Heterogeneity, contact patterns and modeling options

Jonathan Dushoff, McMaster University
http://lalashan.mcmaster.ca/DushoffLab

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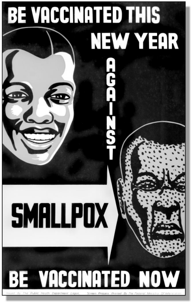
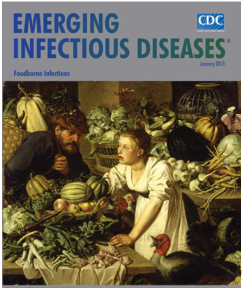
http://www.ici3d.org/mmed/

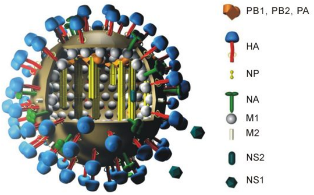
The resilience of infectious disease

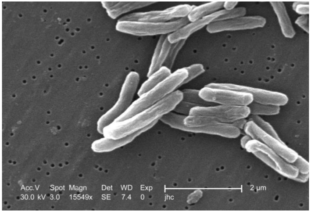
1967: It's time to close the book on infectious diseases





Pathogen evolution





Human heterogeneity

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Outline

Homogeneous disease models

The importance of heterogeneity

Effects of heterogeneity

Modeling approaches

Homogeneous disease models

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  - probability of mixing with each person

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  - D: Average duration of infection
- A disease can invade a population if and only if $\mathcal{R}_0 > 1$.

Equilibrium

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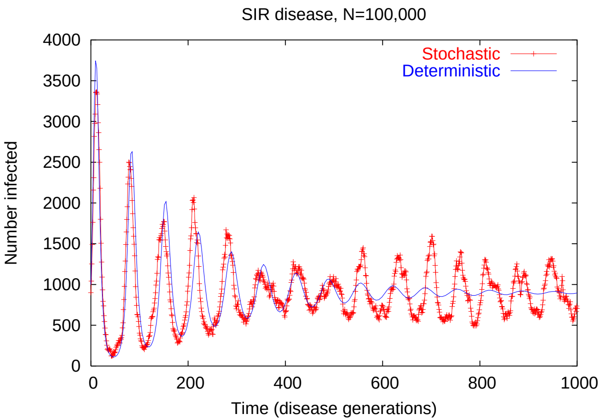
-



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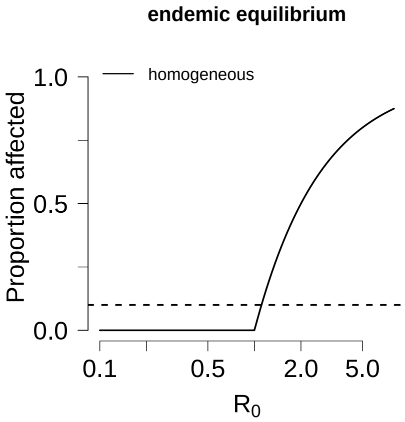
- Proportion 'affected' is $V = 1 - S/N = 1 - 1/R_0$.

Homogeneous endemic curve



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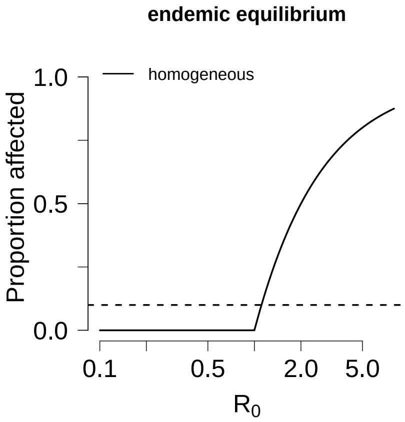

- Threshold value

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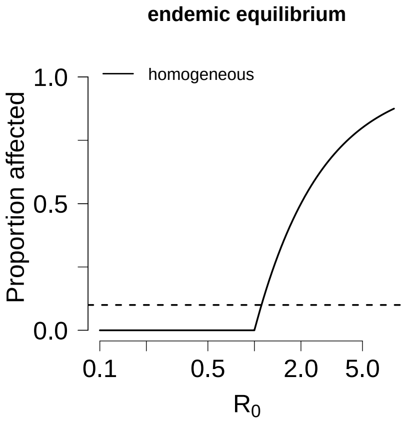

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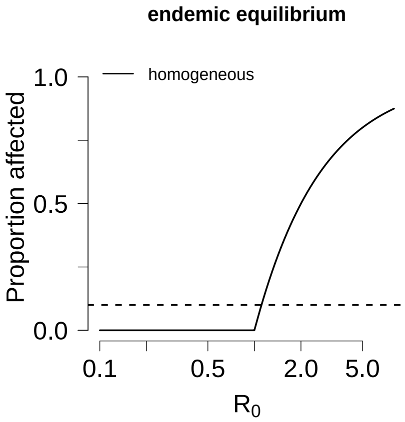

- Threshold value
- Sharp response to changes in factors underlying transmission
- Works – sometimes

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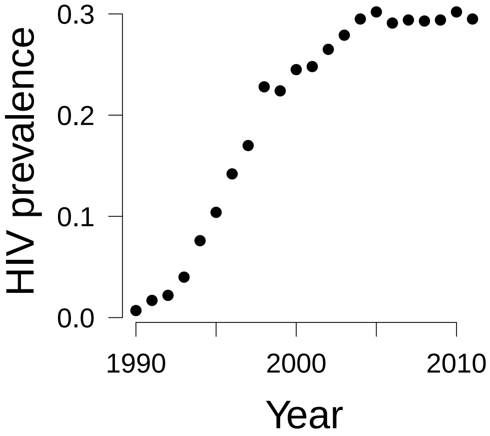
  - $\bar{P} = 0.95 \times (2\mathrm{wk}/60\mathrm{yr})$.

Disease dynamics



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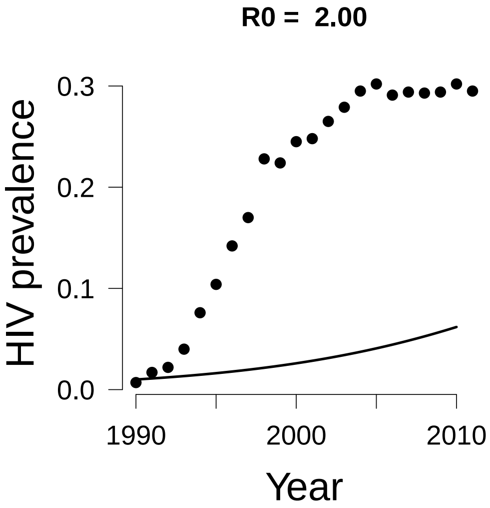

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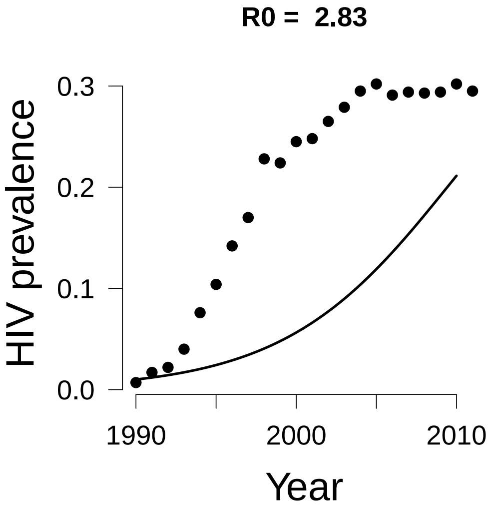

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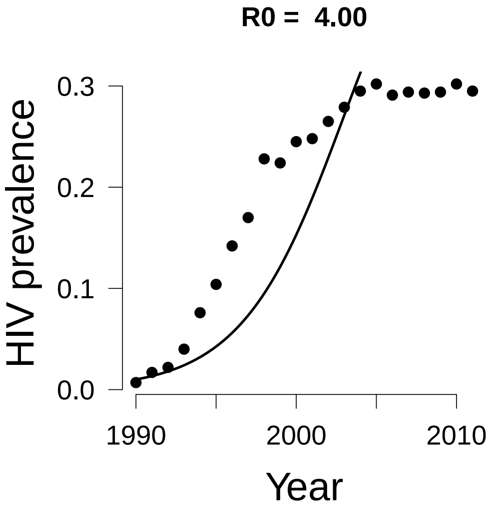

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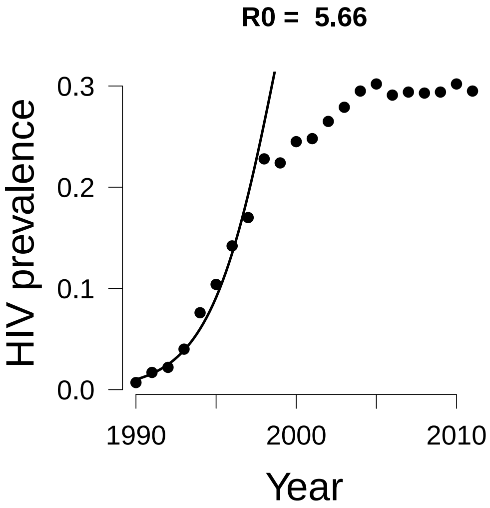

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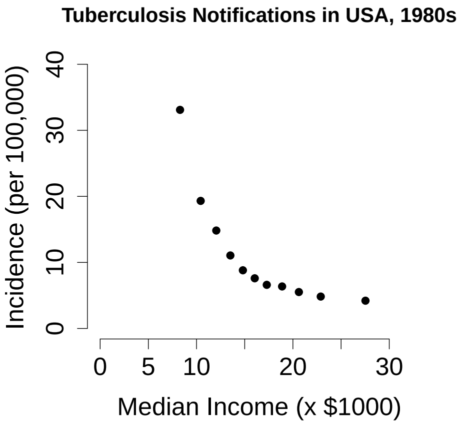
Heterogeneity in TB



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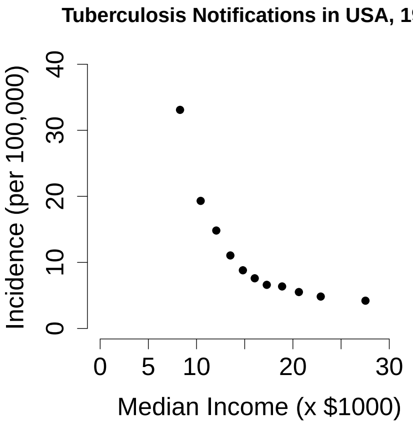

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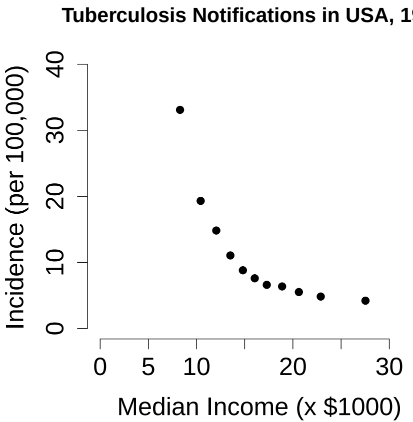

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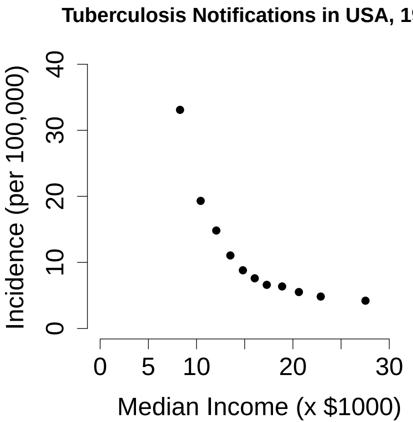

- **Progression**: Nutrition, stress
- **Contact**: Overcrowding, poor ventilation
- **Cure**: Access to medical care

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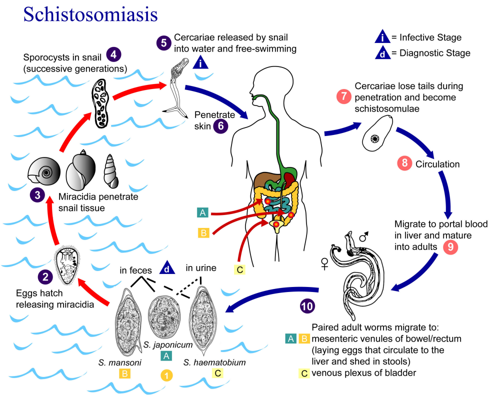
- **Every disease!**

Large-scale heterogeneity



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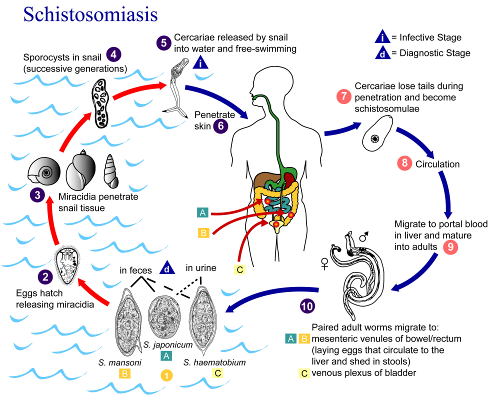

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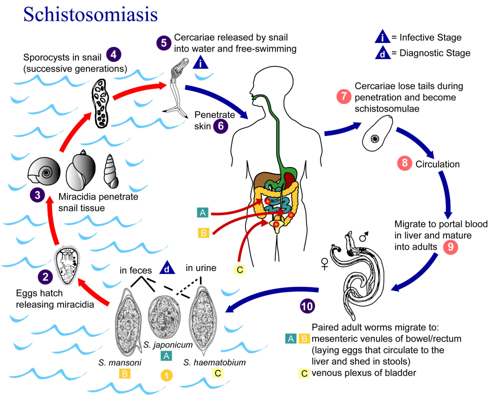

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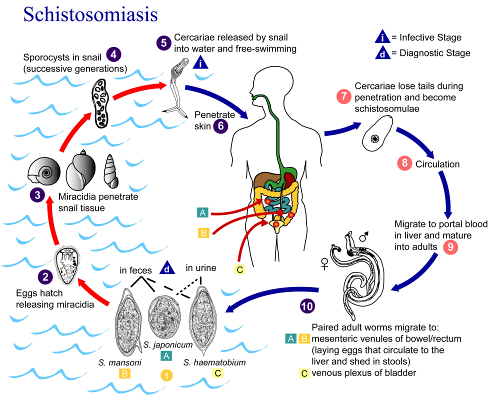

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- This effect operates at many scales.

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  - $\mathcal{R}_{eff} = \sigma\tau cDS/N$

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- σ applies to susceptible individuals $\to \sigma_S$
- c is complicated $\to c_S c_I / \bar{c}$

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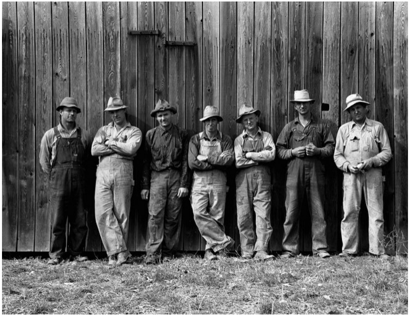
  - $c_S < \bar{c}$; $c_I \to \bar{c}$.

Simpson's paradox



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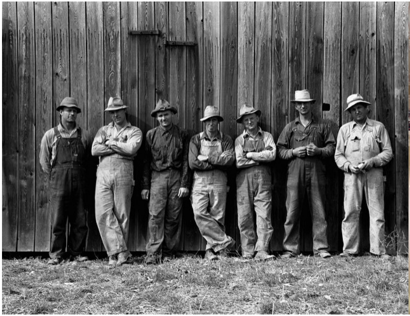

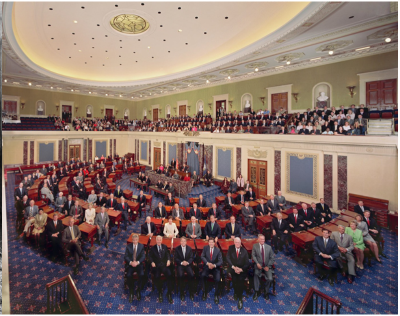

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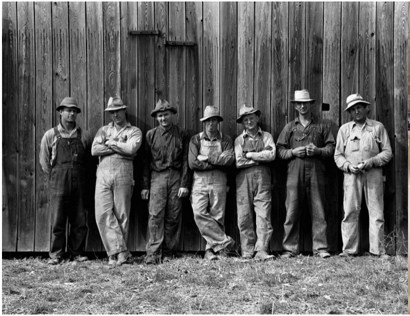 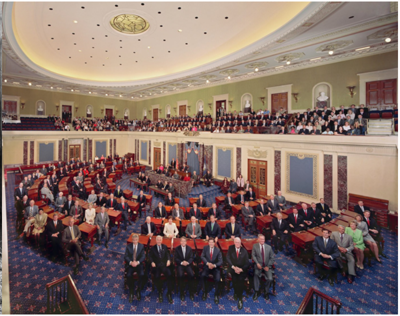

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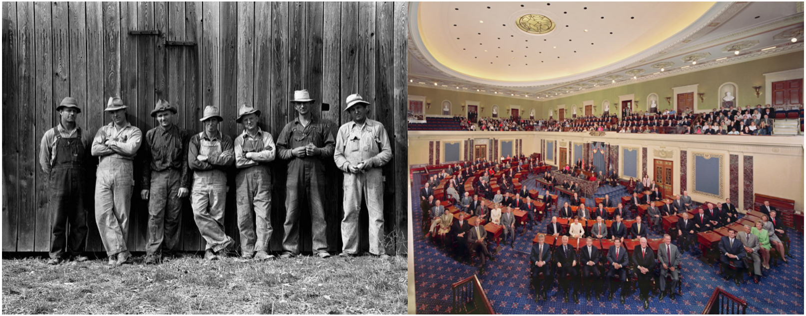

- What happens when a peanut farmer is elected to the US Senate?
- The average IQ goes up in both places!

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- When the disease invades:
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  - The infectious population is likely to have higher values of c, D and/or τ
- $\mathcal{R}_0$ is typically greater than you would expect from a homogeneous model

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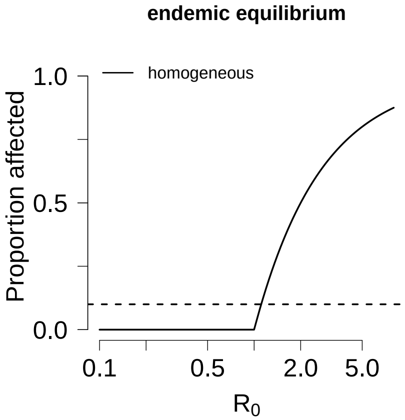
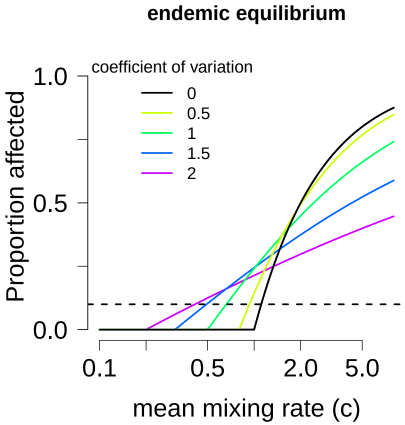
- $\rightarrow$ lower proportion affected *for a given value of* $\mathcal{R}_0$.

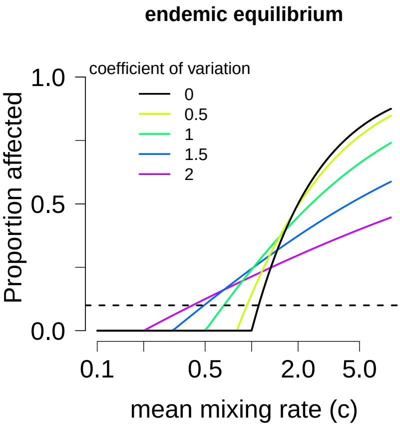
Homogeneous endemic curve



Heterogeneous endemic curves



Heterogeneity and disease



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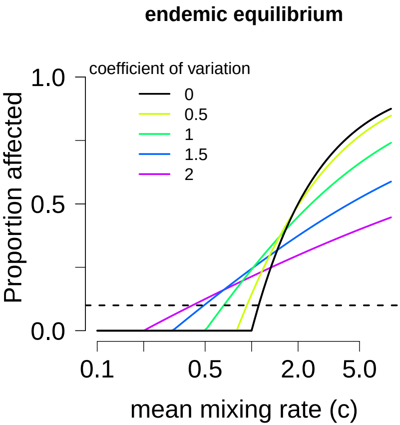

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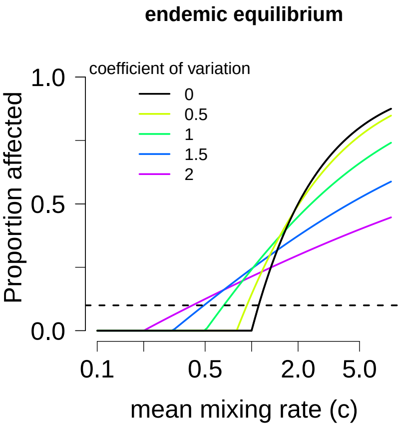

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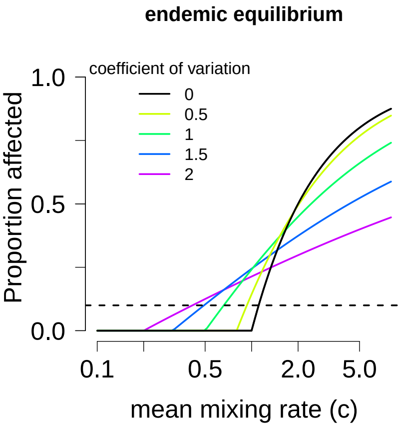

- Heterogeneity has a double-edged effect
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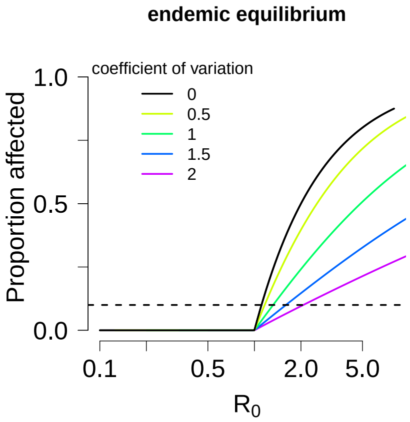
  - But $\mathcal{R}_0$ is *higher* for given mean values of factors underlying transmission

Heterogeneous endemic curves



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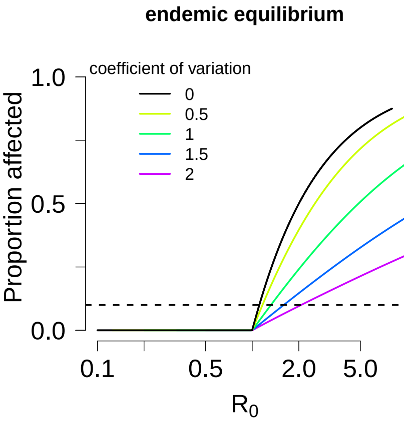

- Heterogeneity makes the endemic curve flatter

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  - Infectious pool less infectious

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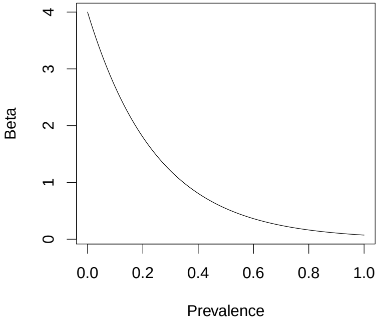
  - people who are nearby geographically or in the contact network
- More wasted contacts further flatten the endemic curve

Outline

Phenomenological



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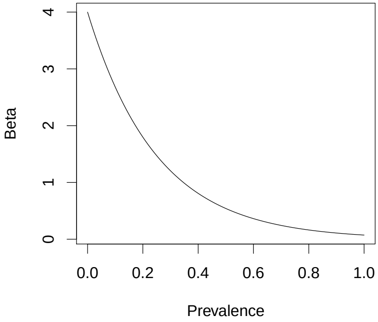
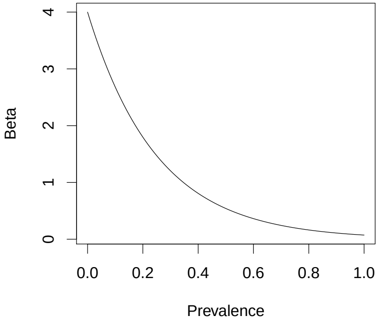


- You can simply *make* β go down as prevalence goes up

Phenomenological



- You can simply *make* β go down as prevalence goes up
  - Need to choose a functional form

Multi-group models

Multi-group models

- Divide the population into groups.

Multi-group models

- Divide the population into groups.
  - cities and villages

Multi-group models

- Divide the population into groups.
  - cities and villages
  - rich and poor

Multi-group models

- Divide the population into groups.
  - cities and villages
  - rich and poor
  - high and low sexual activity

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  - rich and poor
  - high and low sexual activity
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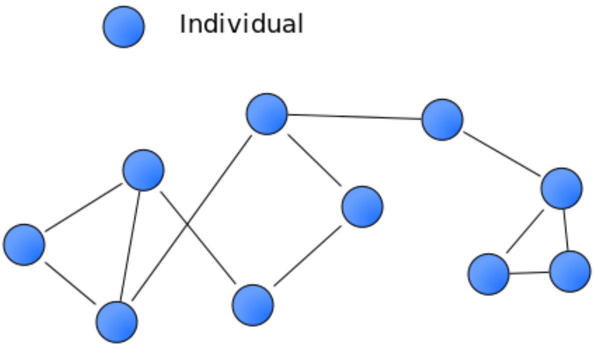
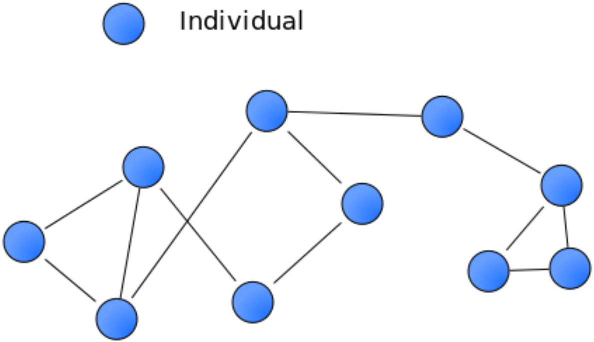
  - ...

Individual-based models

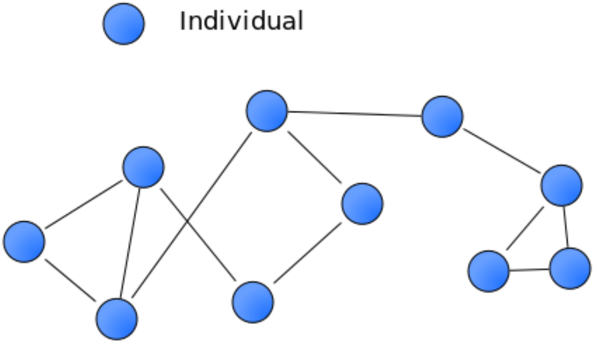


Individual-based models



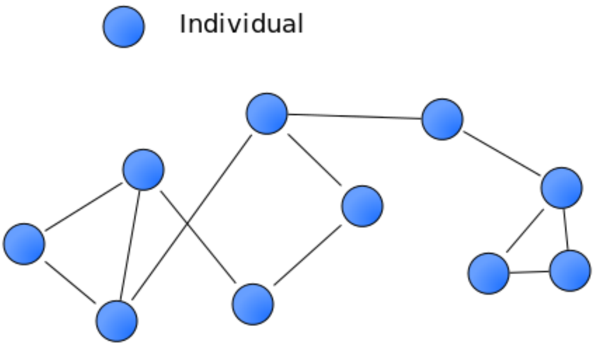
- Allow many possibilities:

Individual-based models



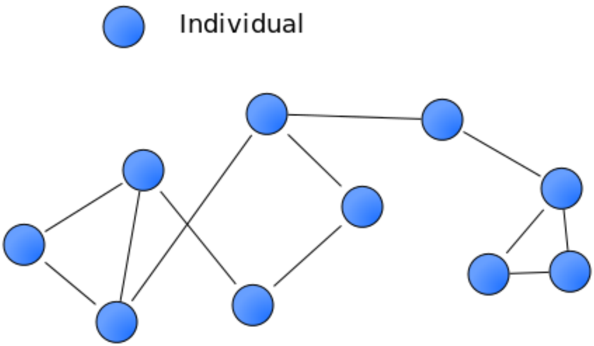
- Allow many possibilities:
  - vary individual characteristics

Individual-based models



- Allow many possibilities:
  - vary individual characteristics
  - add a network of interactions

Individual-based models



- Allow many possibilities:
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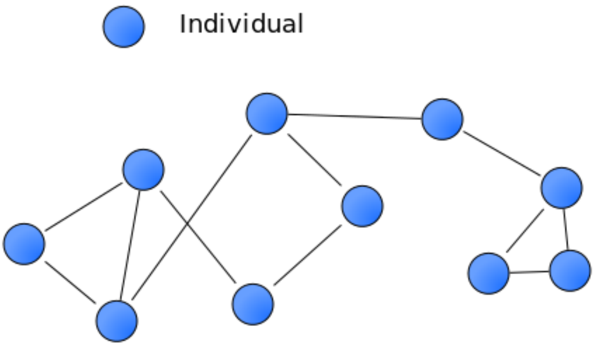
  - add a network of interactions
  - let the network change

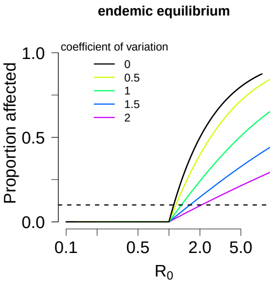
Individual-based models



- Allow many possibilities:
  - vary individual characteristics
  - add a network of interactions
  - let the network change
- Individual-based approaches require stochastic models

Summary


Exit
Madison Avenue
& 42 Street
Open M-F 6:30am-7:30pm


endemic equilibrium
coefficient of variation
0
0.5
1
1.5
2
Proportion affected
1.0
0.5
0.0
0.1
0.5
2.0
5.0
R_0

Summary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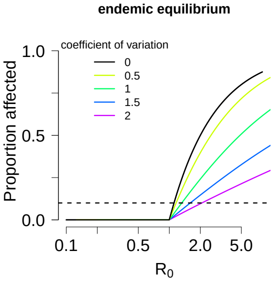
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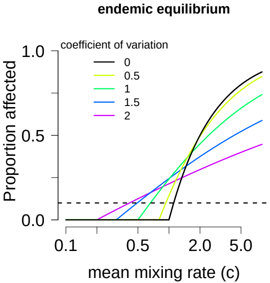
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5.0
mean mixing rate (c)