

Estimating the transmission parameter

MATHEMATICAL MODELING FOR INFECTIOUS DISEASE PLANNING IN AFRICA

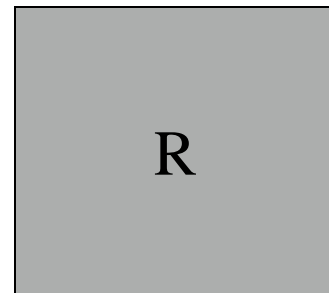
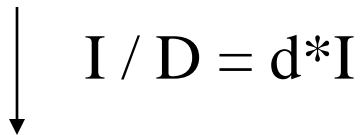
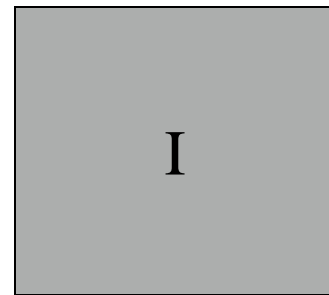
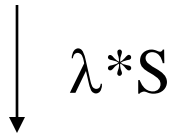
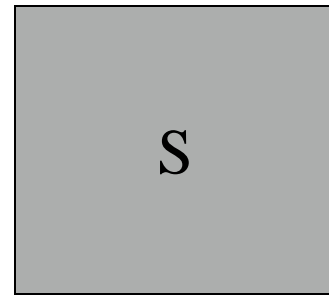
Learning objectives

- Review the transmission parameter and its role in model formulation
- Consider how the transmission parameter is selected
- Understand per-contact infectivity and the potential problems in measuring it.
- Understand the contact rate and the potential problems in measuring it.

Parameters

- Any factor that defines a dynamic system and determines or limits its performance.
- A quantity that characterizes a statistical population and that can be estimated by calculations from **sample data** (i.e. mean and variance.)

State Variables:
S=Susceptibles
I=Infectious
R=Removed



Parameters:

λ = incidence

$\lambda = \mathbf{Beta} * I$

D=duration of
infectiousness

d = recovery rate

Incidence

- The incidence of an infectious disease is a function of
 - Transmission parameter “beta”
 - contact rate, k
 - transmission probability, b
 - prevalence of infectious people
- Theory of dependent happenings
 - number of people affected is dependent on number of people already infected.

Incidence rate as a function of prevalence

$$\lambda(t) = \textit{Beta} * \textit{Prevalence}(t)$$

Where

$$\textit{Prevalence}(t) = I(t)$$

$\lambda(t)$ = incidence rate at time t

$$\textit{Beta} = b * k$$

k = number of people contacted per time unit

b = transmission probability

We can use this to “back into” the transmission parameter.

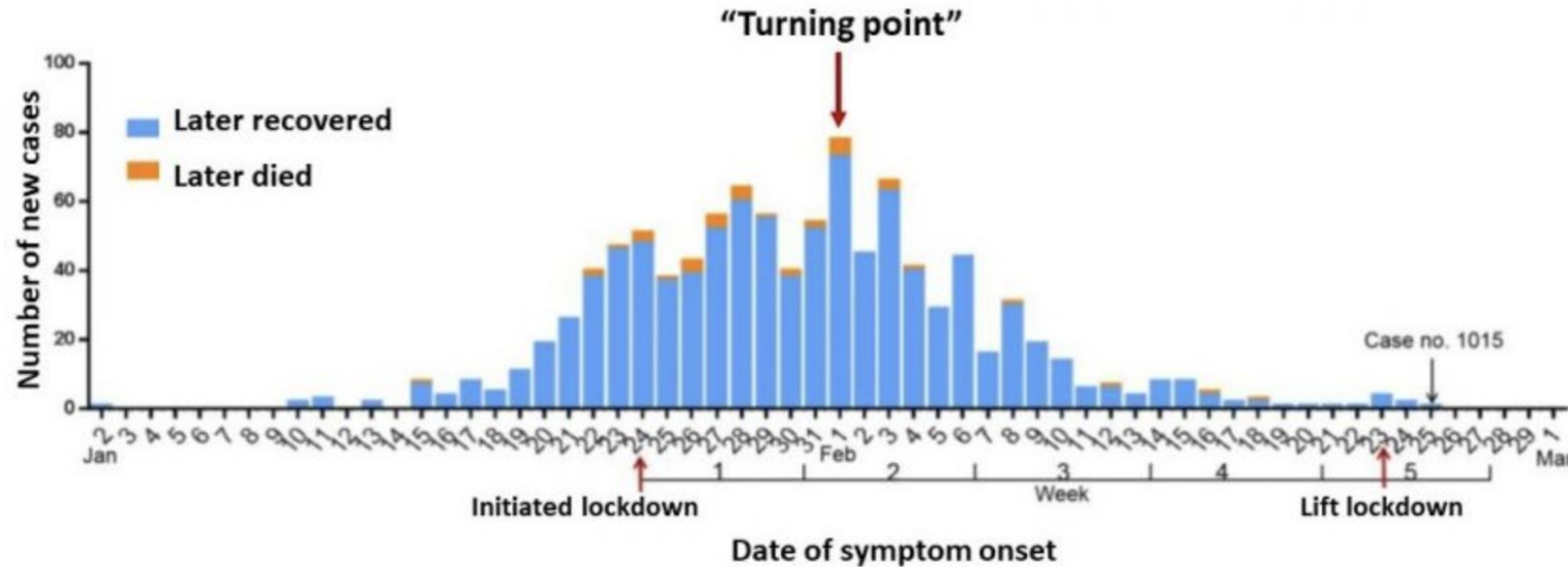
Since

$$\lambda(t) = b * k * I(t) = \textit{Beta} * I(t)$$

then

$$\textit{Beta} = \lambda(t) / I(t)$$

Or we can find the Beta that reproduces our epidemic curve.



Or we can measure the two components of the transmission parameter.

- Per contact infectivity
- Contact rate

How to estimate b (per contact infectivity)

- Decide what constitutes a “contact” for our specific disease.
- Measure the probability that a transmission event occurs when an infectious person contacts a susceptible person.

How Do Bacterial Infections Spread?



- 1 **Airborne or droplet.**
Contaminated dust, droplets of water or mucus.



- 2 **Direct or indirect contact.**
Skin or mucous membrane contact, contaminated surfaces.



- 3 **Vector.**
Mosquito, tick or flea bite.



- 4 **Vehicular.**
Contaminated food or water.

Discrete exposures

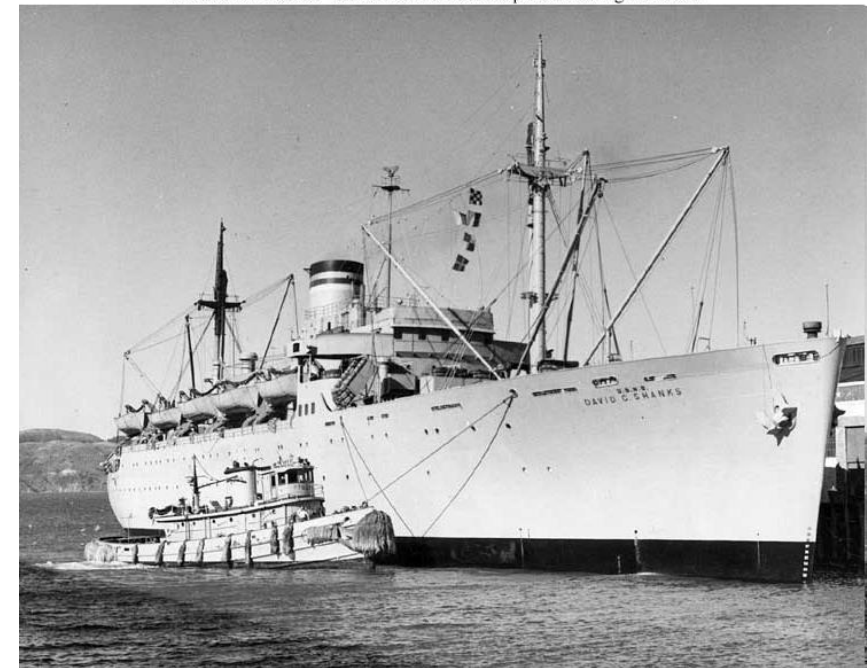
- Needle stick injuries
- Blood transfusions
- **Sexual encounters**
- Insect bites

COHORT STUDY OF VENEREAL DISEASE. I: THE RISK OF GONORRHEA TRANSMISSION FROM INFECTED WOMEN TO MEN

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- Objectives
 - Describe method of measuring STD infectiousness.
 - Measure transmission probability for Gonorrhea.
 - Measure factors that alter the transmission probability.

Photo # NH 103783 USNS David C. Shanks pierside during the 1950s



Measuring per-contact infectivity for Gonorrhea

- How many men got GC?
 - Of 498 men on shore leave from naval ship who reported unprotected sex, 54 were found to have GC.
 - $54 / 498 \text{ infected} = .102$

Binomial chain model:

Conditioning for multiple exposures

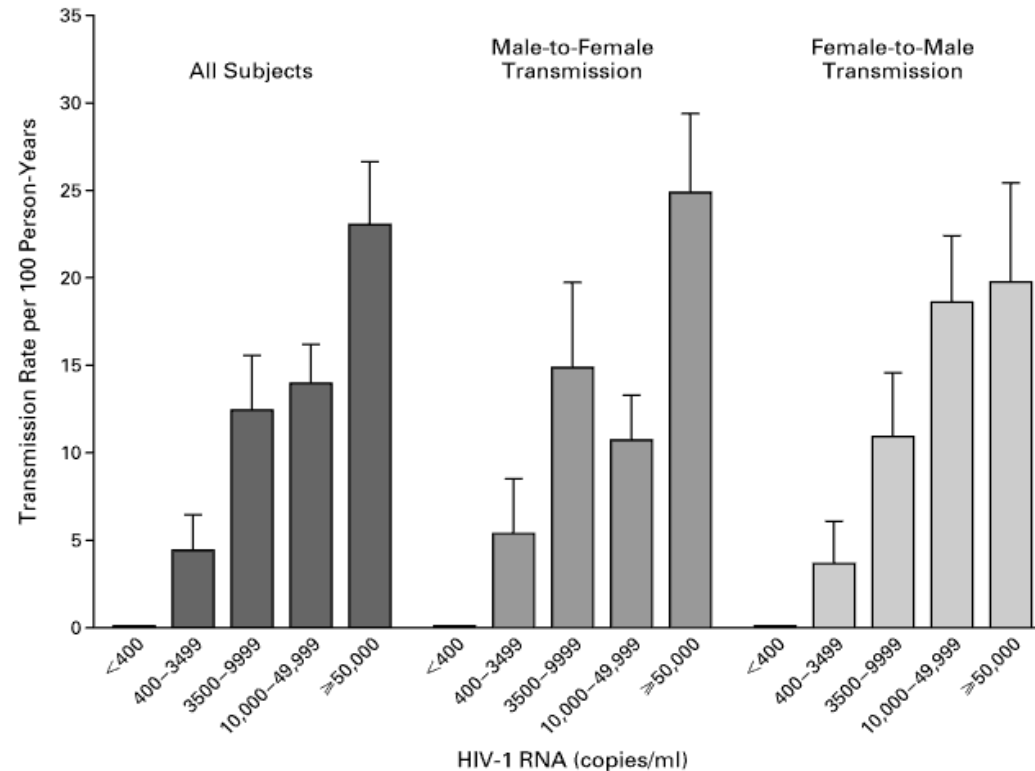
- Let p = risk of infection per contact
- Let $1-p$ = risk of not being infected
- Let n = number of contacts

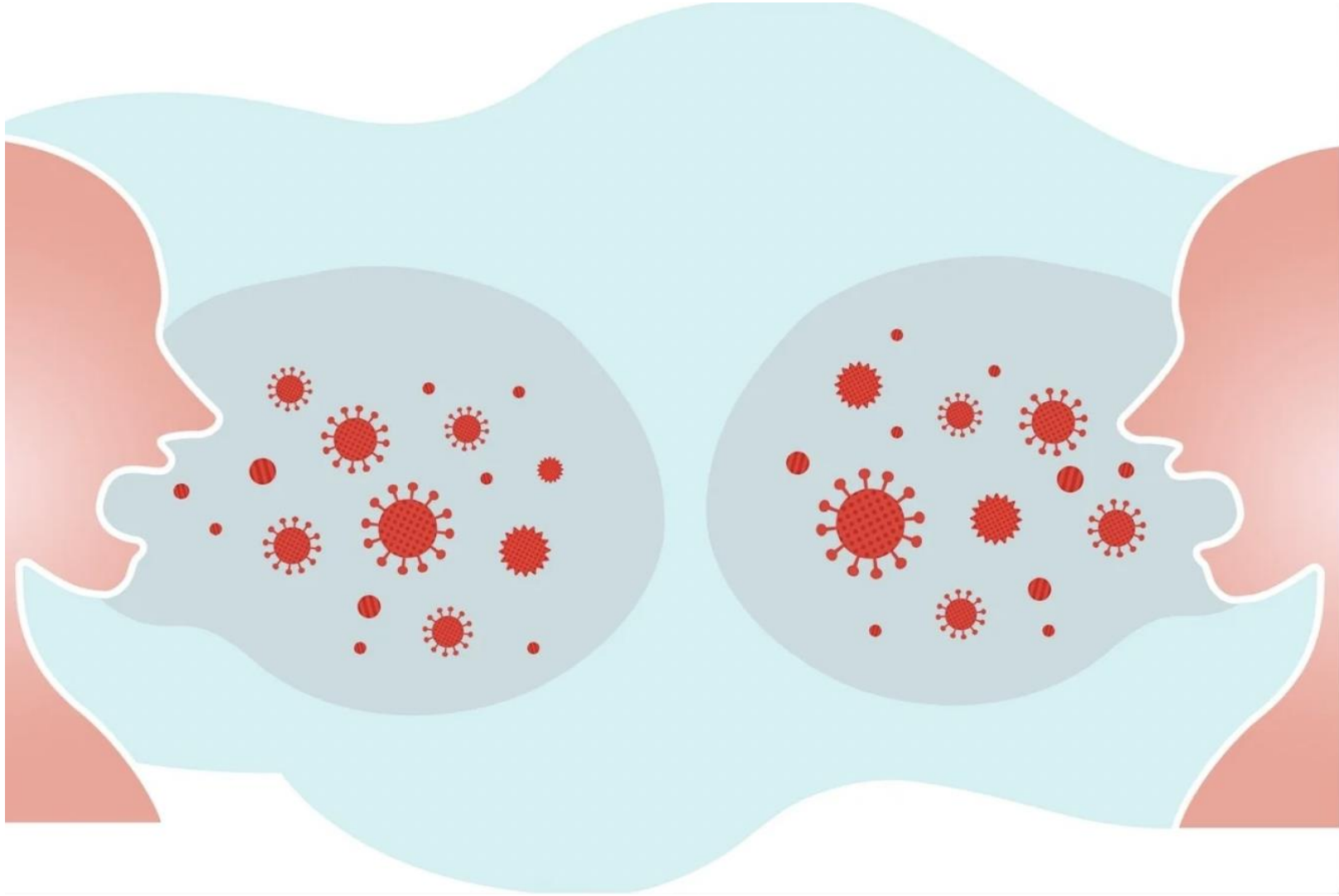
Then risk of *not* being infected after n contacts
 $= (1-p)^n$

And risk of being infected after n contact
 $= 1 - (1-p)^n$

Complexity

- Not all contacts are the same
- For HIV depends on viral load, presence of other STDs, age, whether transmission is from men to women or vice versa.





THE LANCET

Secondary attack rate and superspreading events for SARS-CoV-2

Yang Liu • Rosalind M Eggo • Adam J Kucharski ✉

Published: February 27, 2020 • DOI: [https://doi.org/10.1016/S0140-6736\(20\)30462-1](https://doi.org/10.1016/S0140-6736(20)30462-1)

	Date of exposure	Setting	Number at gathering (excluding primary case)	Subsequently infected
Harbin, Heilongjiang, China	Jan 24, 2020	Meal (home)	8	8
Shuangyashan, Heilongjiang, China	Jan 24, 2020	Meal (home)	13	4
Hangzhou, Zhejiang, China	Jan 17, 2020	Meal (unknown location)	1	1
Nanjing, Jiangsu, China	Jan 23, 2020	Meal (unknown location)	8	7
Nanjing, Jiangsu, China	Jan 24, 2020	Meal (restaurant)	14	3
Enshi, Hubei, China	Unknown	Meal (unknown location)	17	2
Enshi, Hubei, China	Unknown	Meal (unknown location)	47	10
Haute-Savoie, France	Jan 24–28, 2020	Chalet	11	5
Hong Kong	Unknown	Meal (home)	18	8

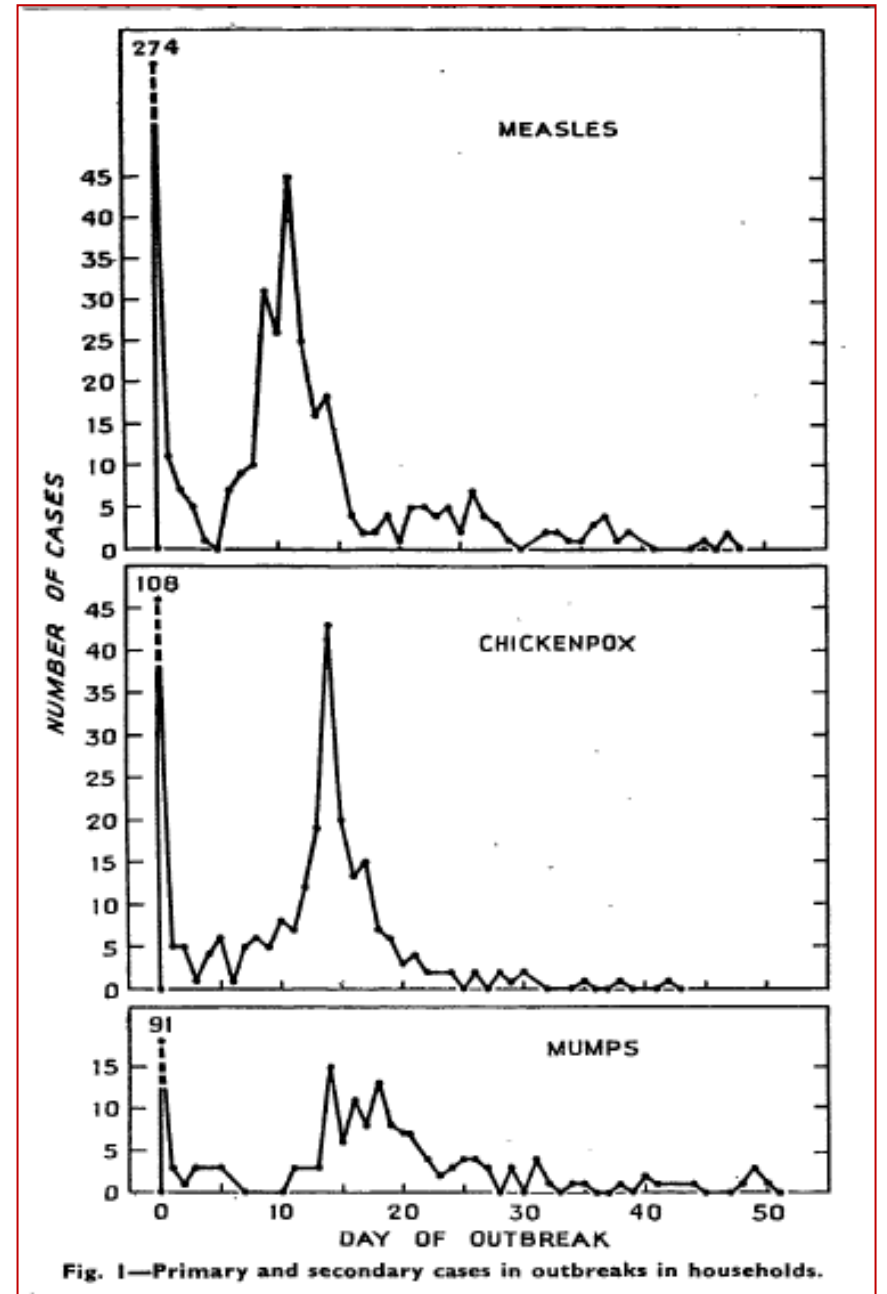
Full details are provided in the appendix.

Table: Summary of severe acute respiratory syndrome coronavirus 2 transmission events where the numbers of people exposed and subsequently infected were known, assuming a single primary case, by location

Drawing on data from nine recent reports of secondary transmission associated with a specific event such as a meal or holiday visit, we estimated 48 secondary infections occurred among 137 attendees. Assuming that all these secondary infections were generated by a single primary case, which is probable given the short-term nature of the exposure event.

Hope Simpson Study

- Objectives
 - Determine relative transmissibility measles, chickenpox, mumps
 - Define method for measuring transmissibility
 - Relate age distribution to infectiousness
 - Determine patterns and causes of seasonality

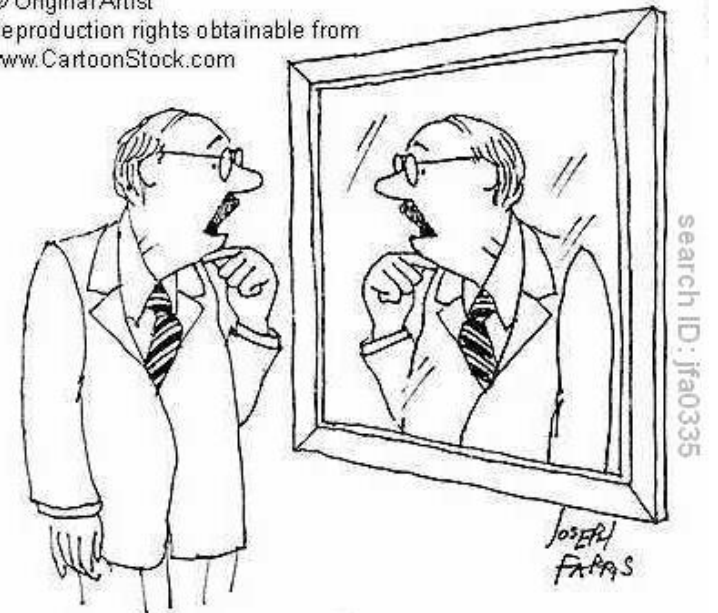


How did Simpson know people had not previously been infected?

- Choose symptomatic illness with characteristic signs
- Age restriction
 - Increasing age brings forgetfulness of childhood ailments, which can be a major source of error in the elderly.



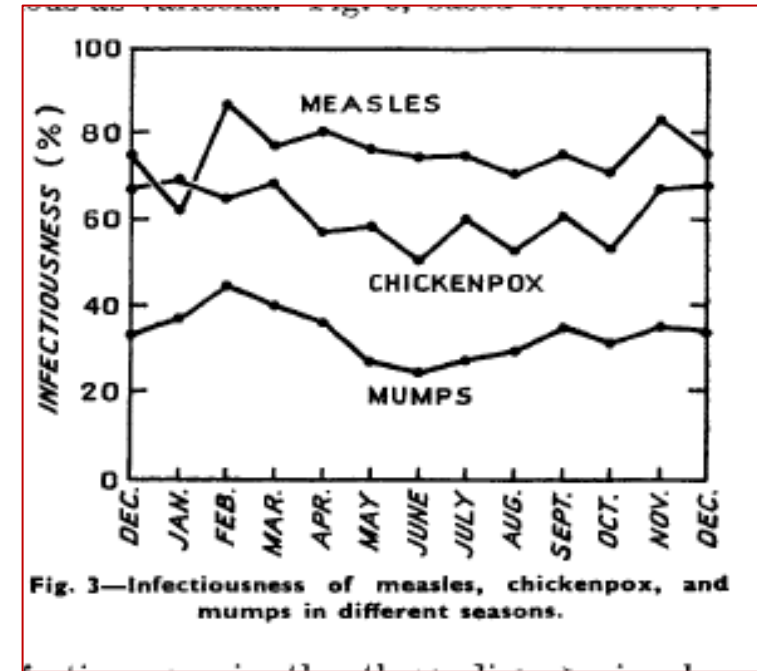
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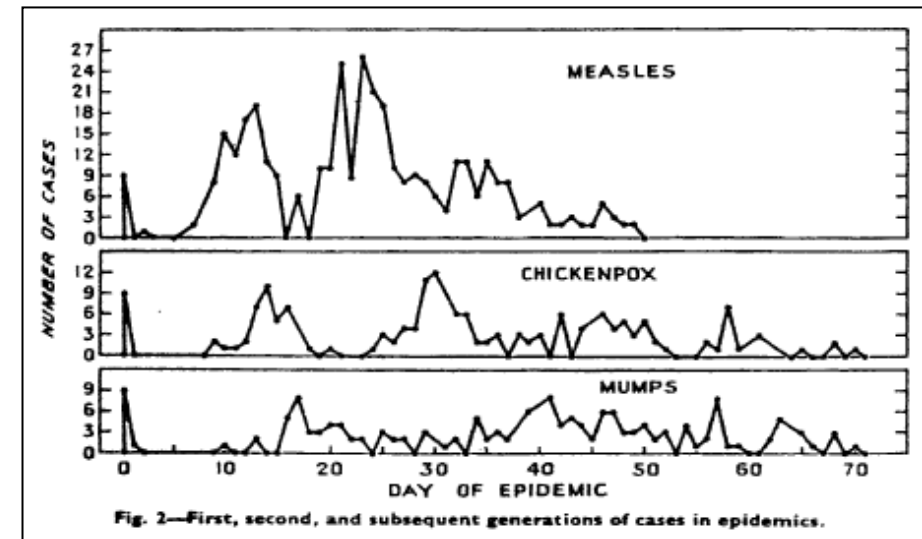
"I remember the face but I've forgotten your name."

Results

- Measles most infectious followed by chickenpox (varicella) and mumps.



- Time course of an epidemic is a function of infectiousness.



Measuring contact rates

Types of contacts

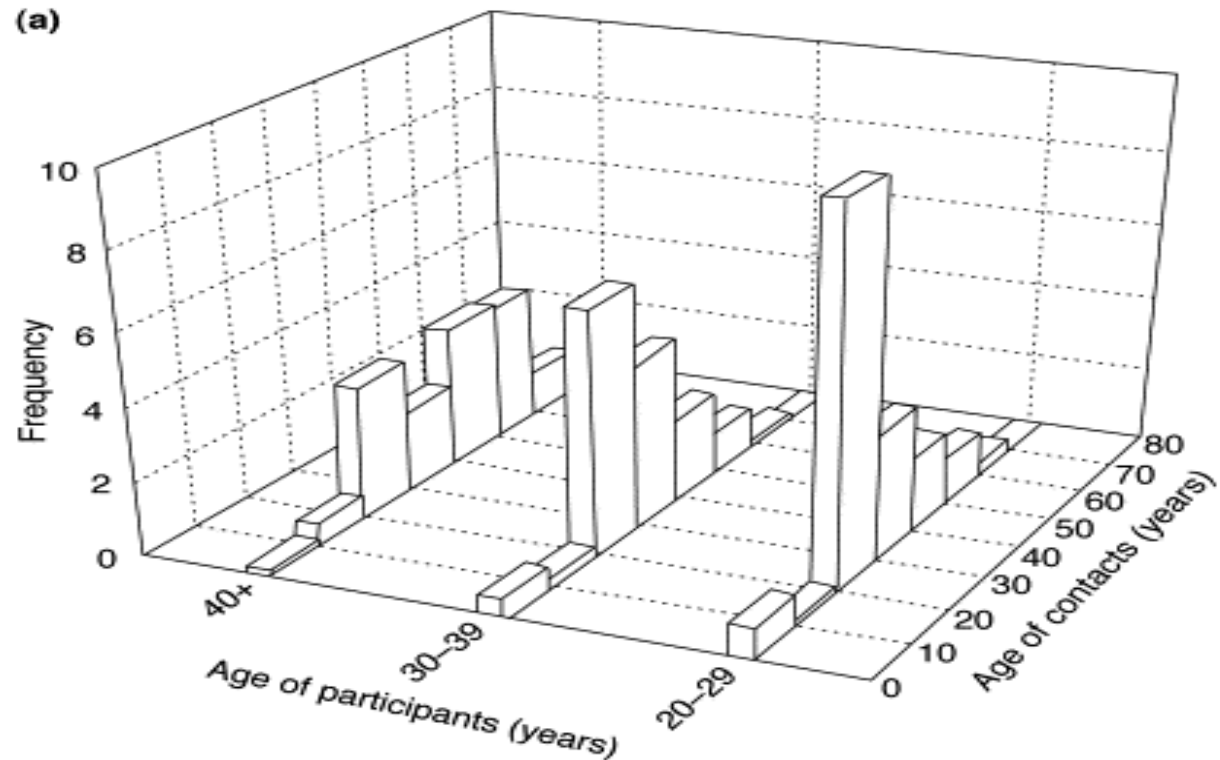
- Countable
 - Sexual
 - Parenteral (needlesticks)
 - Vector-mediated (arthropods)
 - Vertical (pregnancies and births)
- Less countable
 - Respiratory
 - Large droplet versus aerosols
- Even less countable
 - Fecal-oral

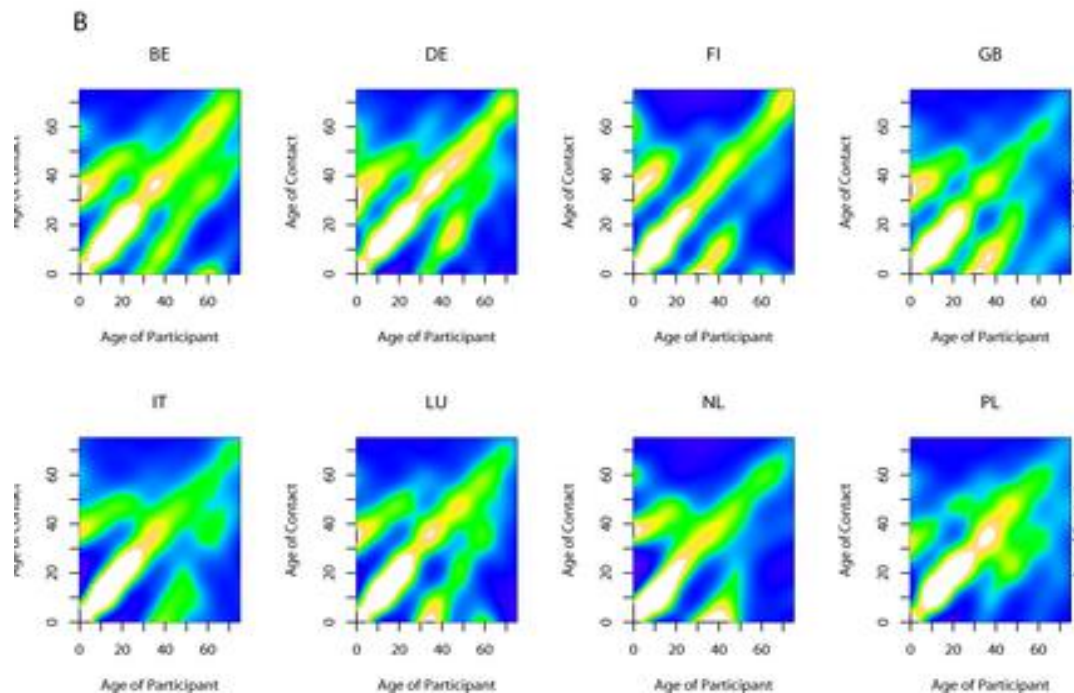
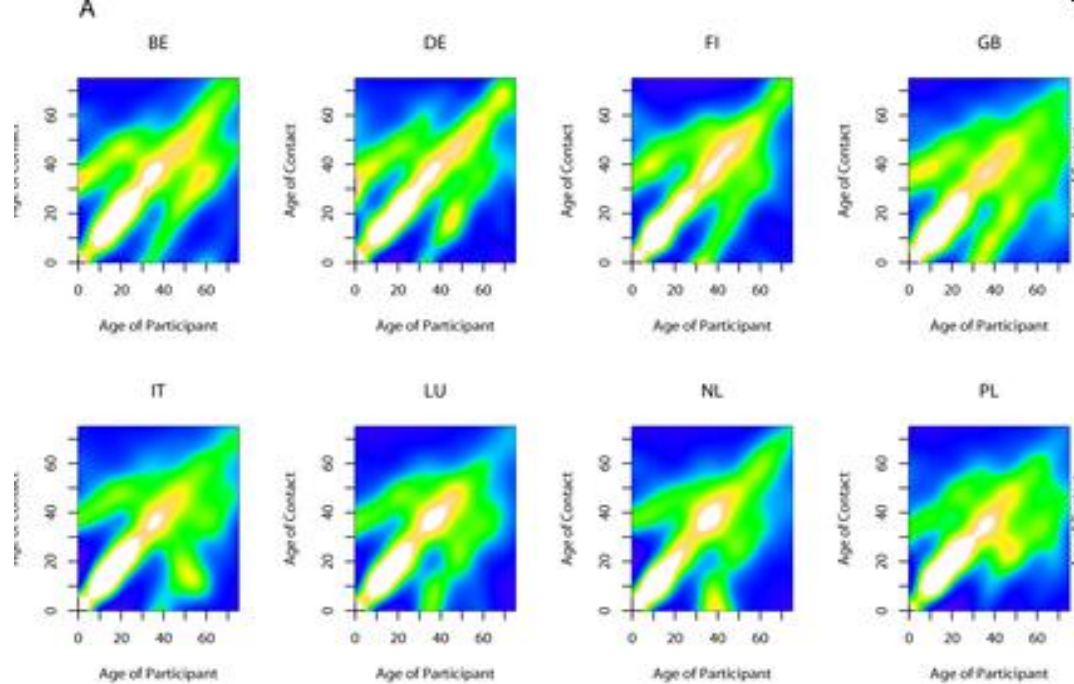
Who are contacts with?

- Age distribution of contacts determines likelihood that an infectious person encounters a susceptible person.
- Contact rates vary with age and “social” activity level

Who contacts whom?

Average # respiratory contacts by age





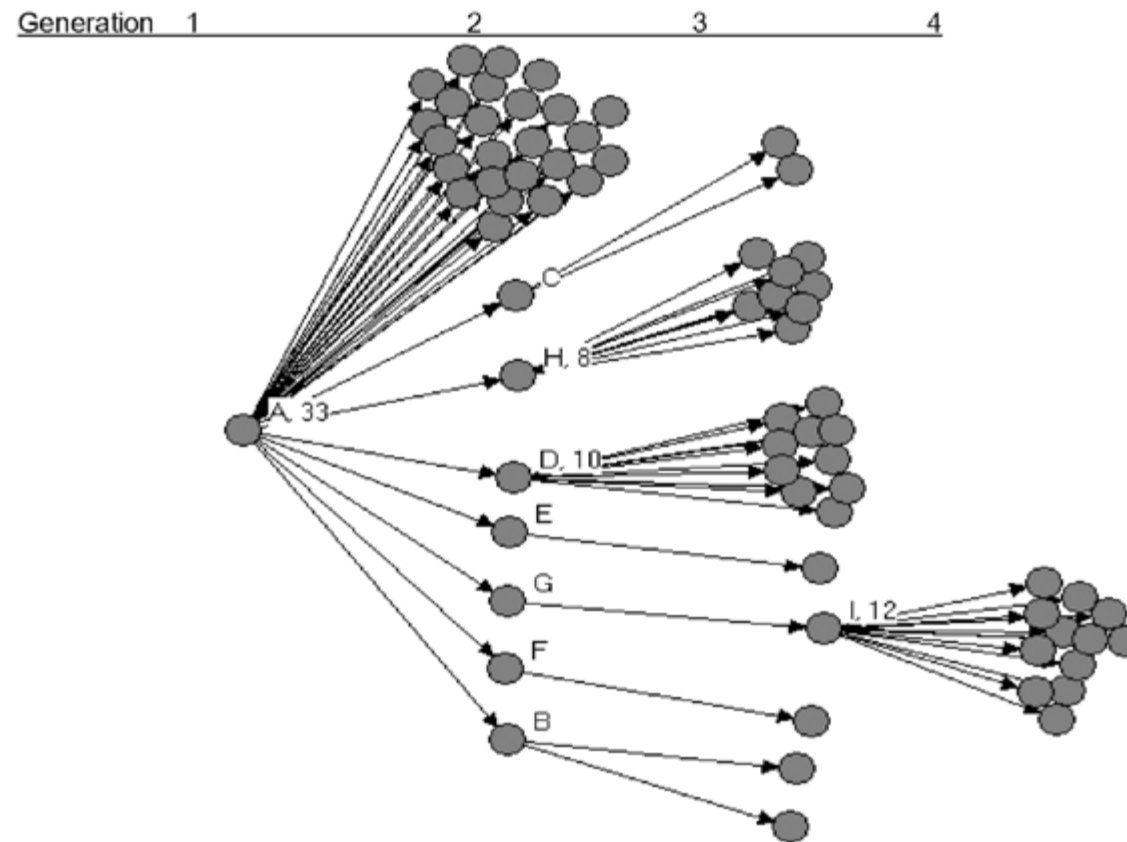
- Contact Matrices for Each Country Based on (A) All Reported Contacts and (B) Physical Contacts.
- White indicates high contact rates, green intermediate contact rates, and blue low contact rates, relative to the country-specific contact intensity.

Definitions

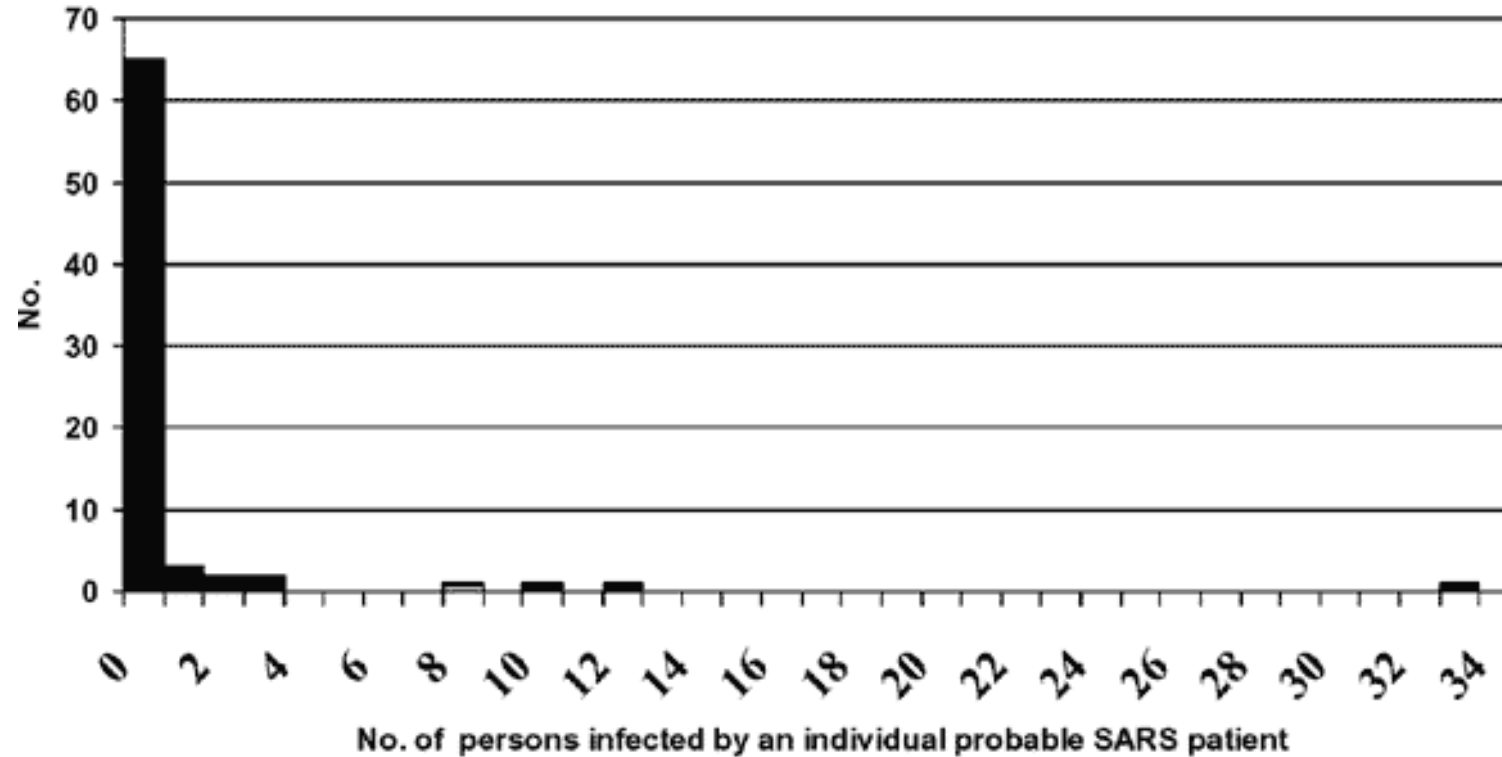
- Assortative mixing means that like mixes with like. For example, school children are more likely to mix with each other than with adults.
- Disassortative mixing means that like mixes with unlike; commercial sex workers may be unlikely to have sex with other CSWs.

What about super-spreading?

Non-homogeneous spread from single infective case



SARS-1 Super-spreading



Superspreading SARS Events, Beijing, 2003

Zhuang Shen,* Fang Ning,* Weigong Zhou,†‡ Xiong He,*
Changying Lin,* Daniel P. Chin,† Zonghan Zhu,§ Anne Schuchat†‡

Who are super-spreaders?

- Disease dependent
 - Route of transmission
 - Biology
 - Carrier state
- Behavior dependent
 - # of contacts people make
 - Concurrency of contacts
 - Links between social groups
- Environment dependent
 - Ventilation
 - UV
 - Activities

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NEWS FEATURE | 23 February 2021

Superspreading drives the COVID pandemic – and could help to tame it

Uneven transmission of the SARS-CoV-2 coronavirus has had tragic consequences – but also offers clues for how best to target control measures.

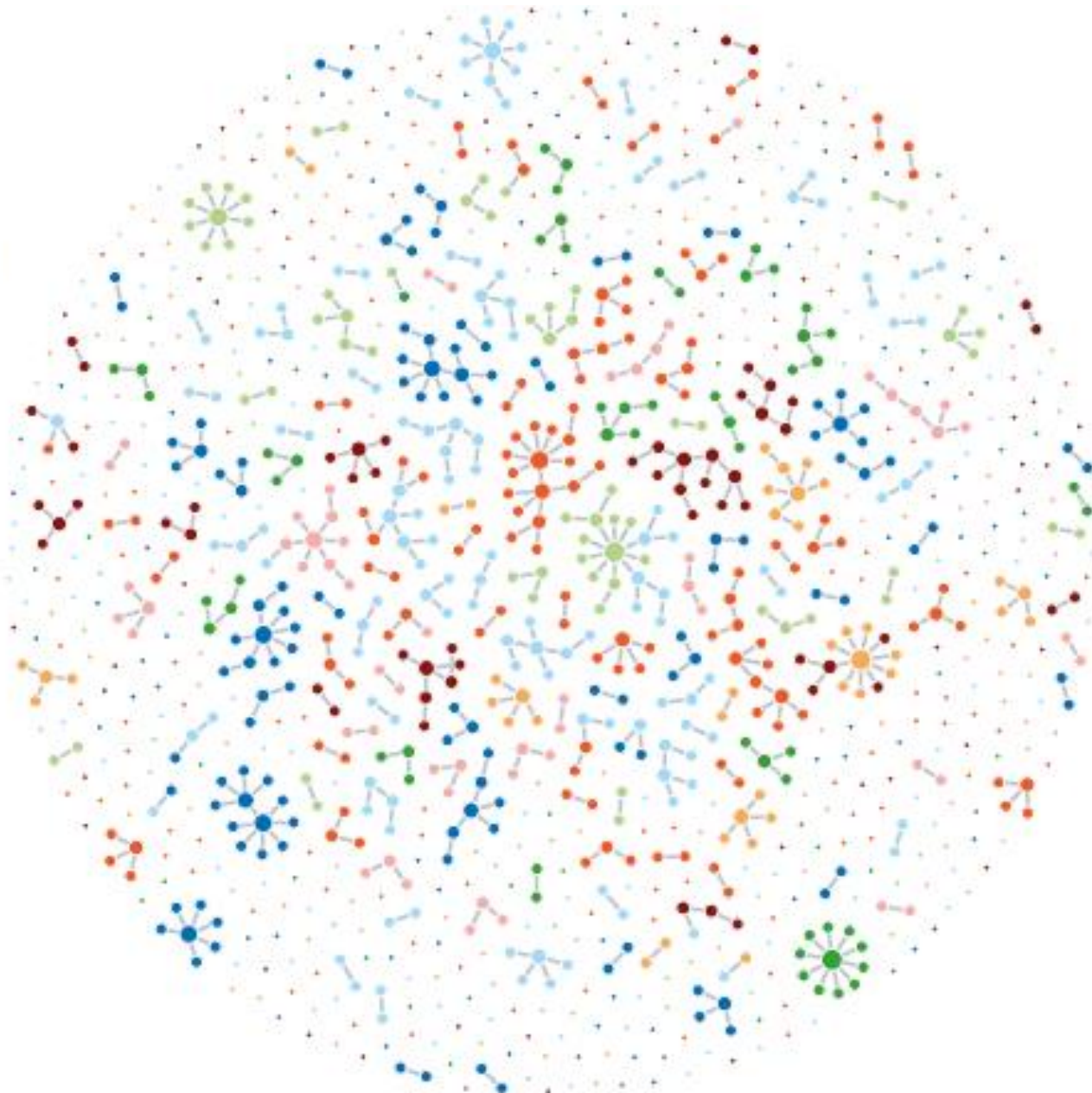


INFECTION CONNECTIONS

Coloured dots represent people infected with SARS-CoV-2 in early 2020 in Hunan province, China. Researchers reconstructed chains of transmission for 1,178 people, represented by lines connecting the dots. Most individuals did not infect anybody else, but 15% of people accounted for 80% of secondary infections — an indication that superspreading played a major part in transmissions.

Prefectures in Hunan

- Changsha
- Yueyang
- Shaoyang
- Loudi
- Changde
- Zhuzhou
- Yiyang
- Others



What does super-spreading and more generally, heterogeneity in contact rates mean for models?

Summary

- Transmission parameters often “fitted” to epidemic data.
- Useful to do a “reality check” by measuring per contact infectivity and contact rates to verify correct parameters and to consider possible issues with models.
- Incorporation of realistic age and other heterogeneity and super-spreading complicates models and their interpretation.