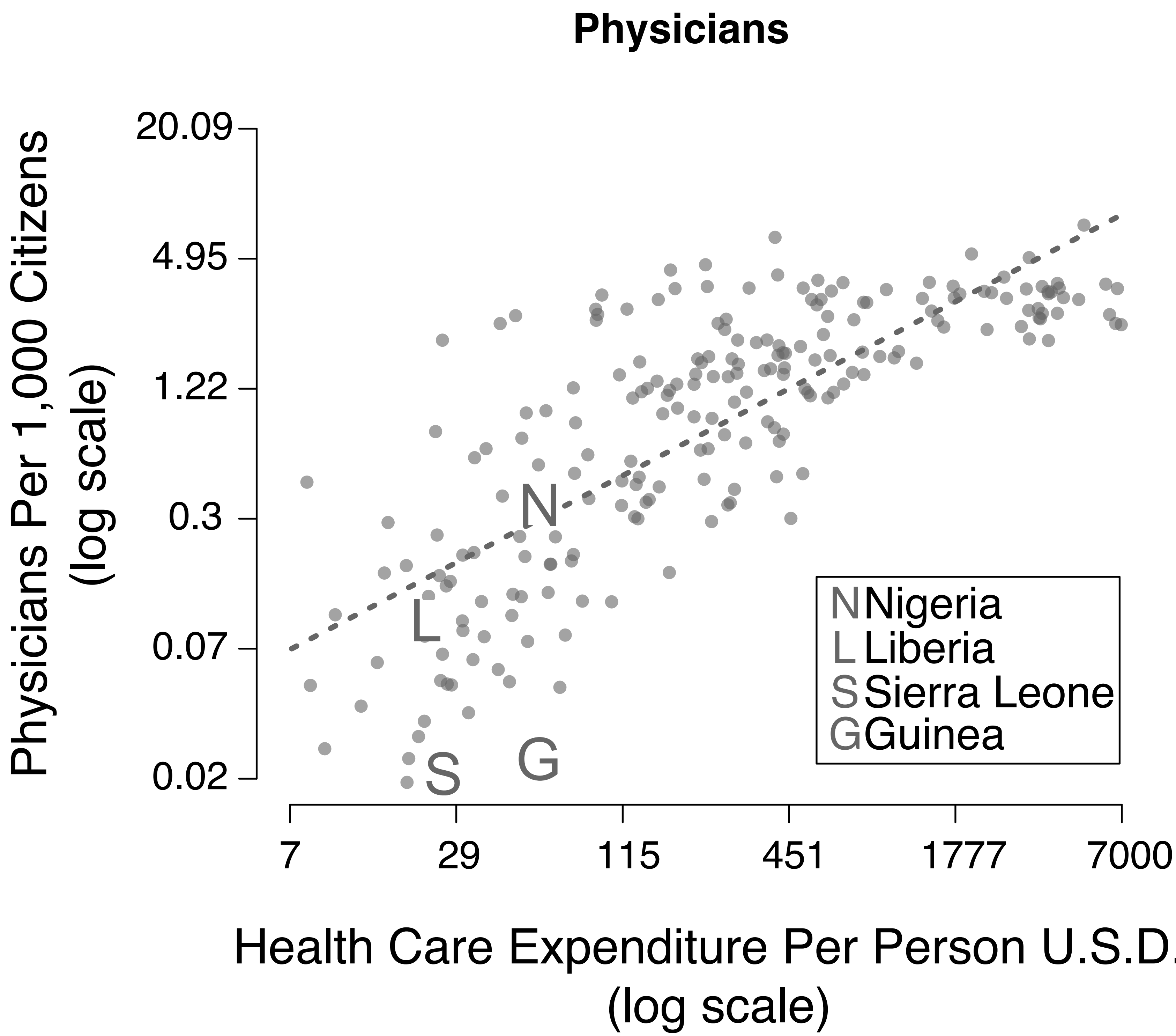
modified from Shi et al. 1999

The current Ebola outbreak



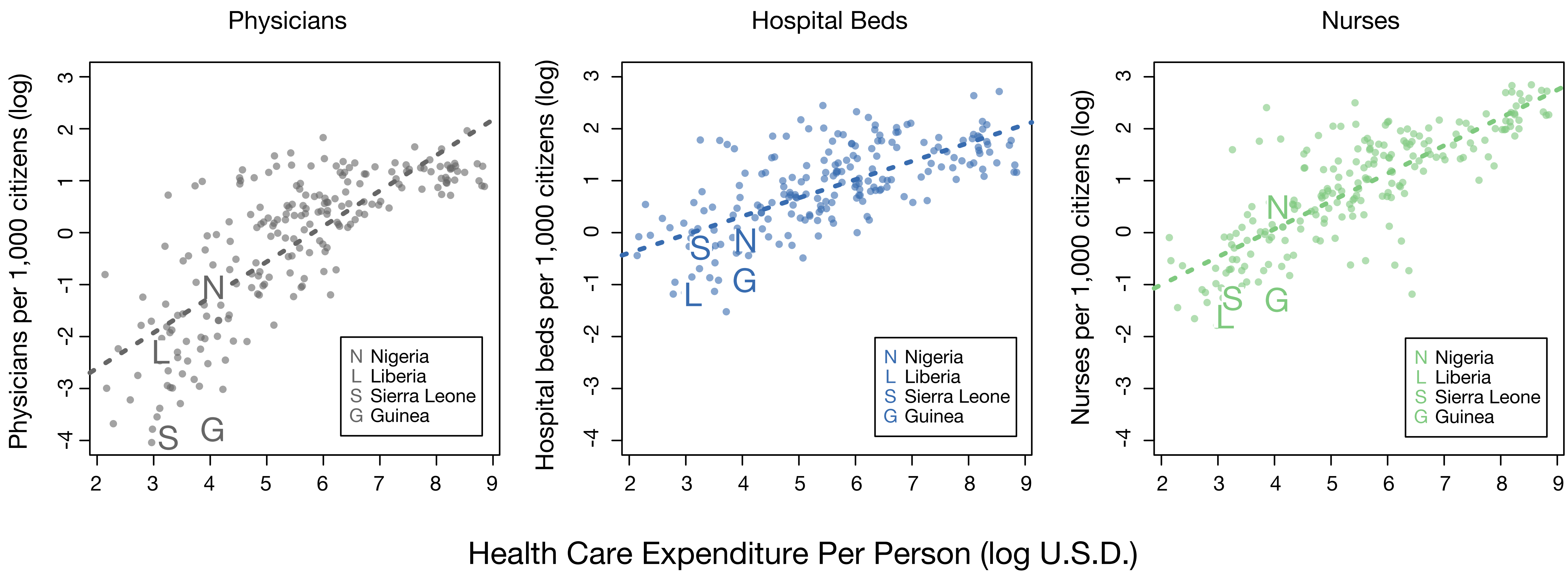


Poverty and the current Ebola virus outbreak

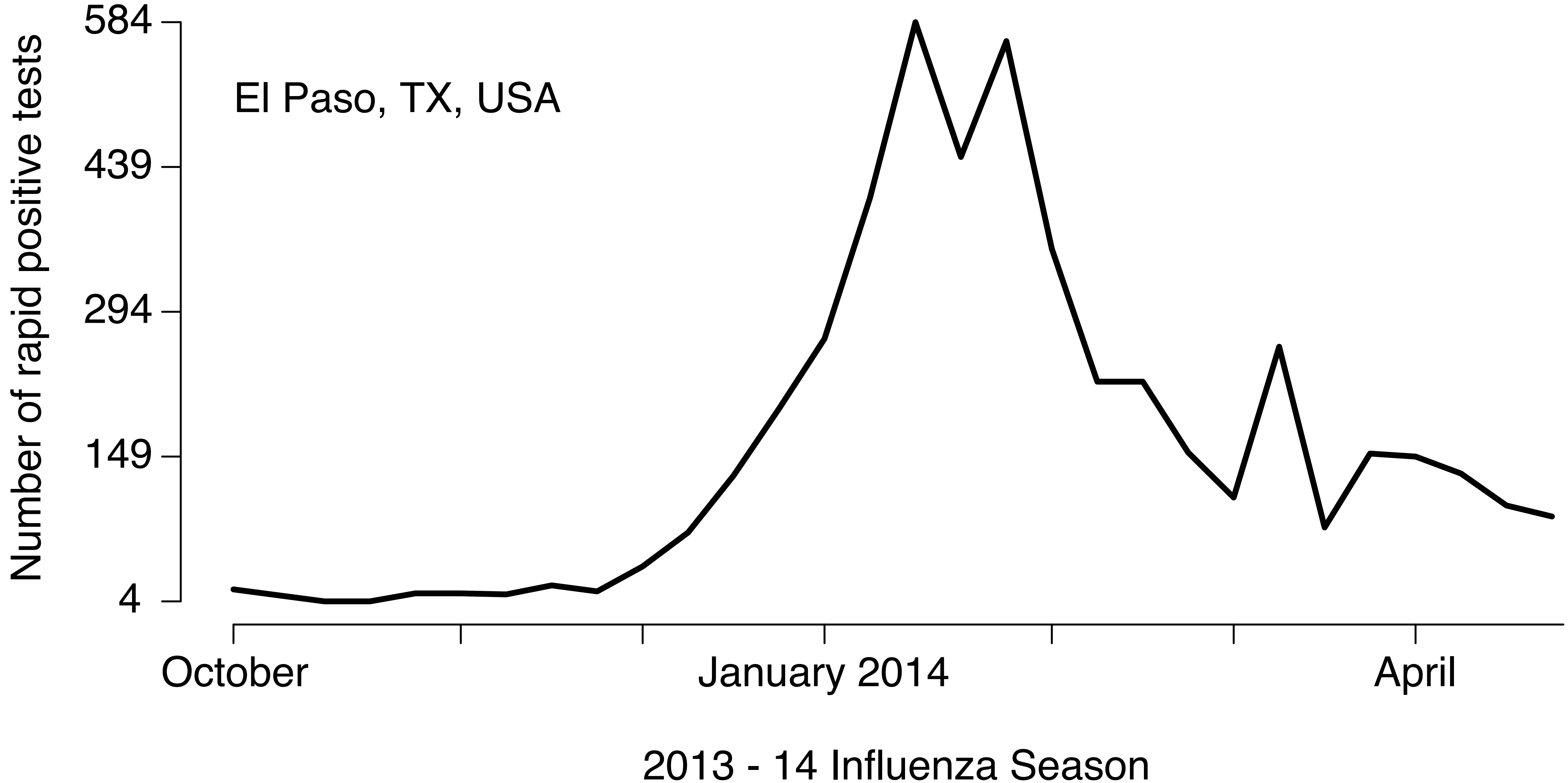


Scarpino 2015

Poverty and the current Ebola outbreak

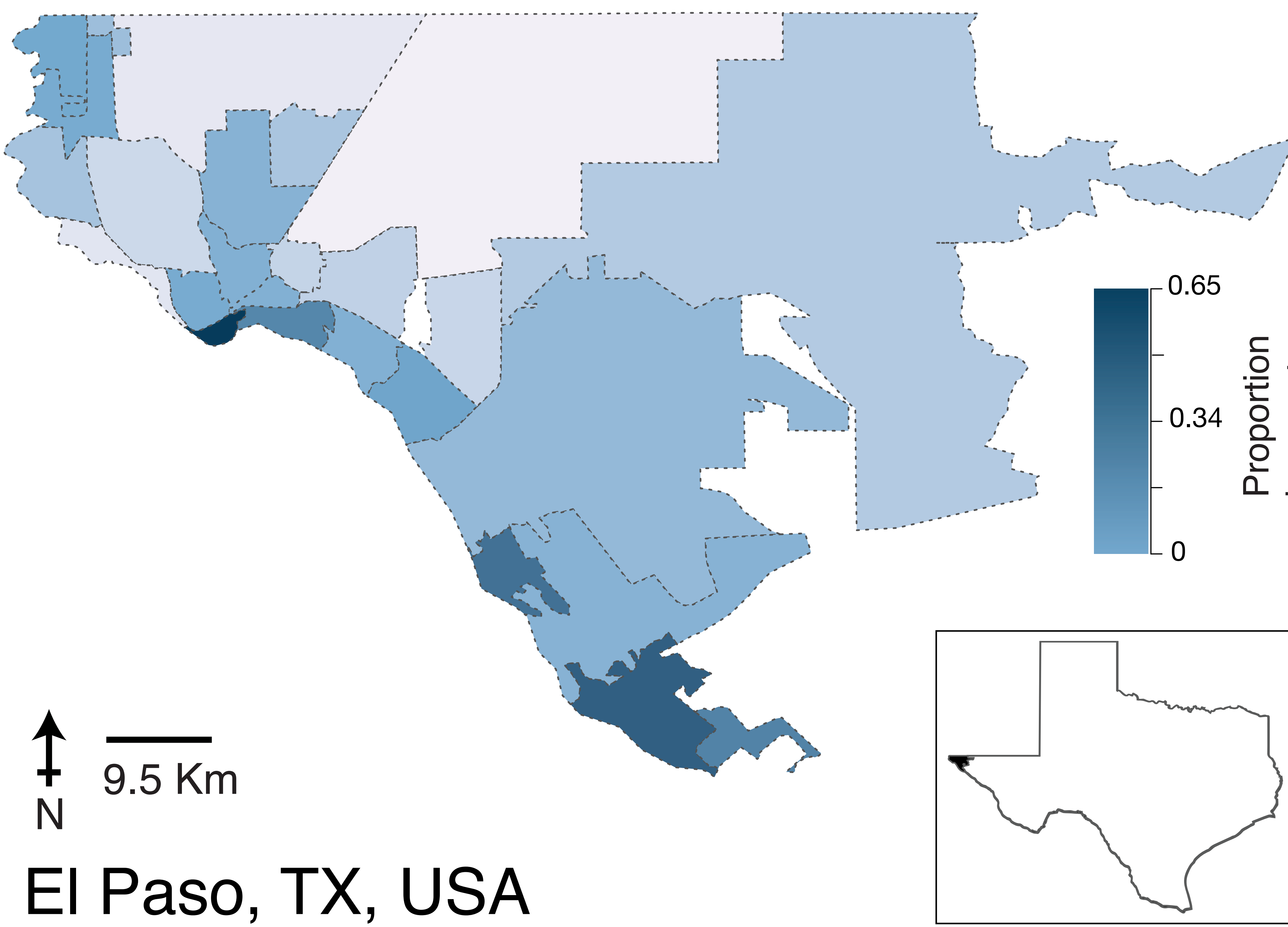


Influenza in El Paso, TX



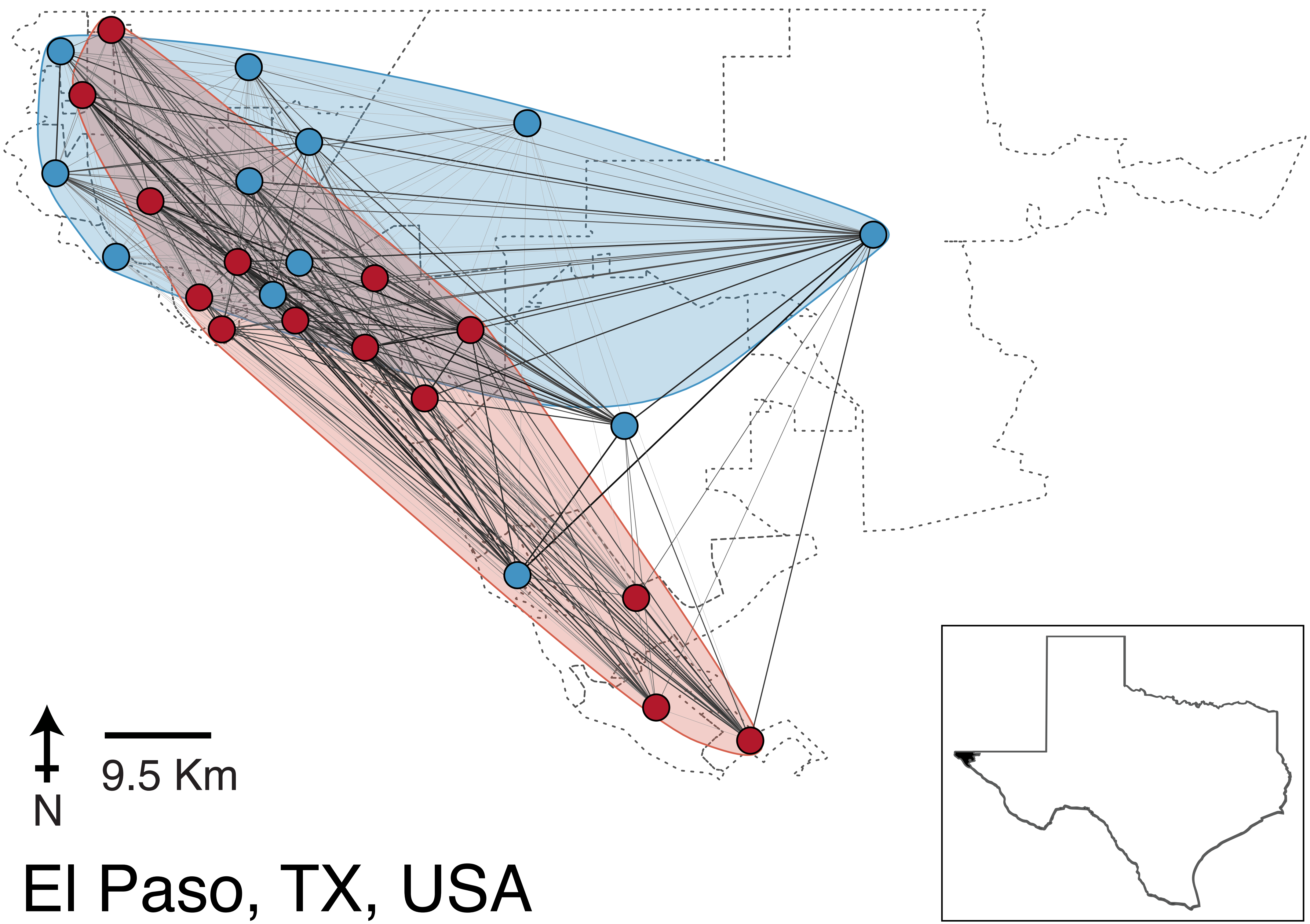

El Paso, TX
2014 - 15 Influenza Season
Las Cruces
White Sands
Mesilla
10
Anthony
Queen
Whites City
Cornudas
Ciudad Ju
10
Allamoore
Baño
El Uno
El Centro
Tierras Prietas
Villa Ahumada
Los Lamentos
Carrizal
San Gabriel
Valentine
Ryan

Poverty in El Paso

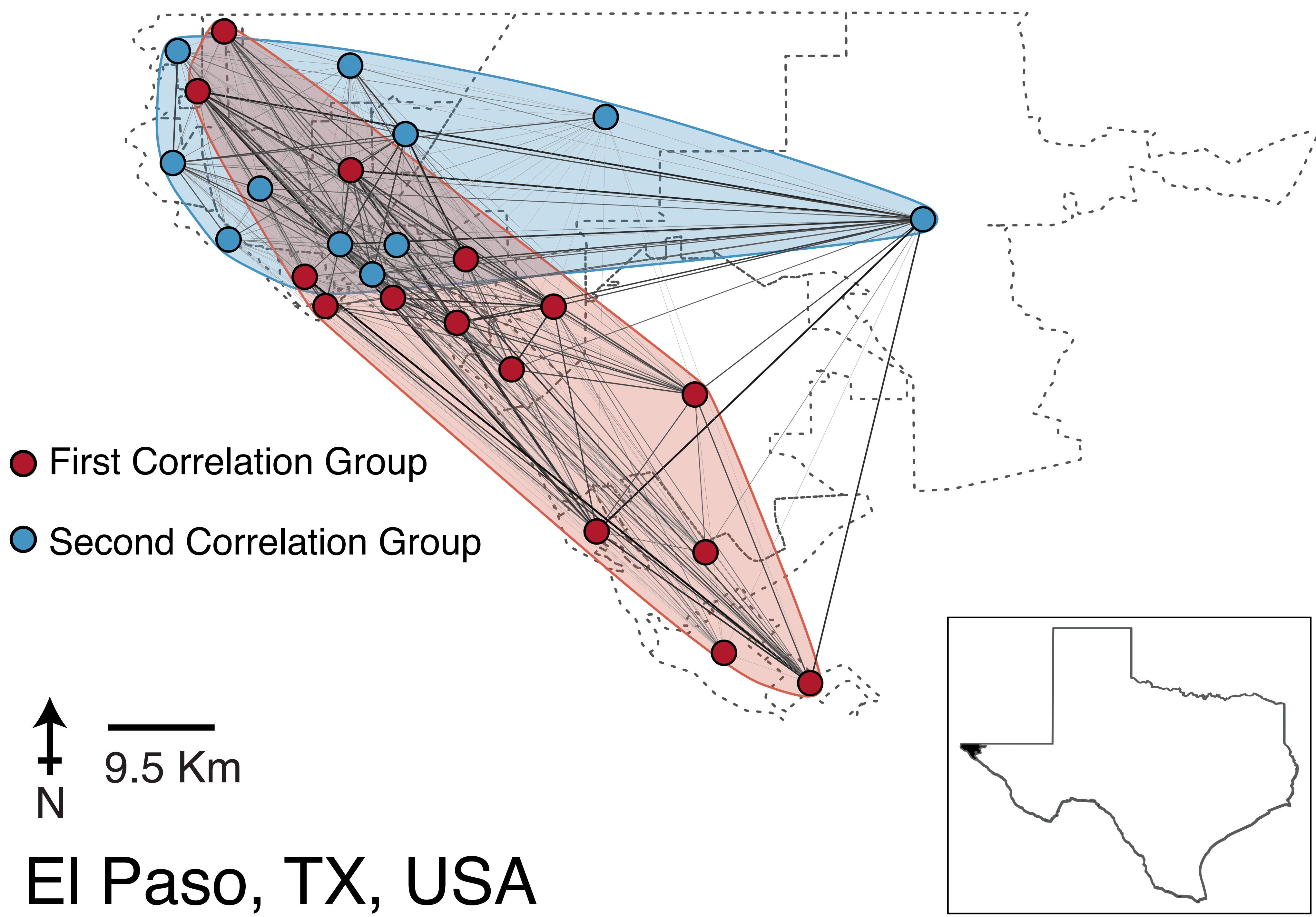


El Paso, TX, USA

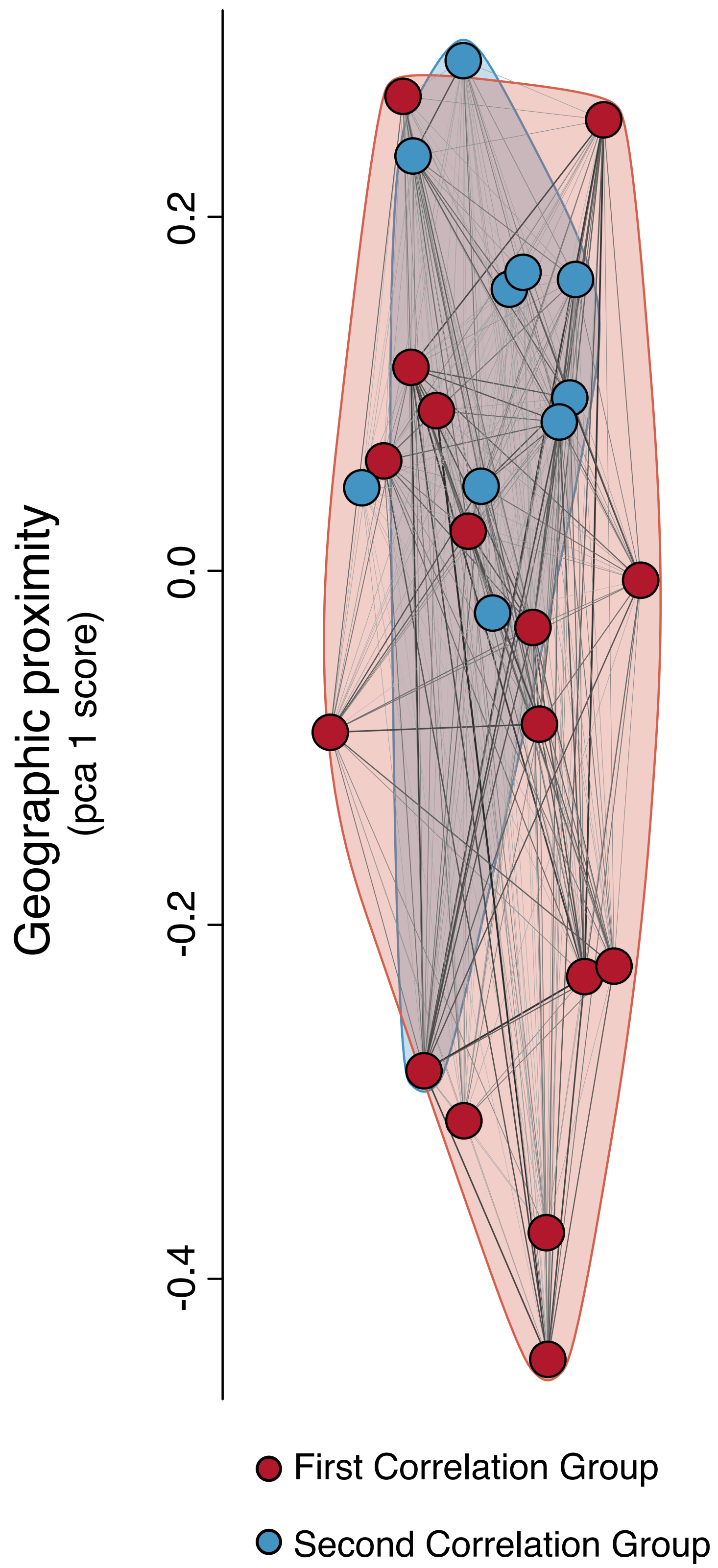
Poverty and flu in El Paso



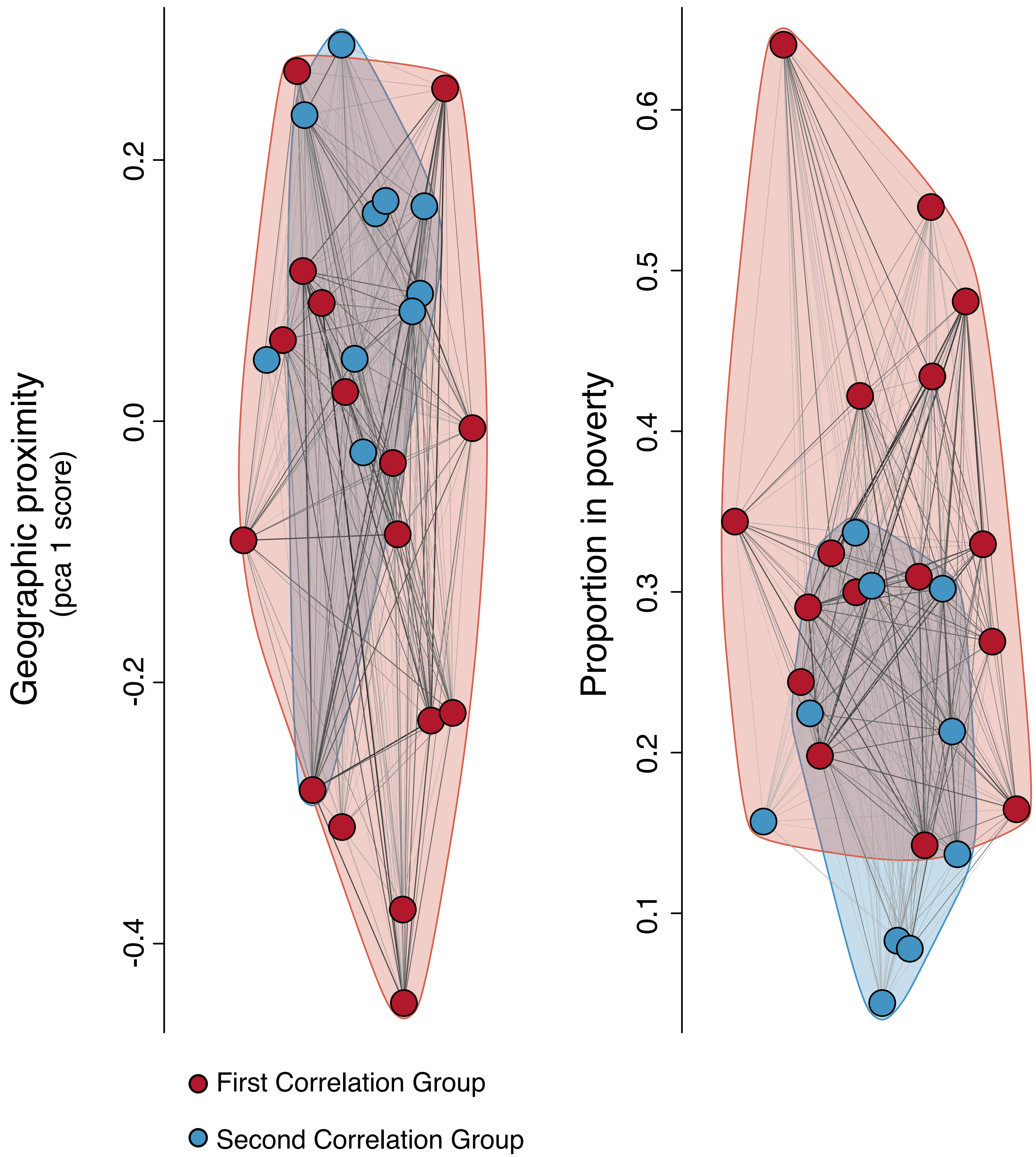
At least two strongly correlated groups



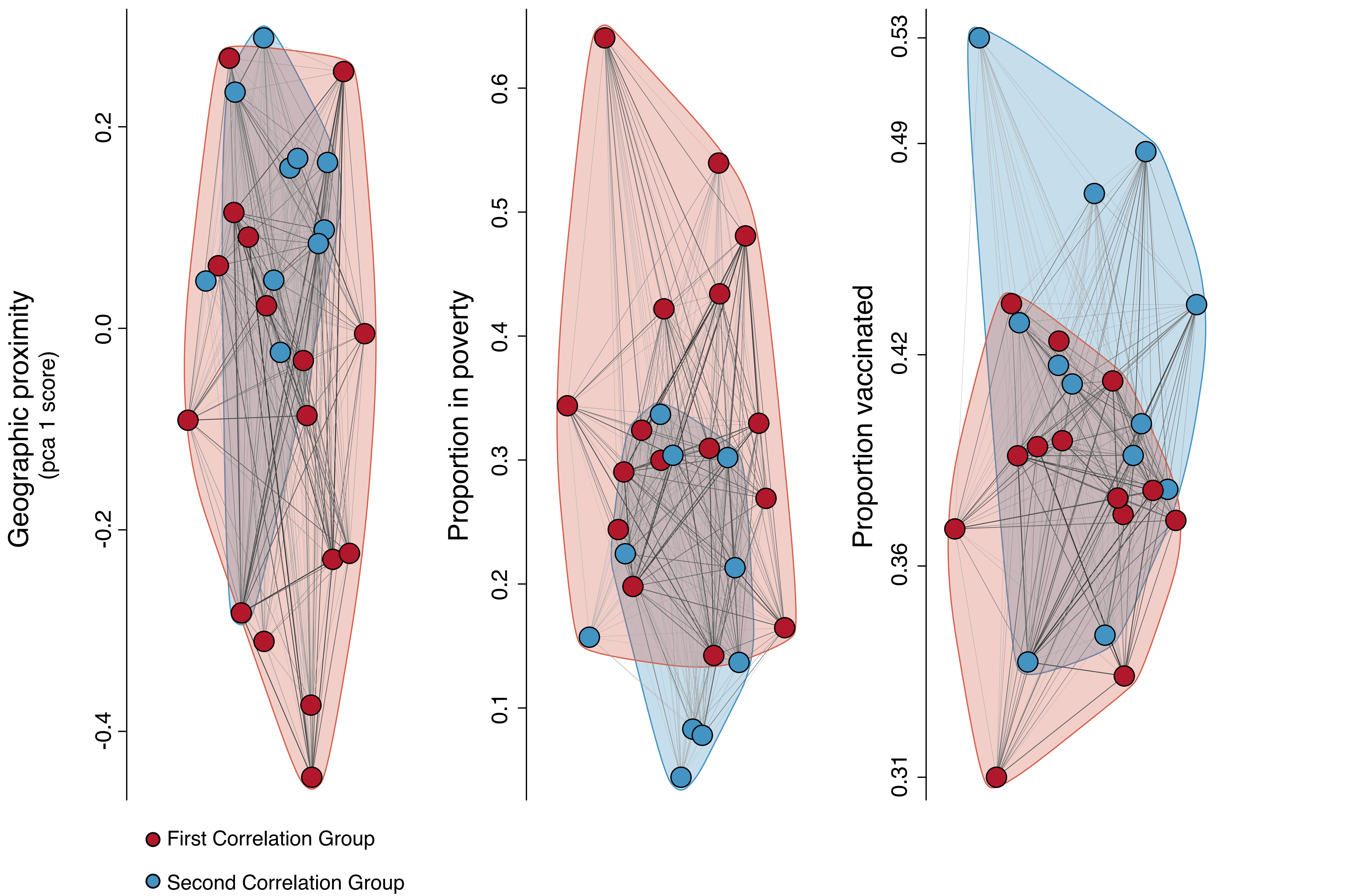
It’s not geographic



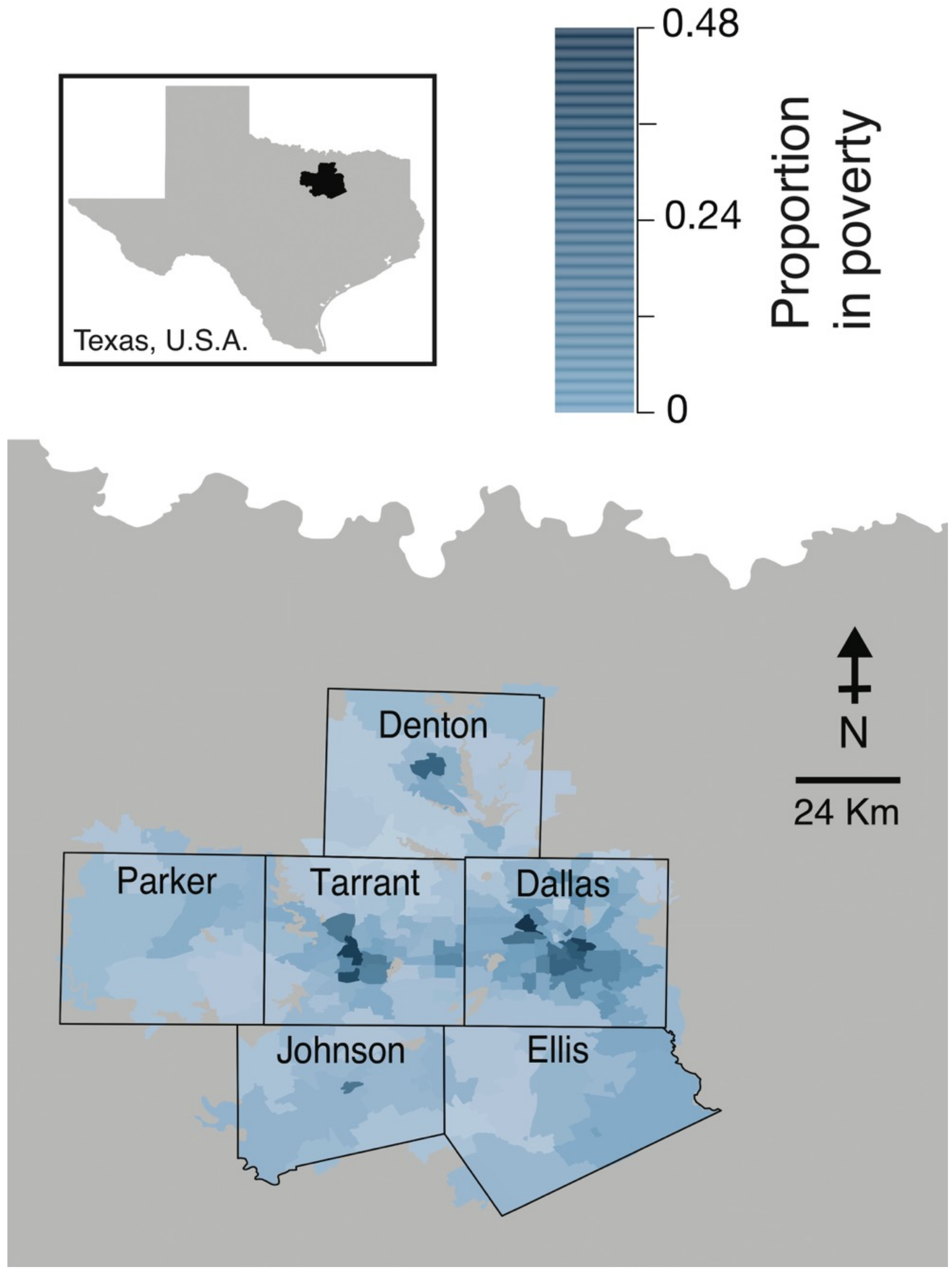
It’s poverty and …



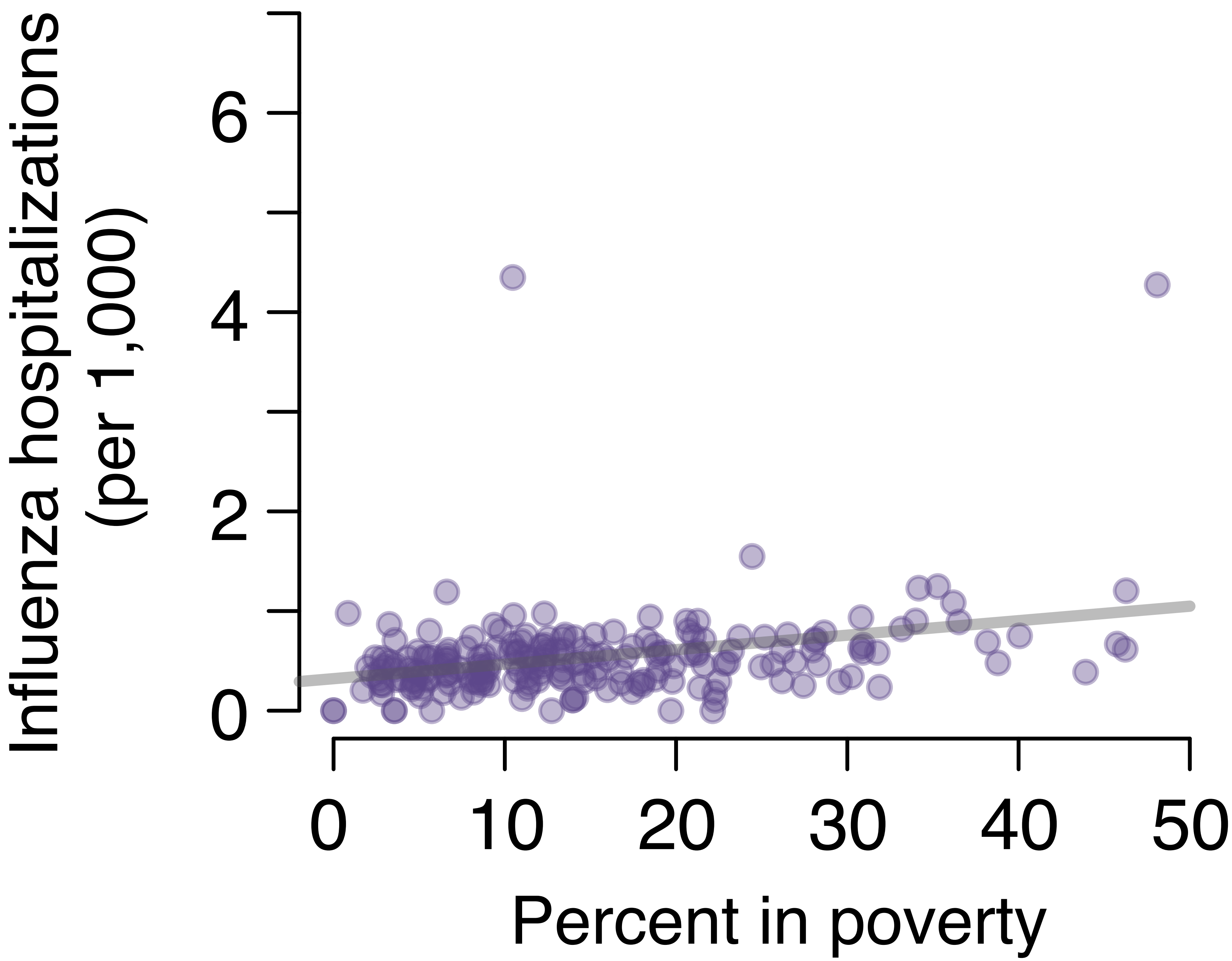
It’s poverty and vaccination



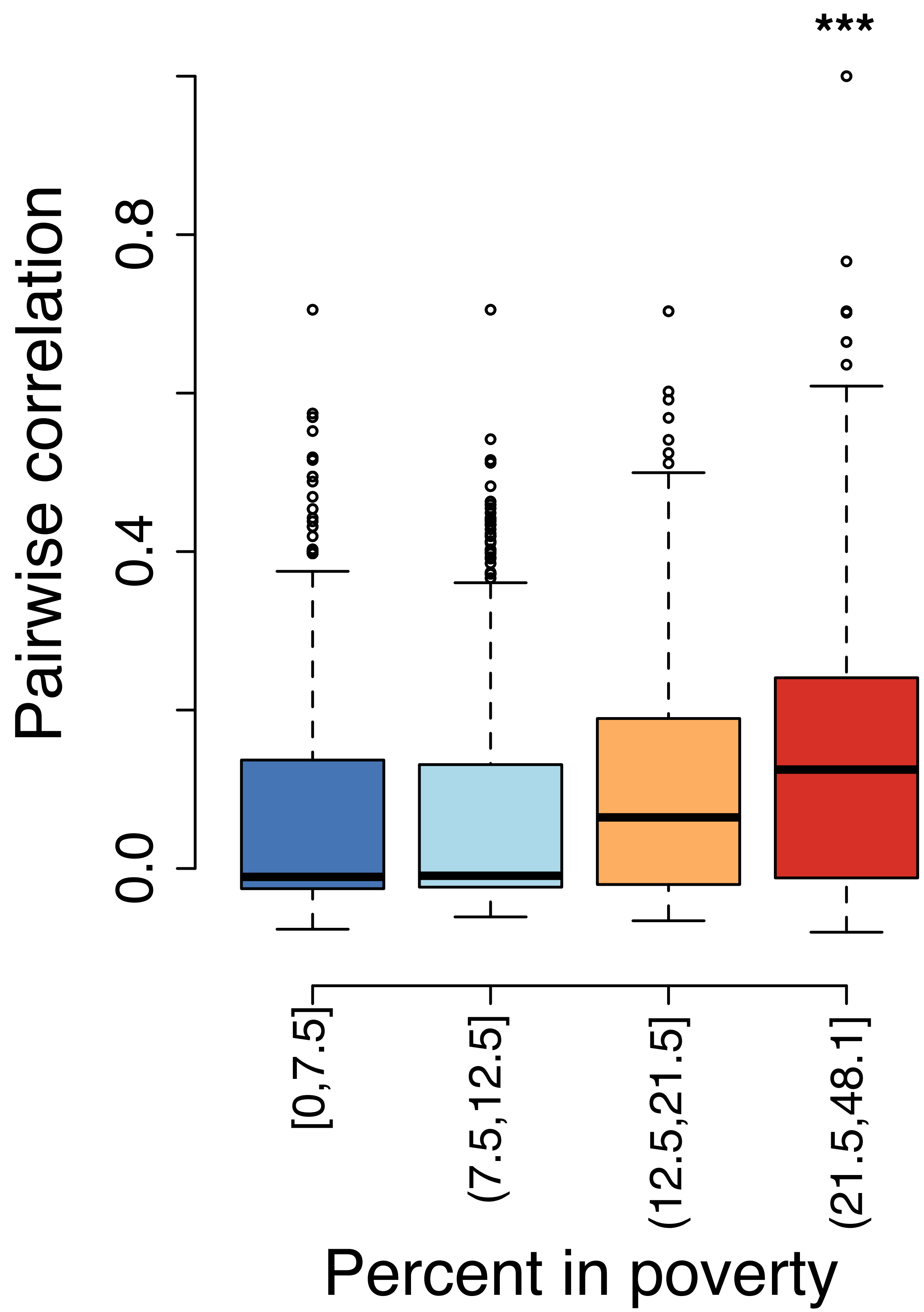
Poverty and influenza in Dallas, TX



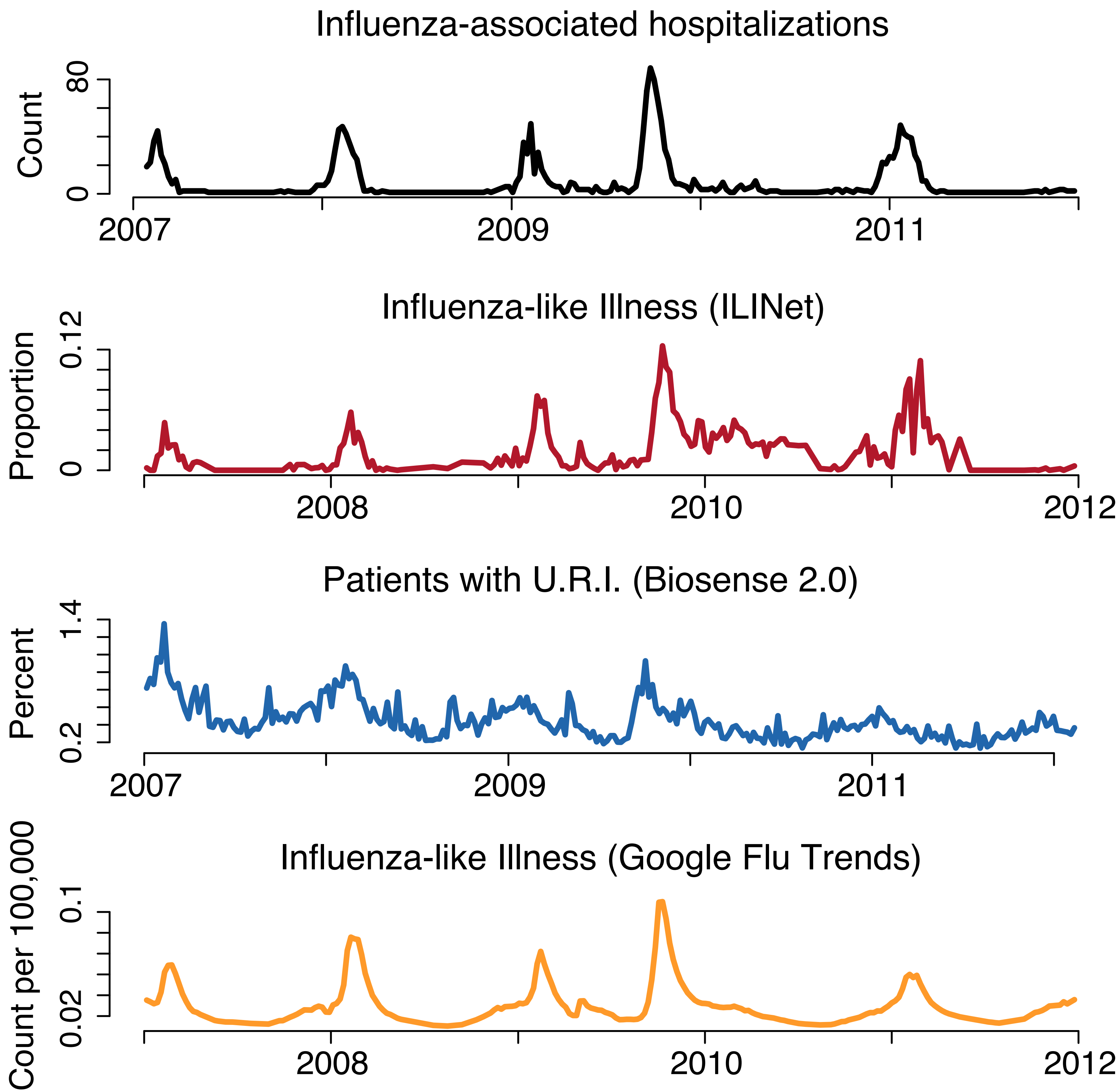
Higher hospitalization rates in poorer zip codes



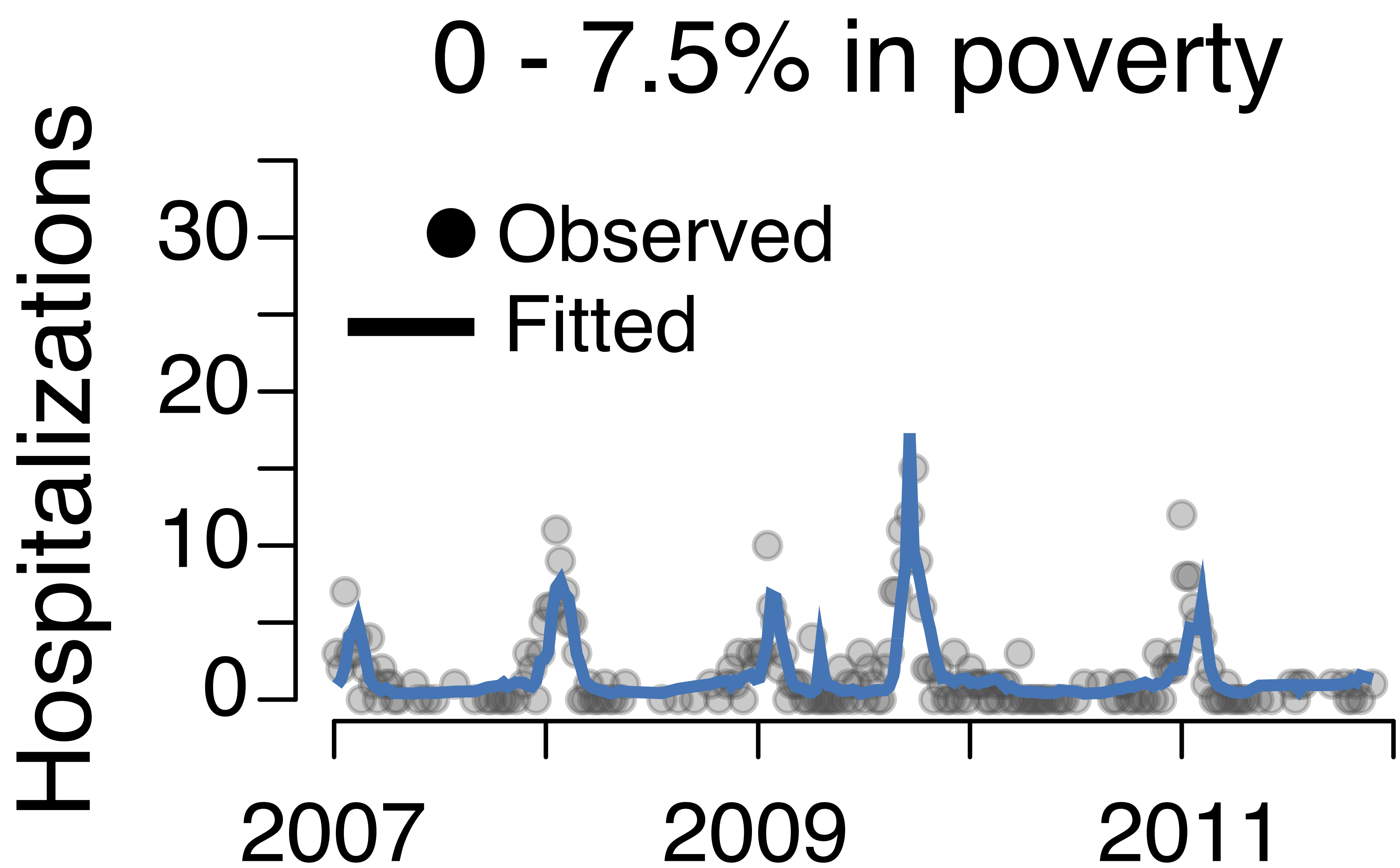
Poorer zip codes are in sync



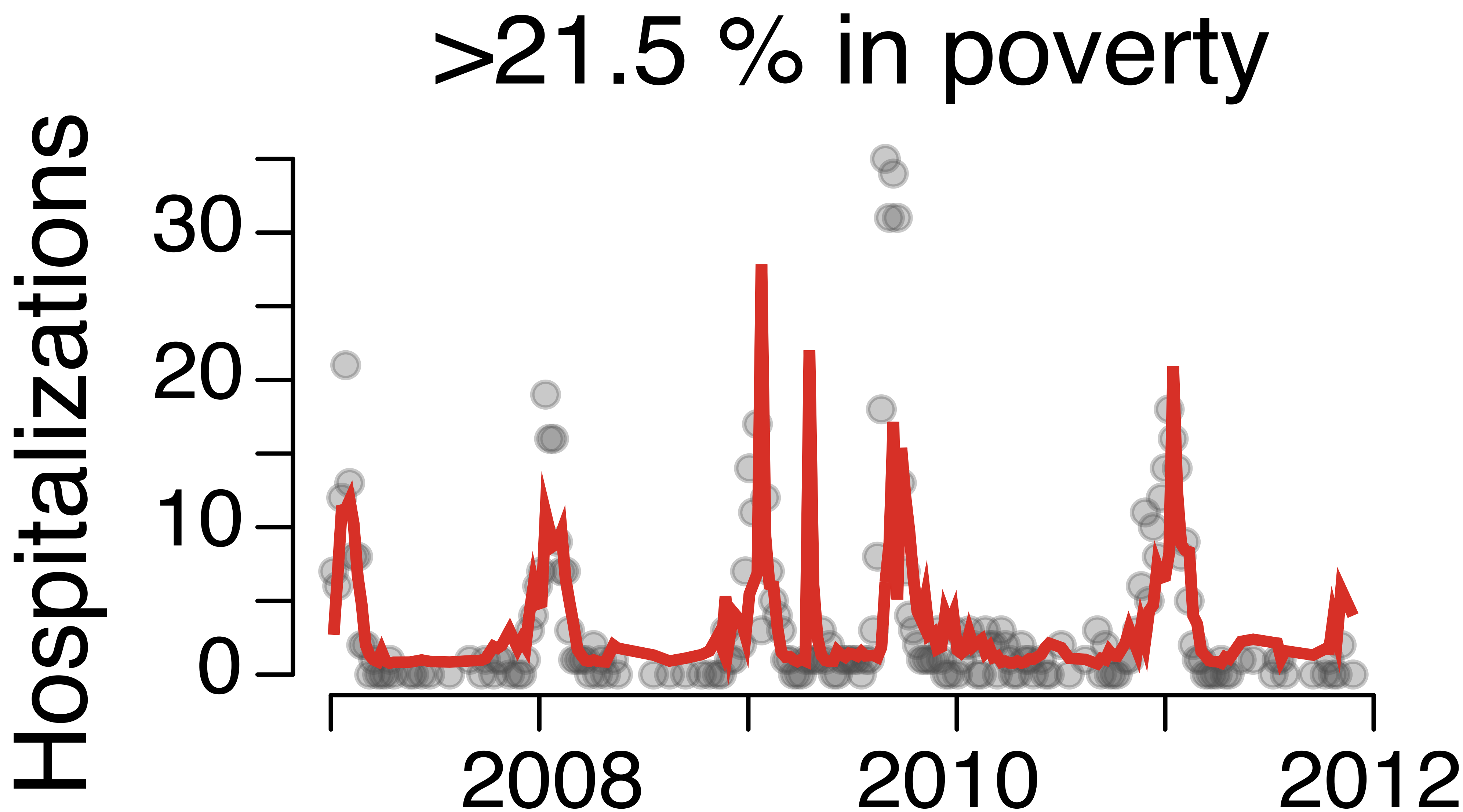
Predicting hospitalizations

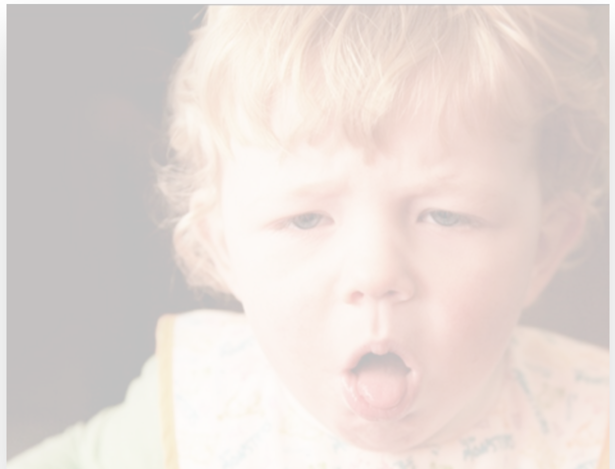


Predicting hospitalizations in the richest areas

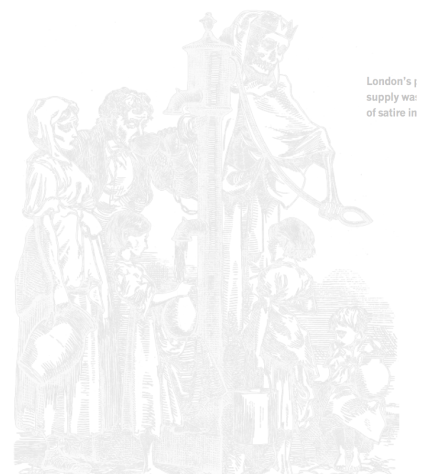


Predicting hospitalizations in the poorest areas

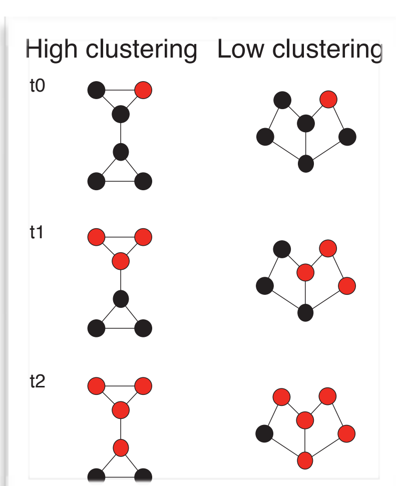


- 

  Modeling infectious diseases

- 
  

  Inequality & disease

- 

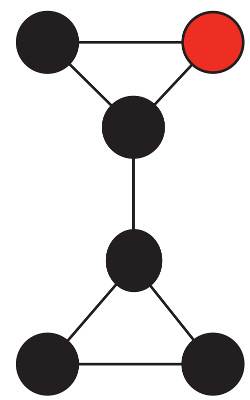
  

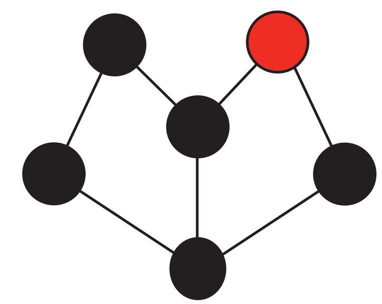
  Social clustering & Ebola

Clustering and disease transmission

High clustering | Low clustering

t0



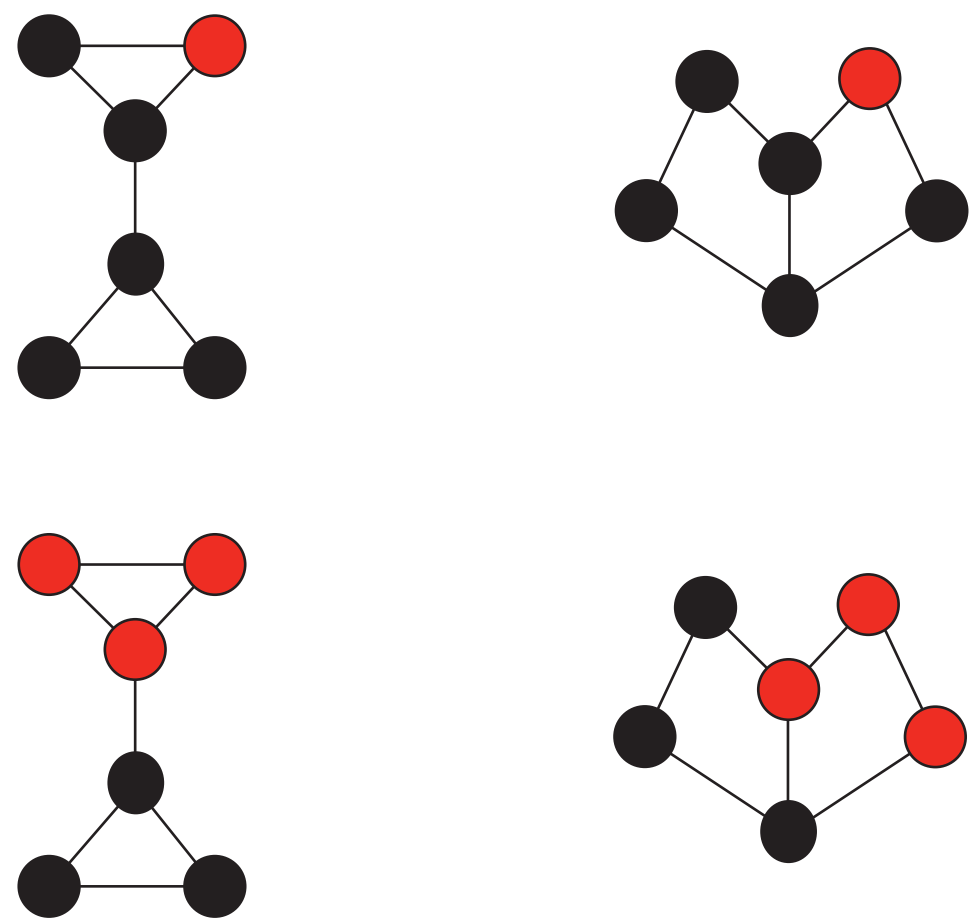


Clustering and disease transmission

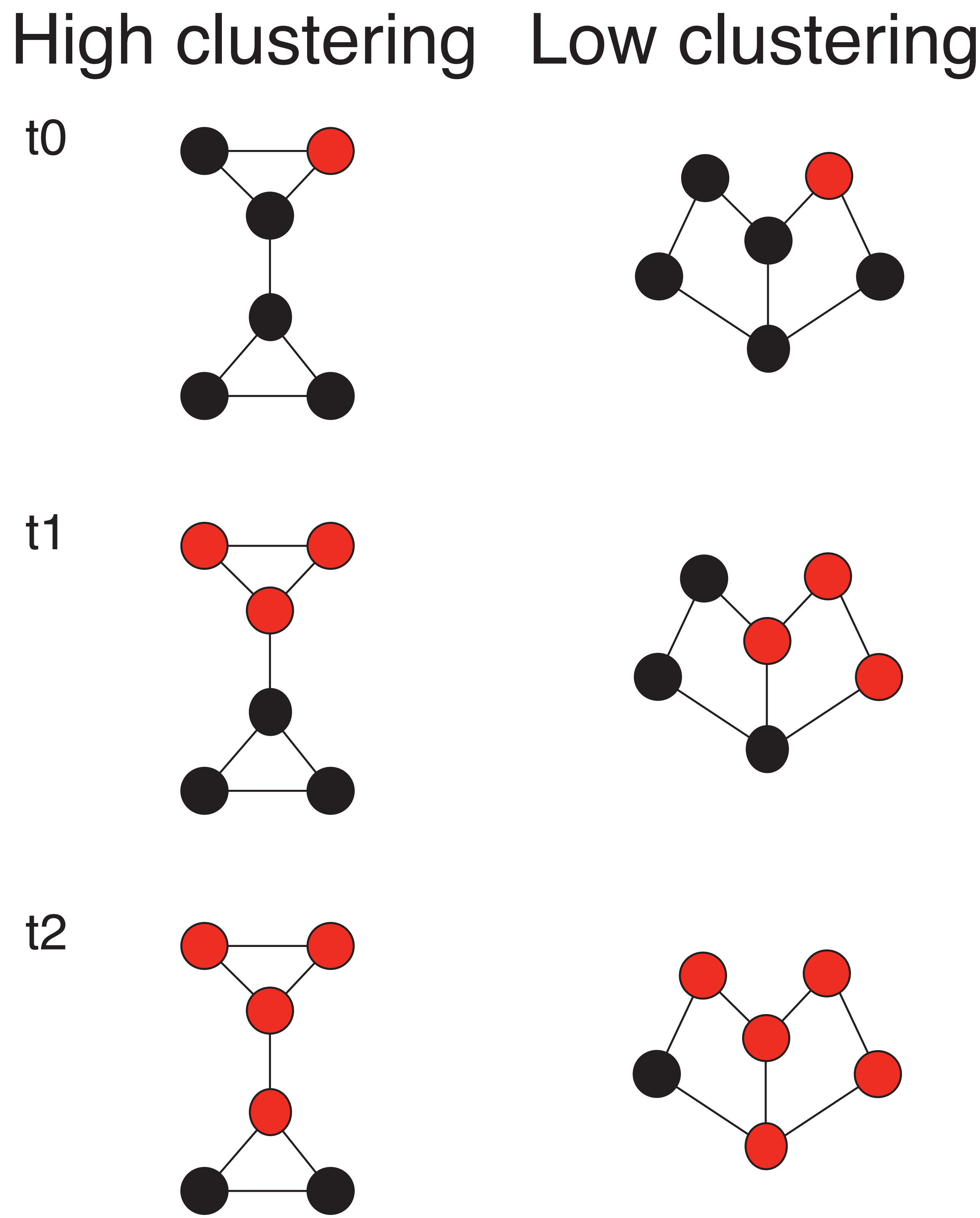
High clustering Low clustering

t0

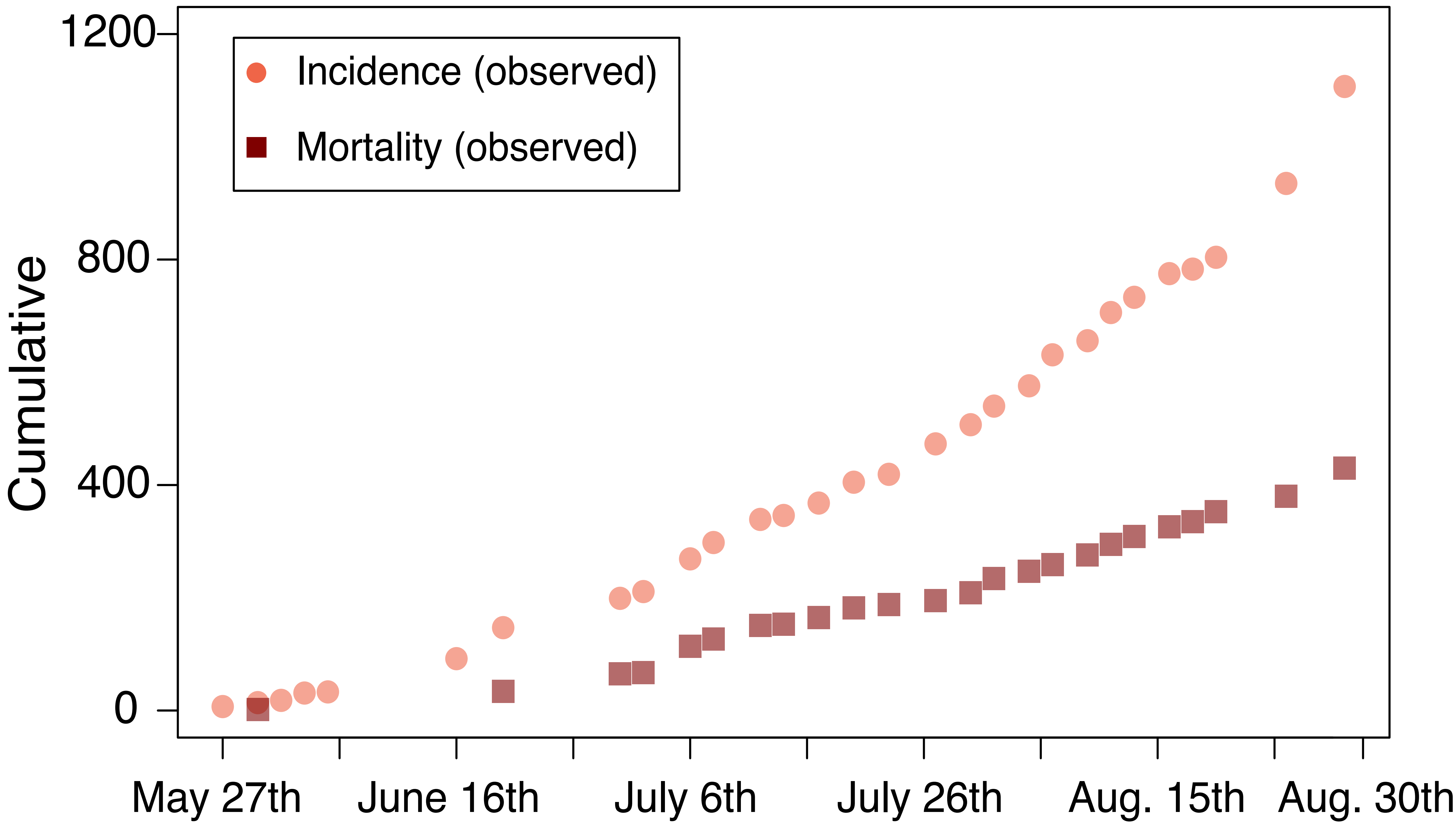
t1



Clustering and disease transmission

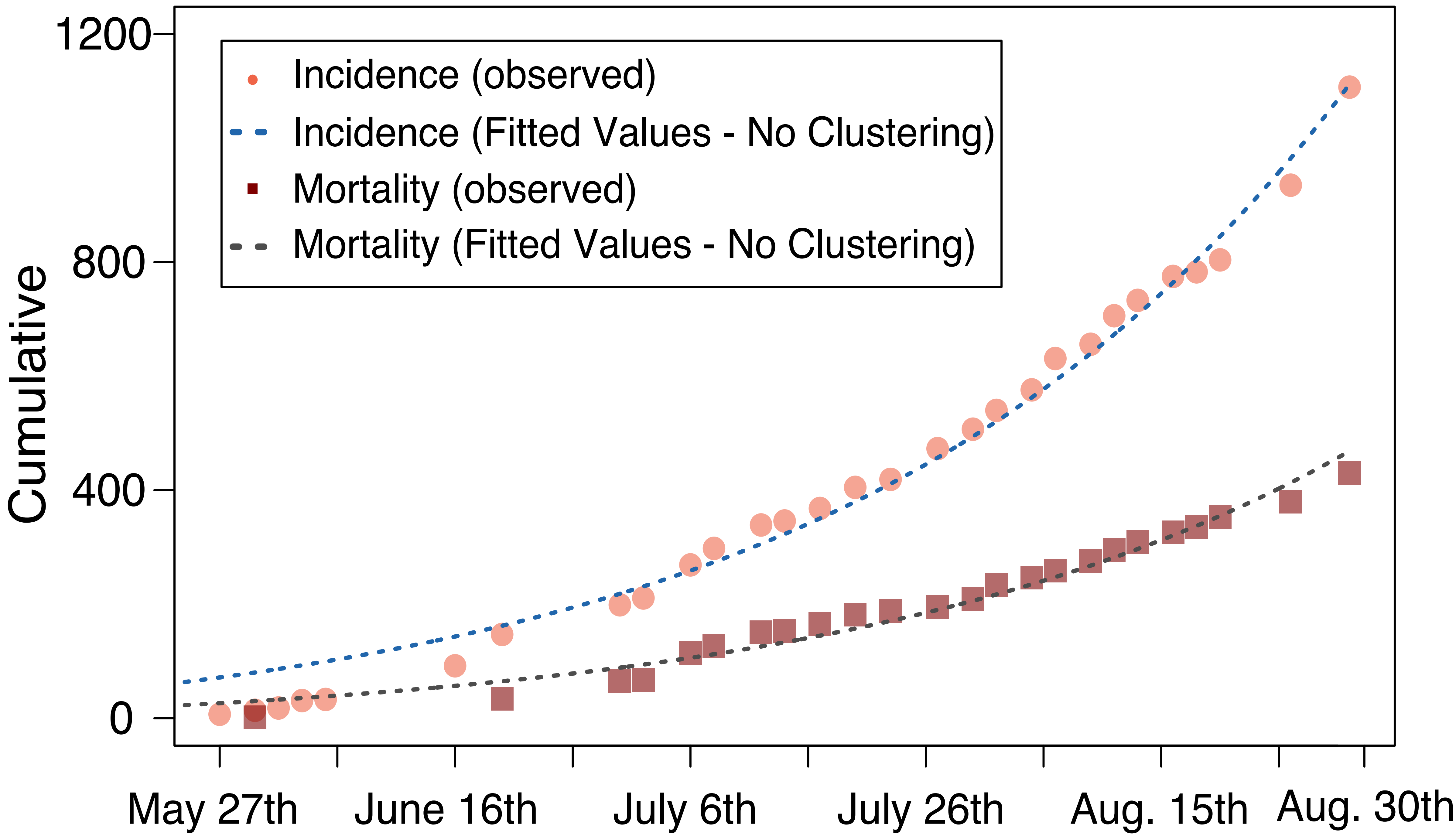


Outbreak in Sierra Leone

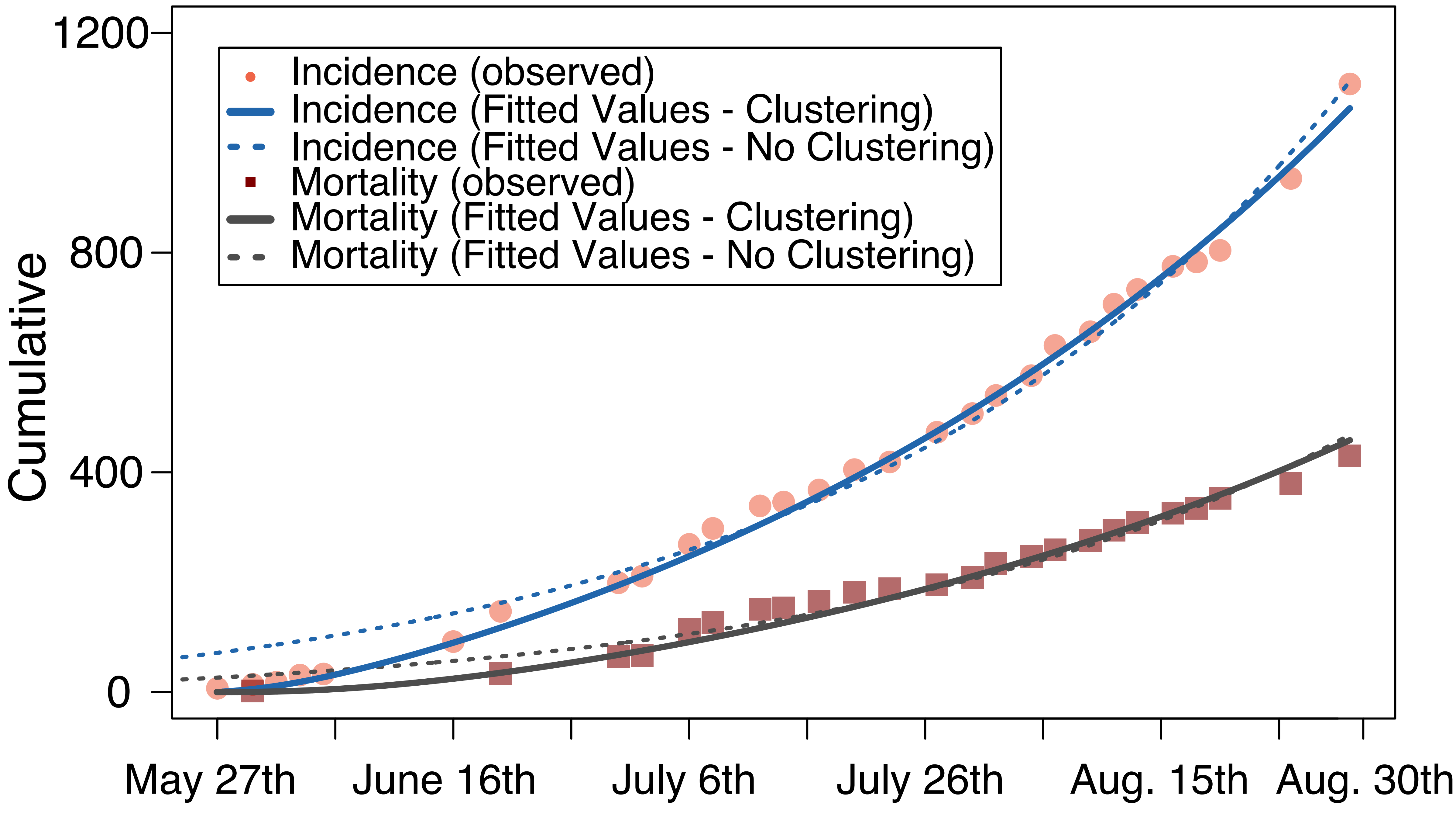


Scarpino & Iamarino et al. 2015

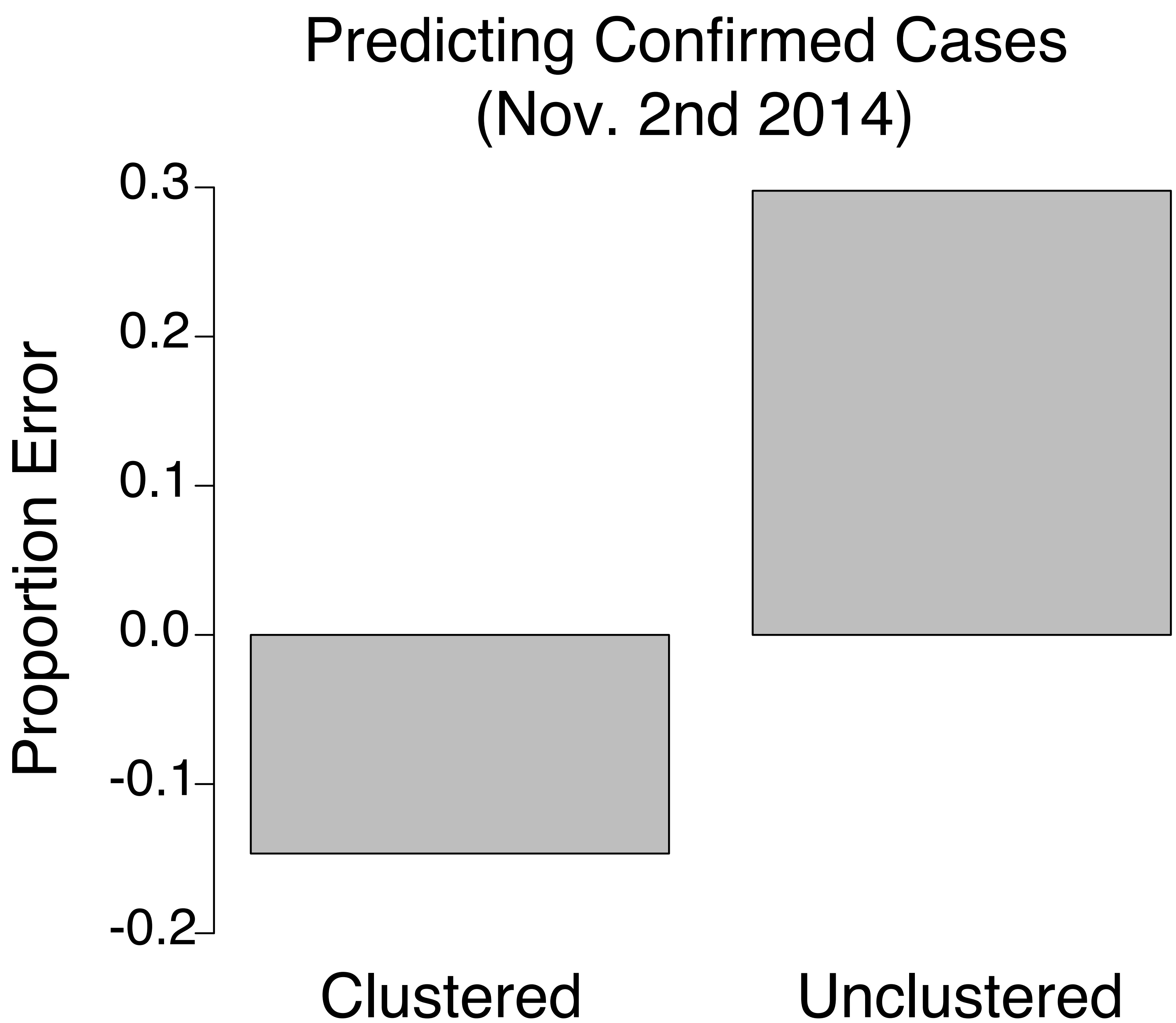
Evidence for clustered transmission



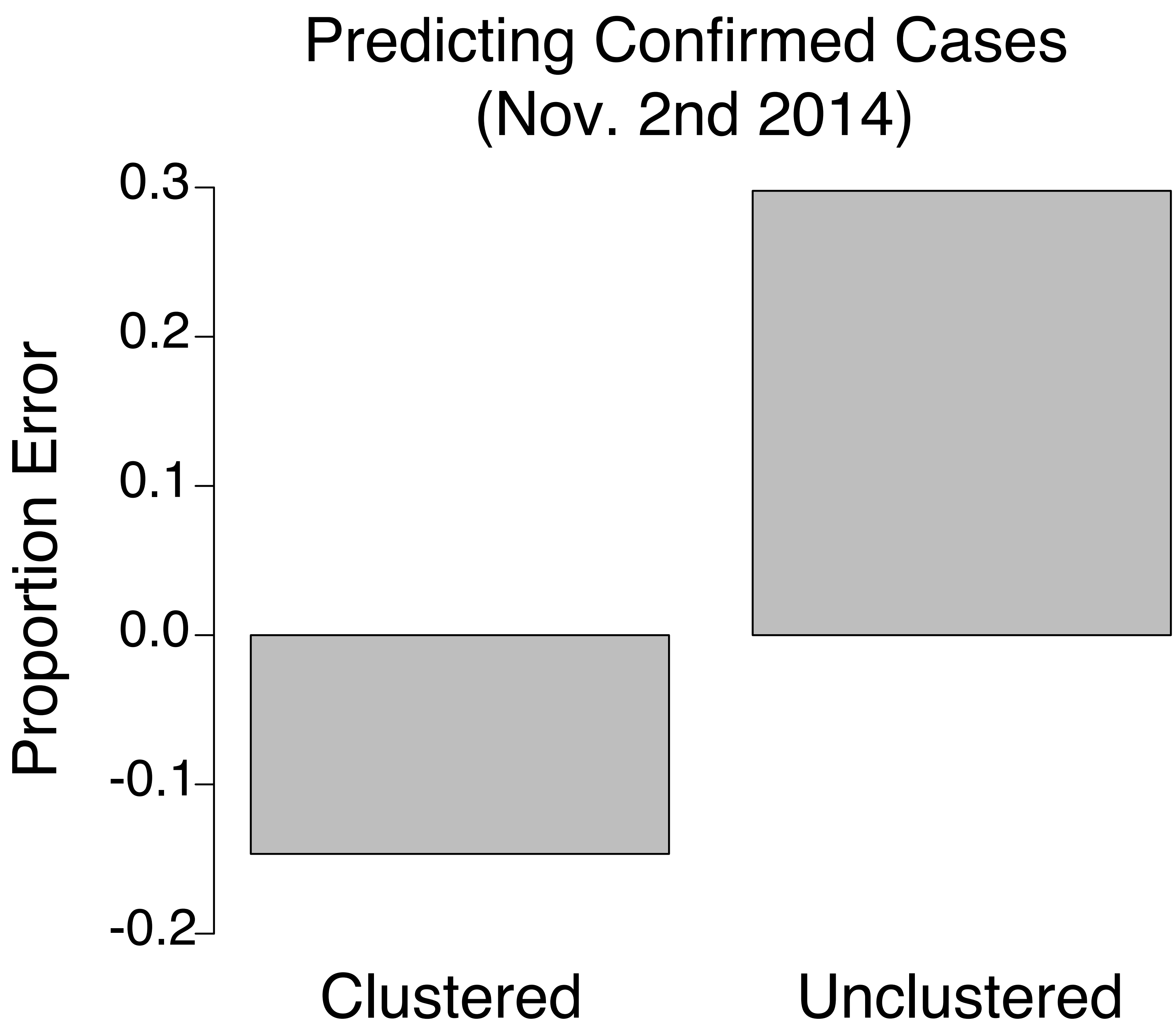
Evidence for clustered transmission



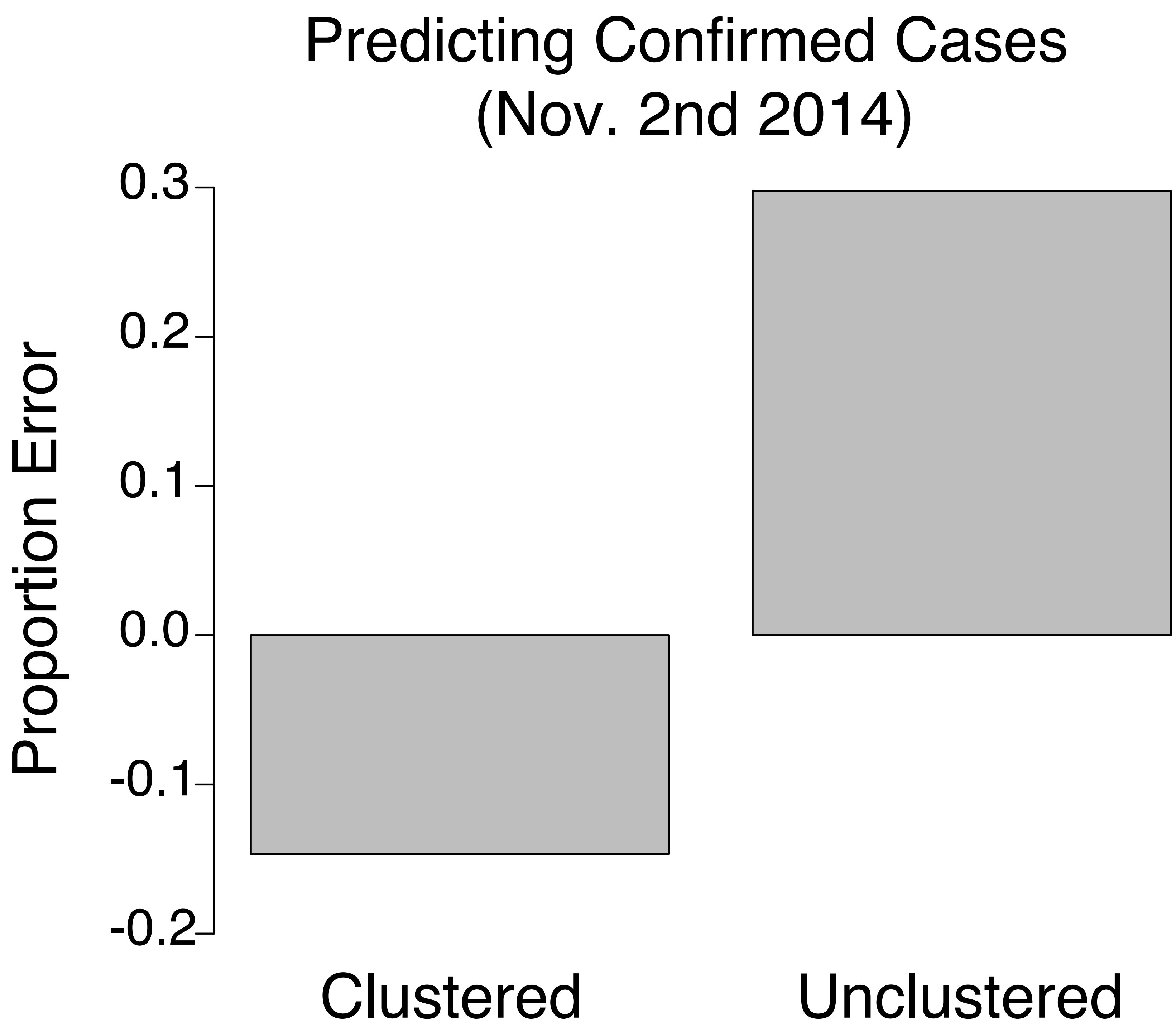
1. Dynamic importance of clustering



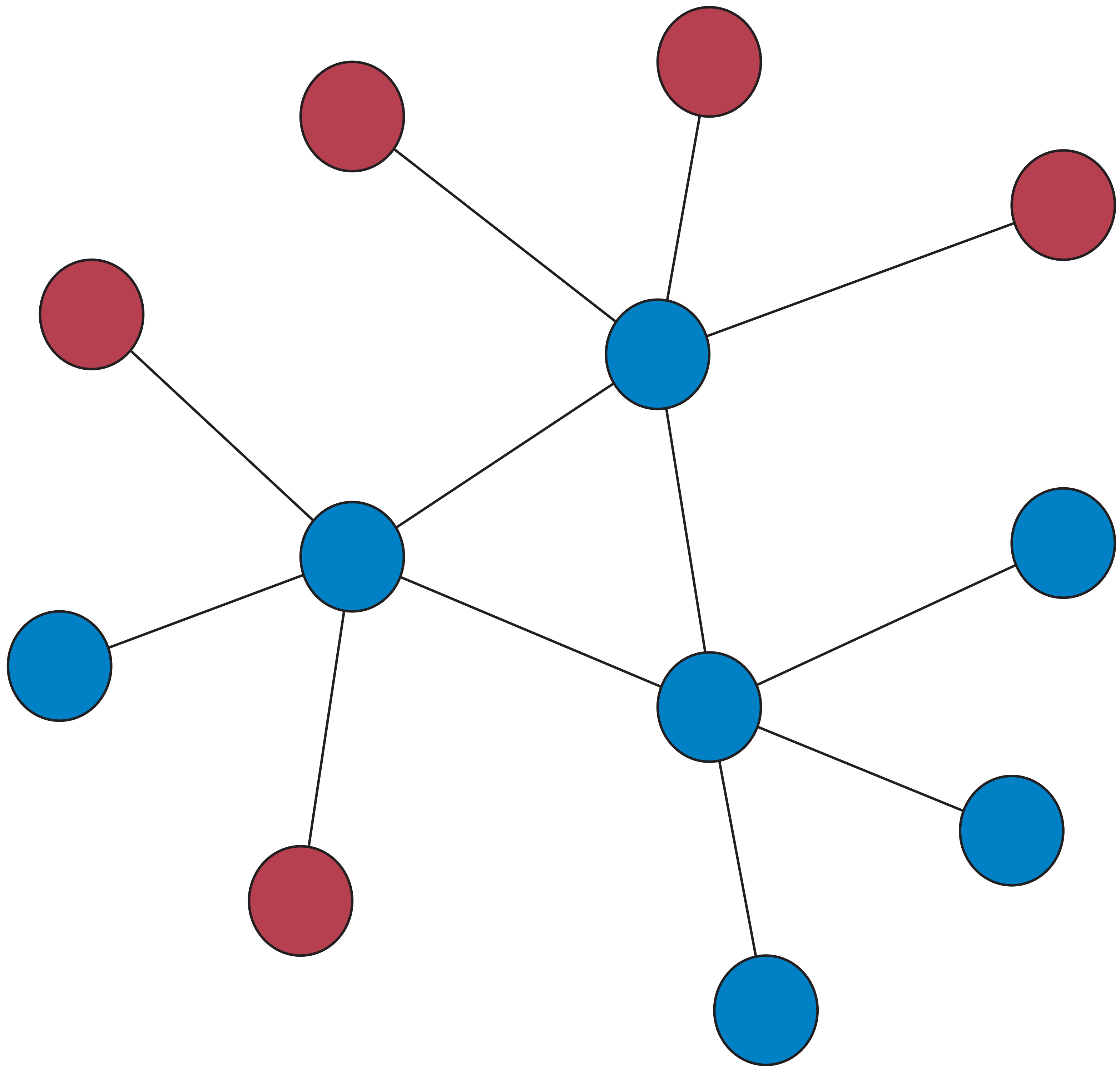
2. No evidence for interventions



3. Perhaps we can forecast outbreaks



What happens when you replace sick workers?



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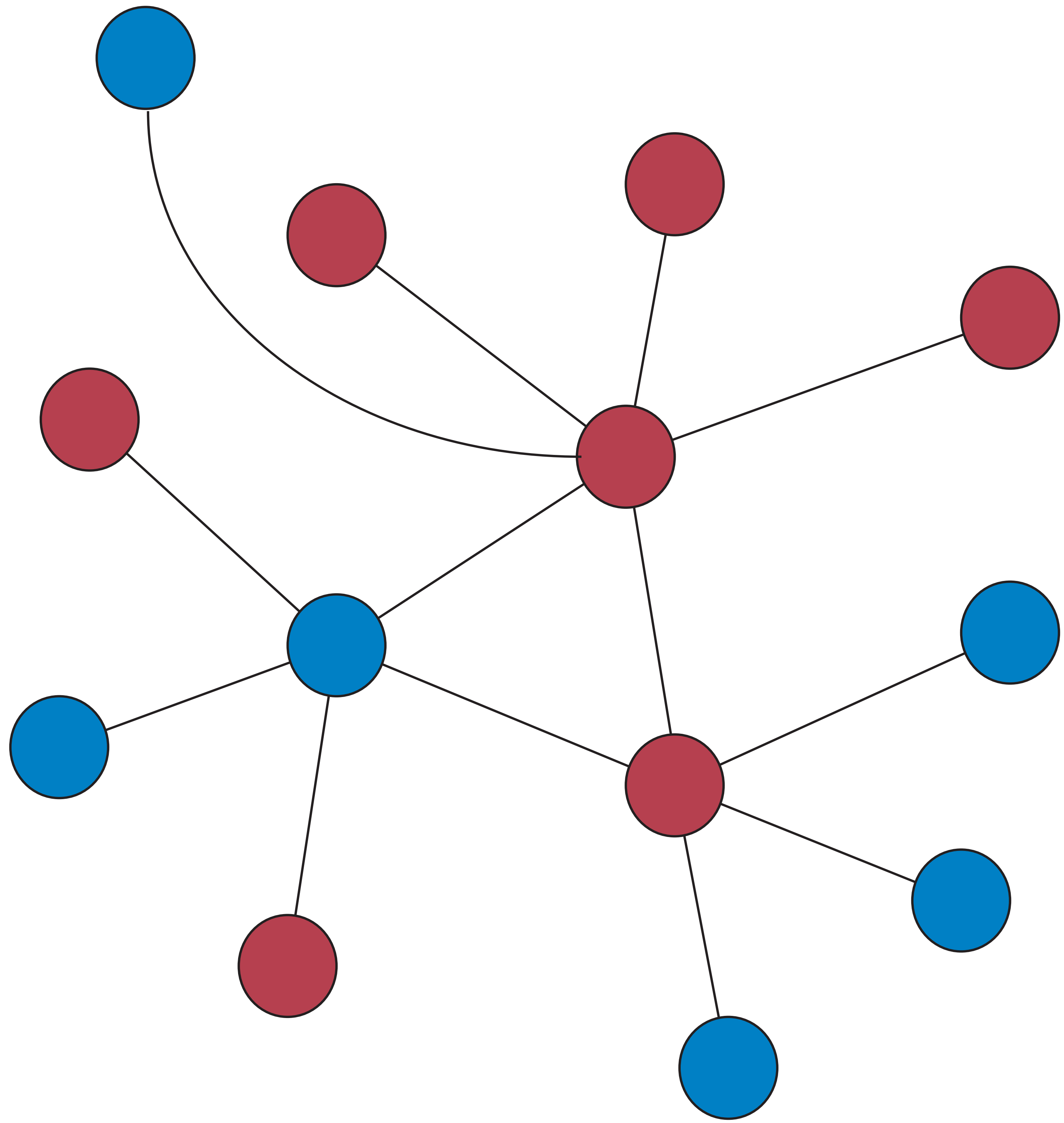

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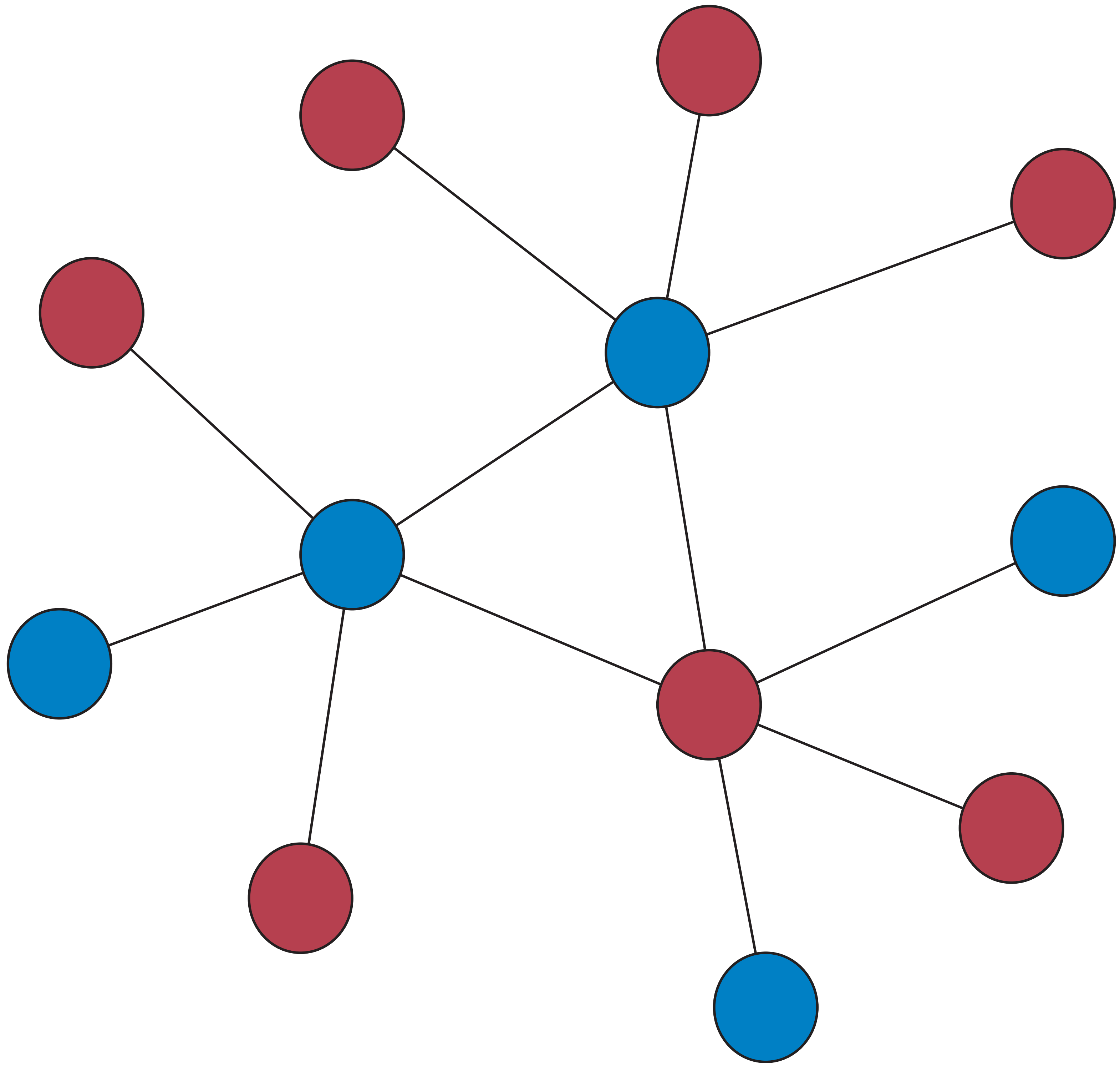
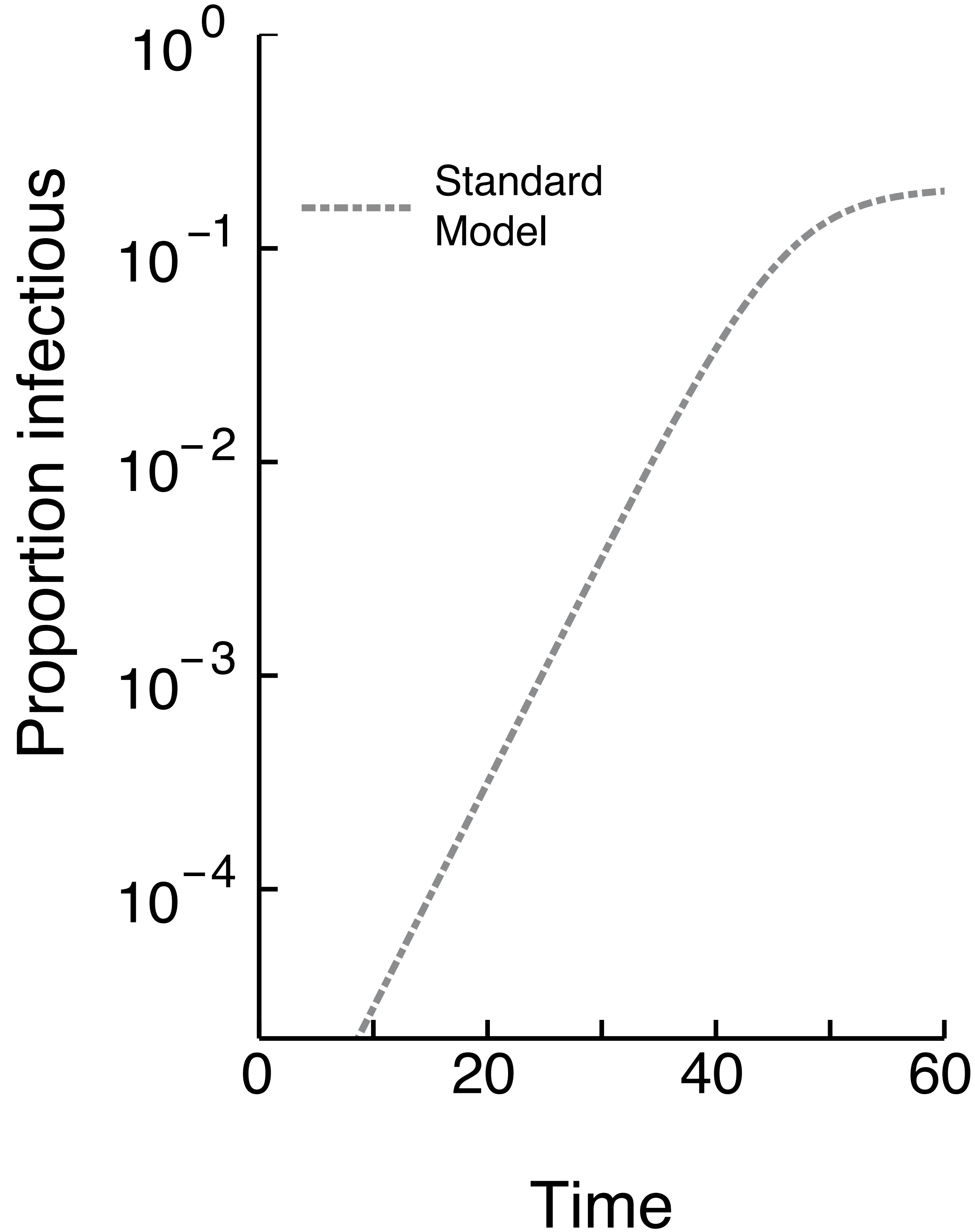


How does *Relational Exchange* work?



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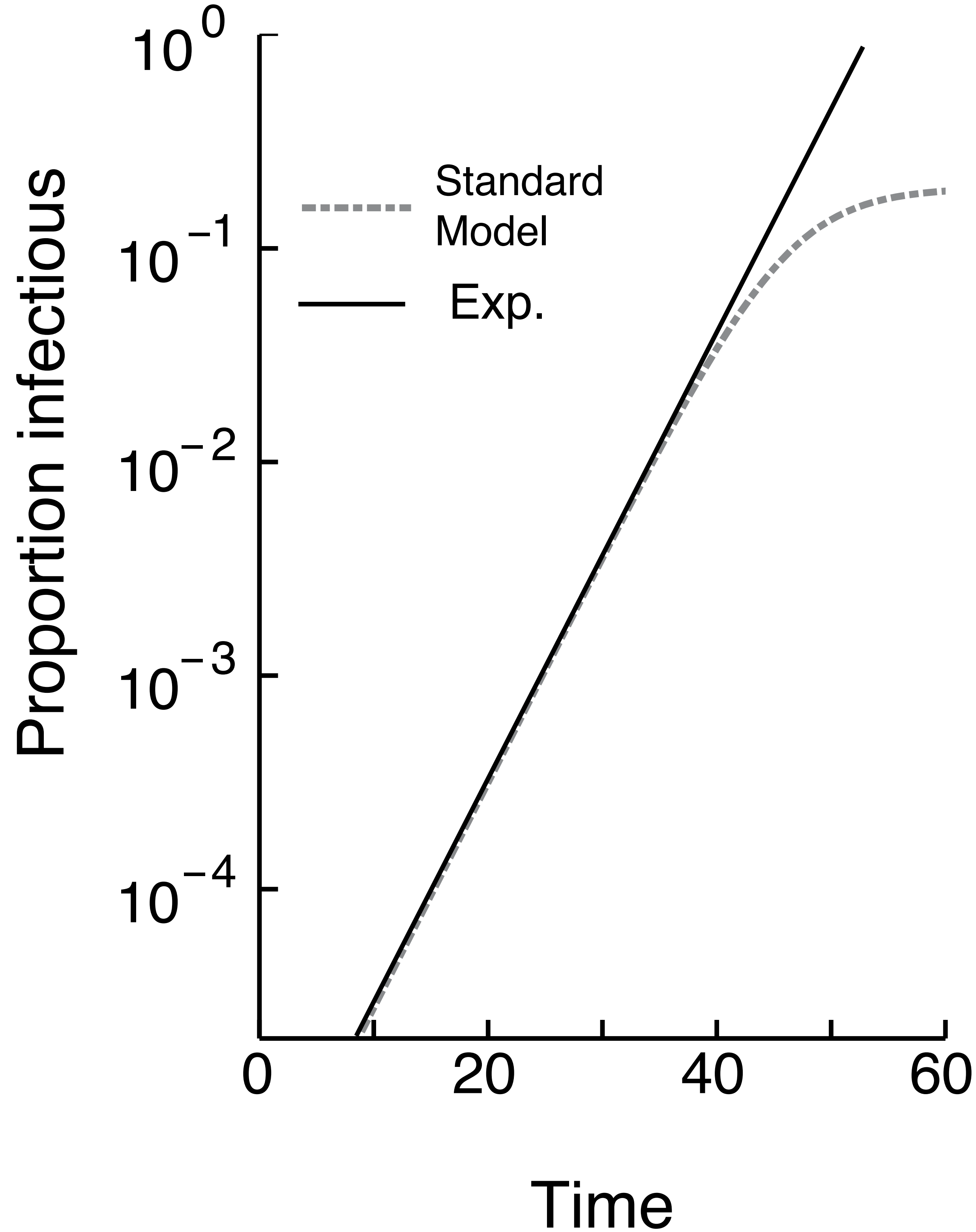
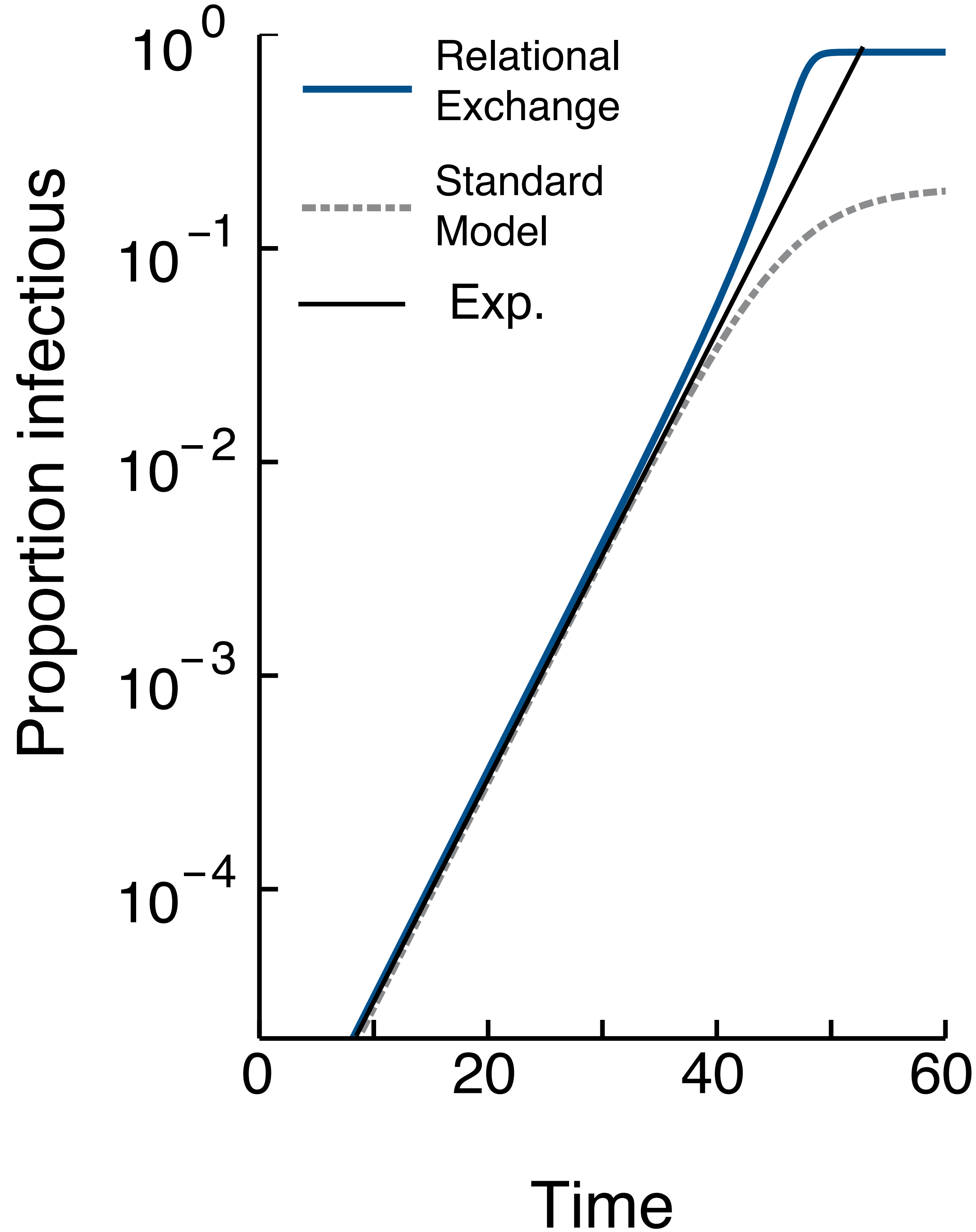
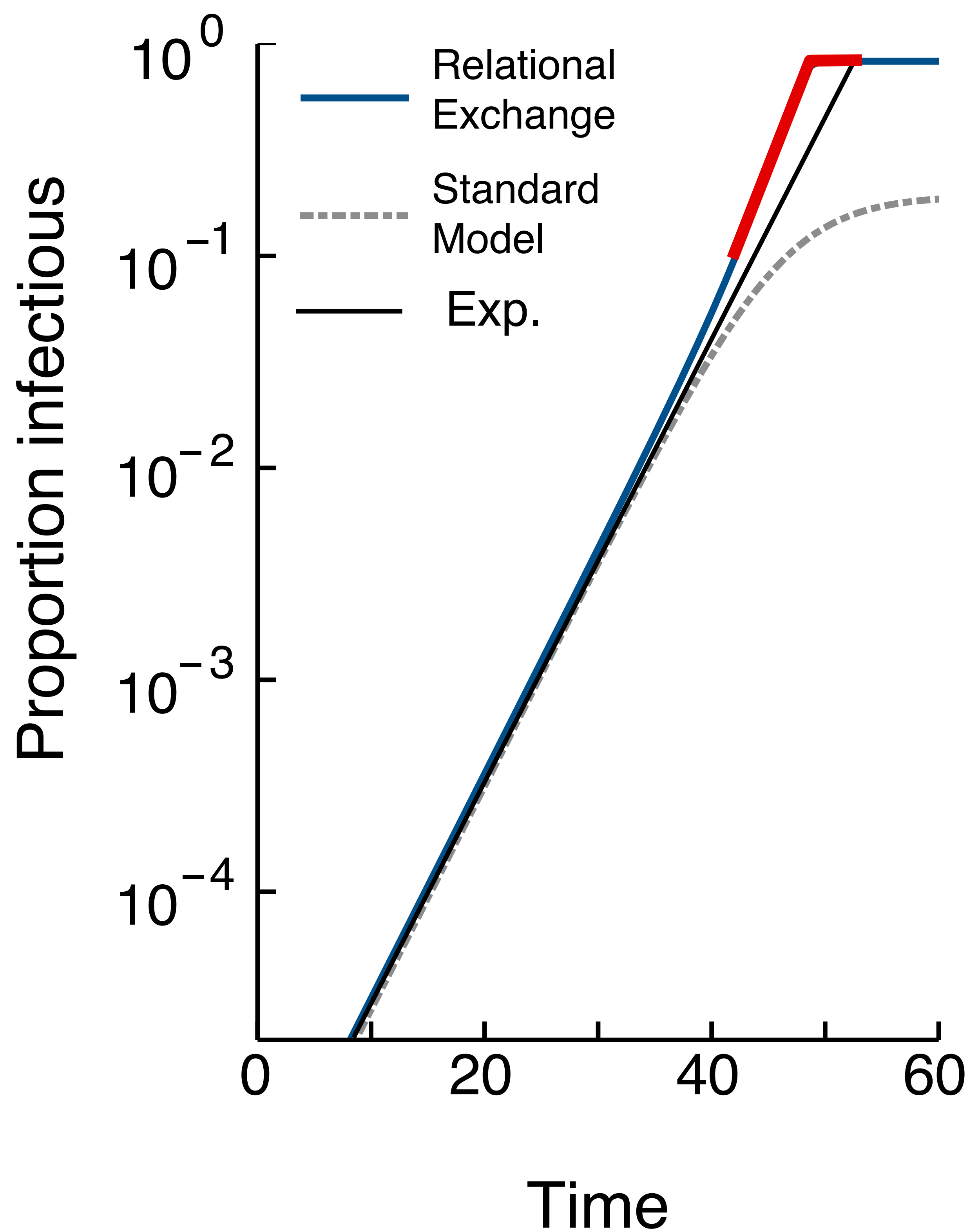


Accelerating exponential growth



Accelerating exponential growth



Empirical evidence for *Relational Exchange*

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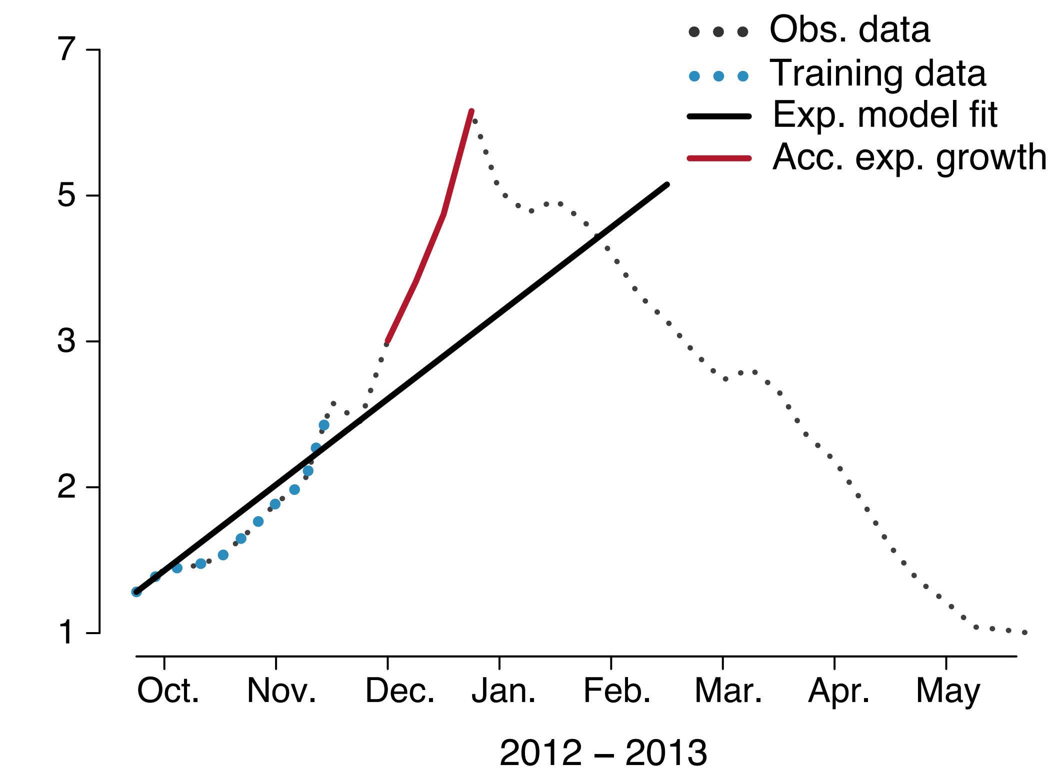
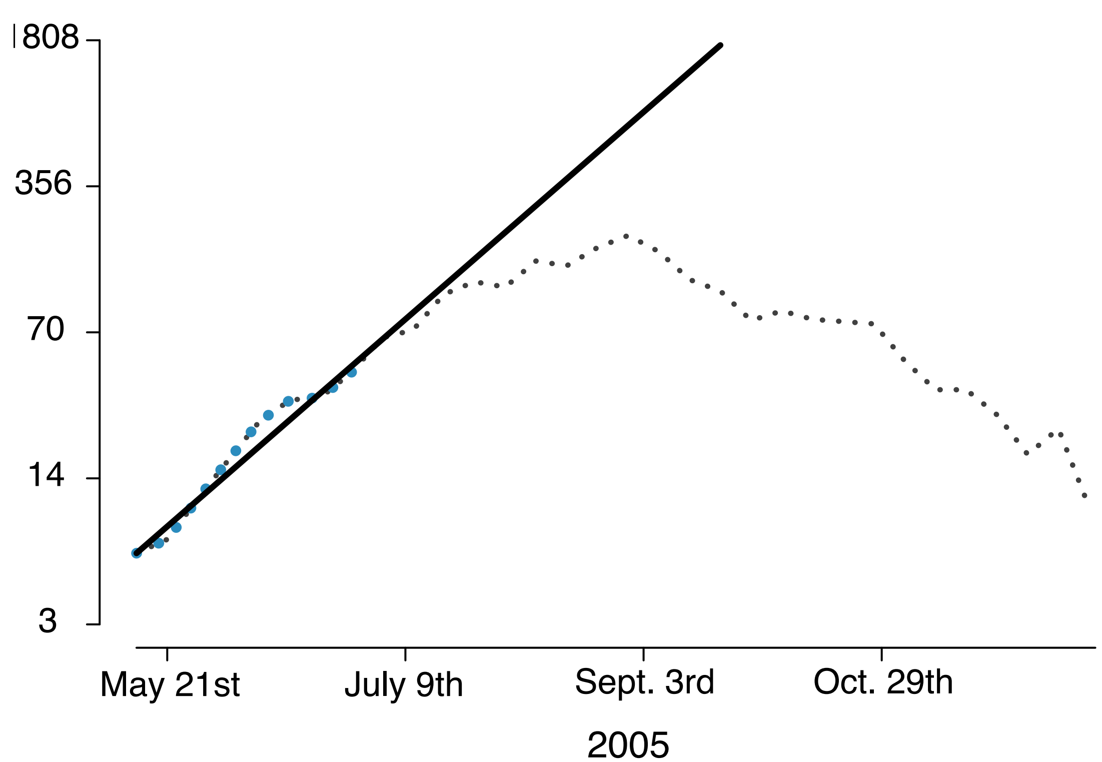


influenza



dengue

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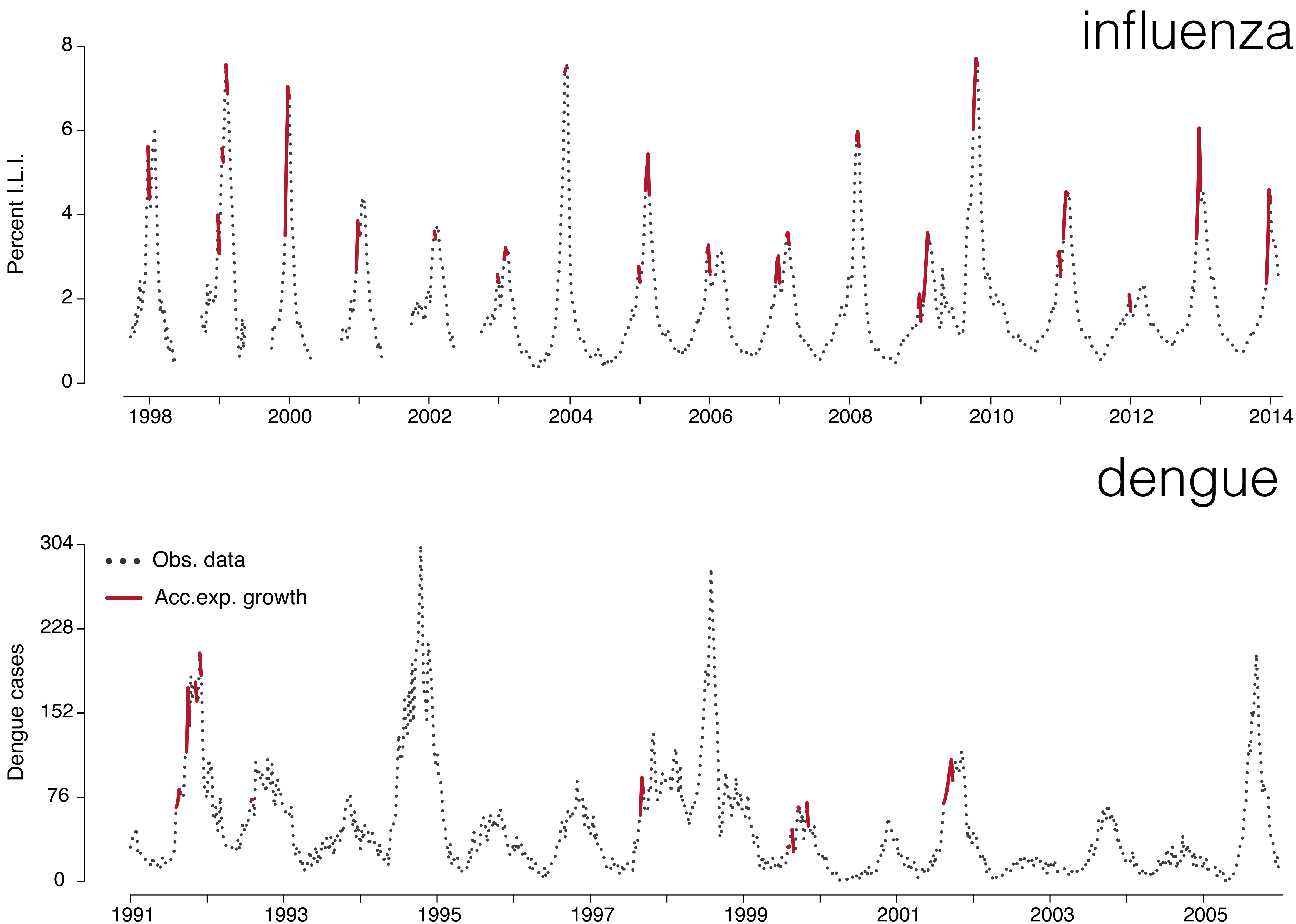

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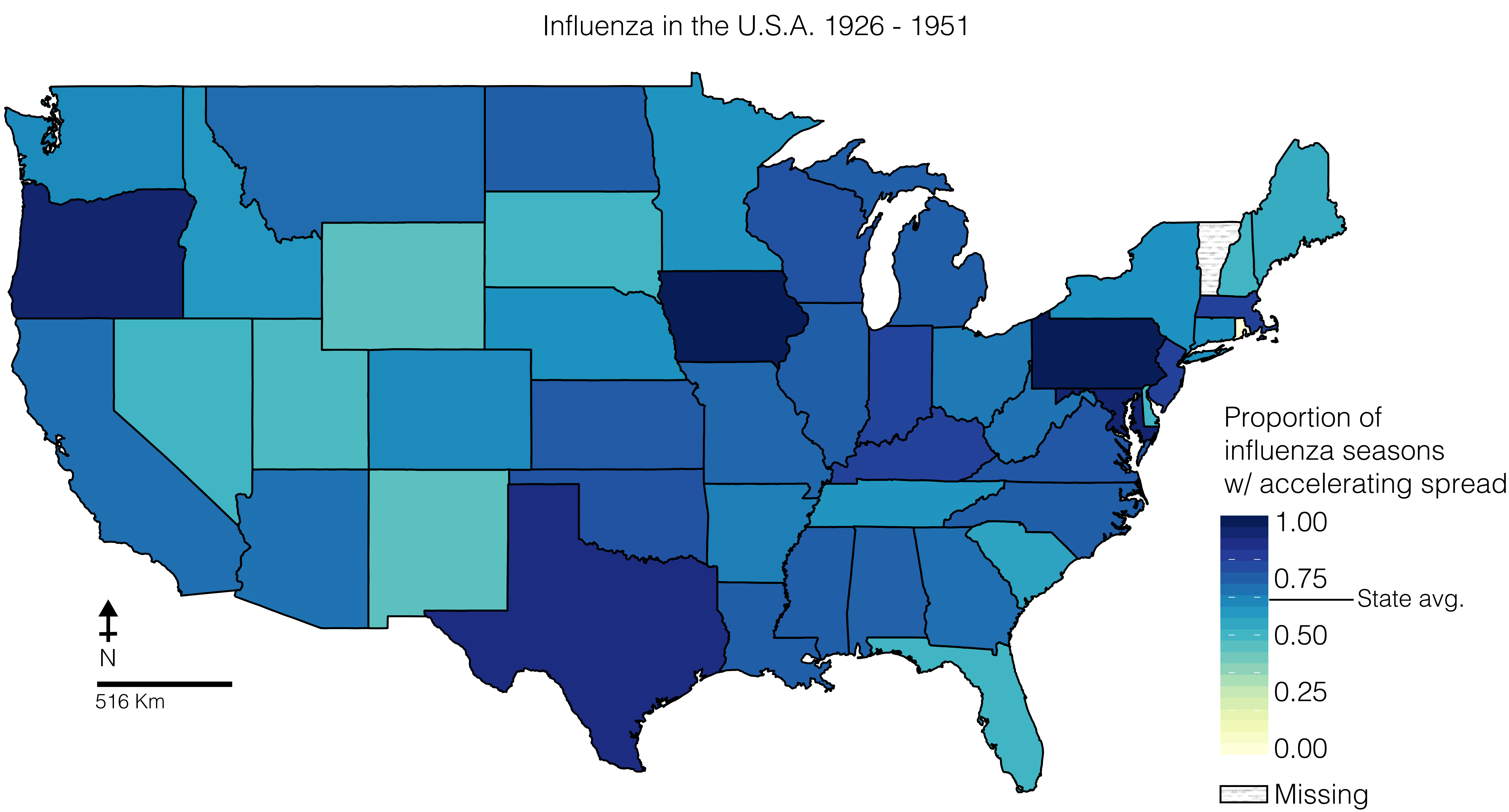
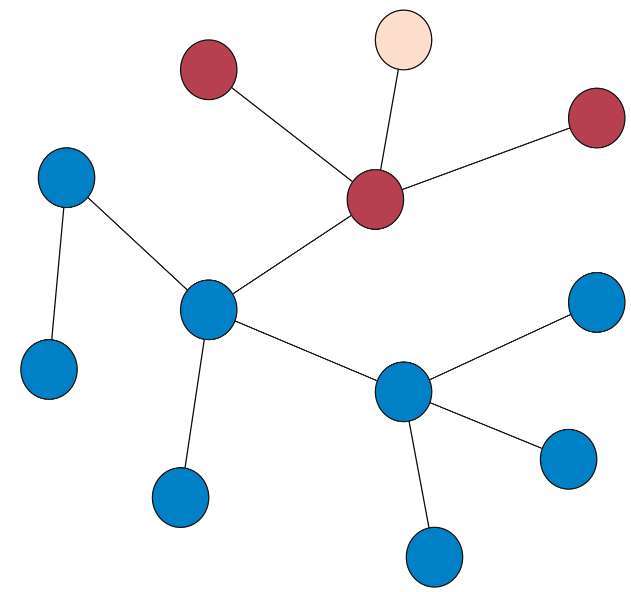


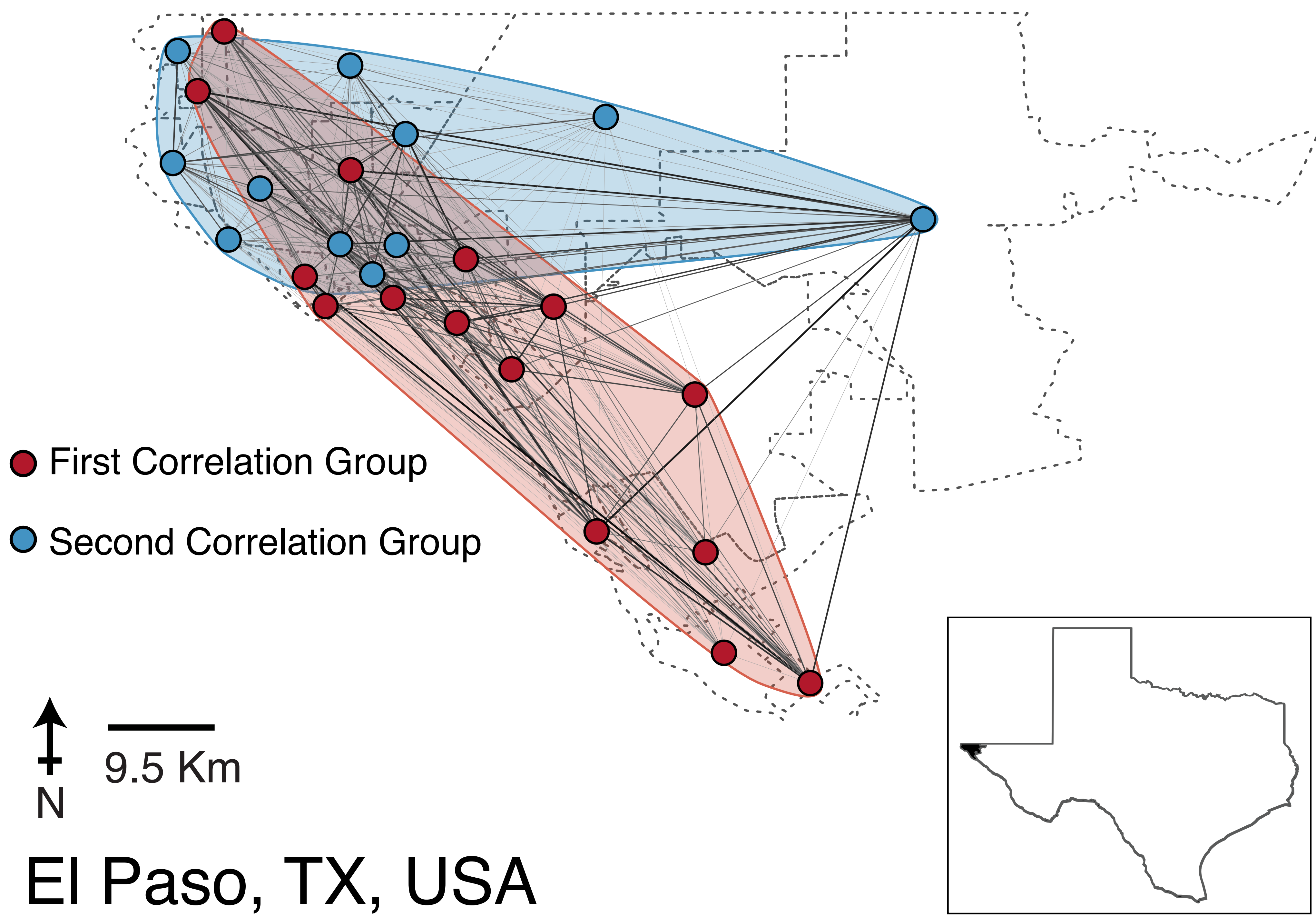
Why do predictions fail?

$$R_0 = T\left(\frac{\langle K^2\rangle - \langle K\rangle}{\langle K\rangle}\right)$$



$$R_0 = \frac{\beta S}{\gamma}$$

Why do predictions fail?



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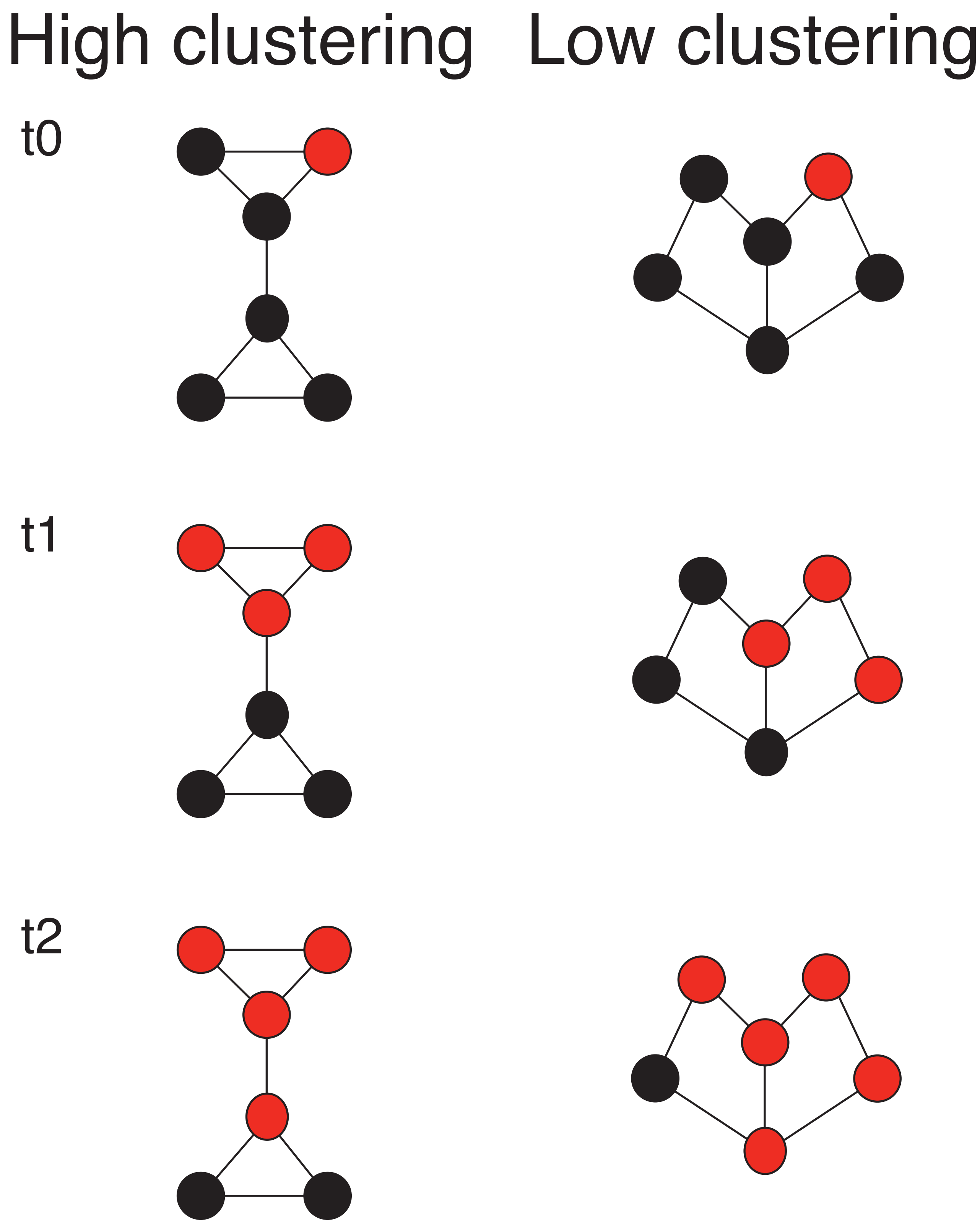

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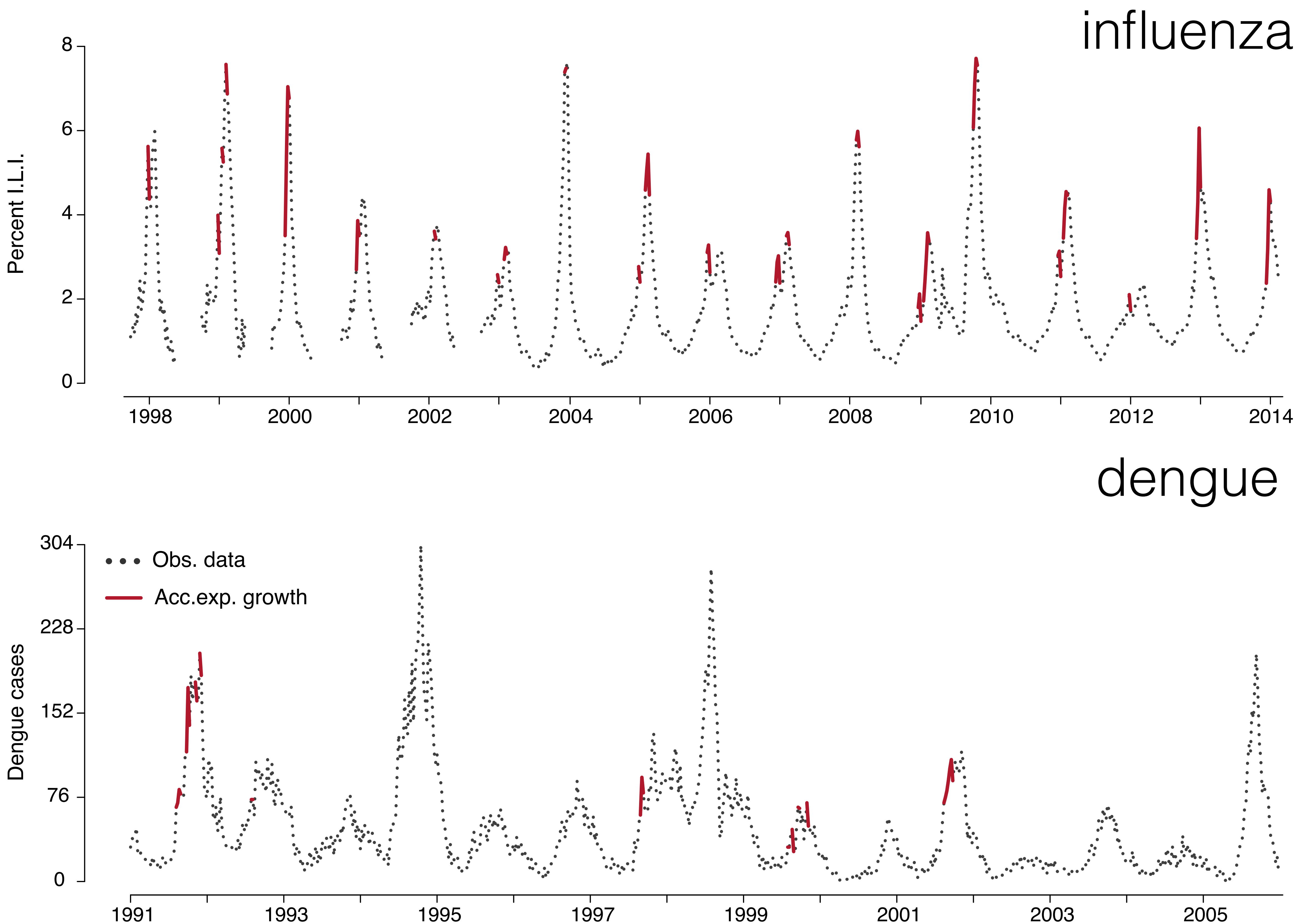
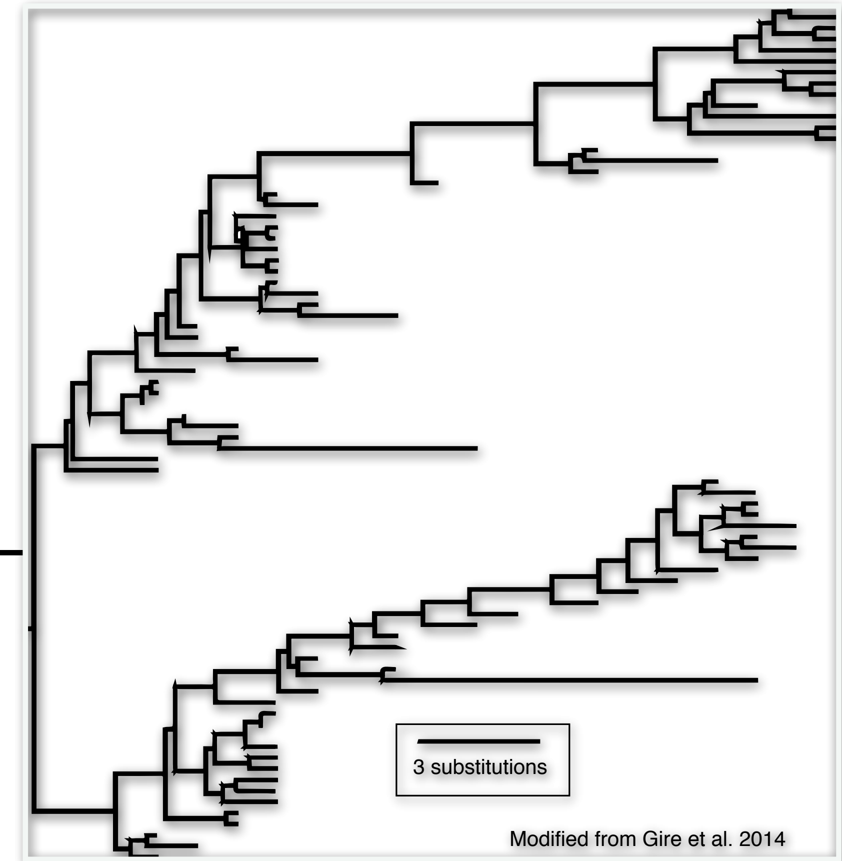


Toward a complex systems theory of disease



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Questions?

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