IDM Annual Symposium
May 2023

Heterogeneity in network structure switches the dominant transmission mode of infectious diseases

Pratyush Kollepara

Dr Rebecca Chisholm and Dr Joel Miller

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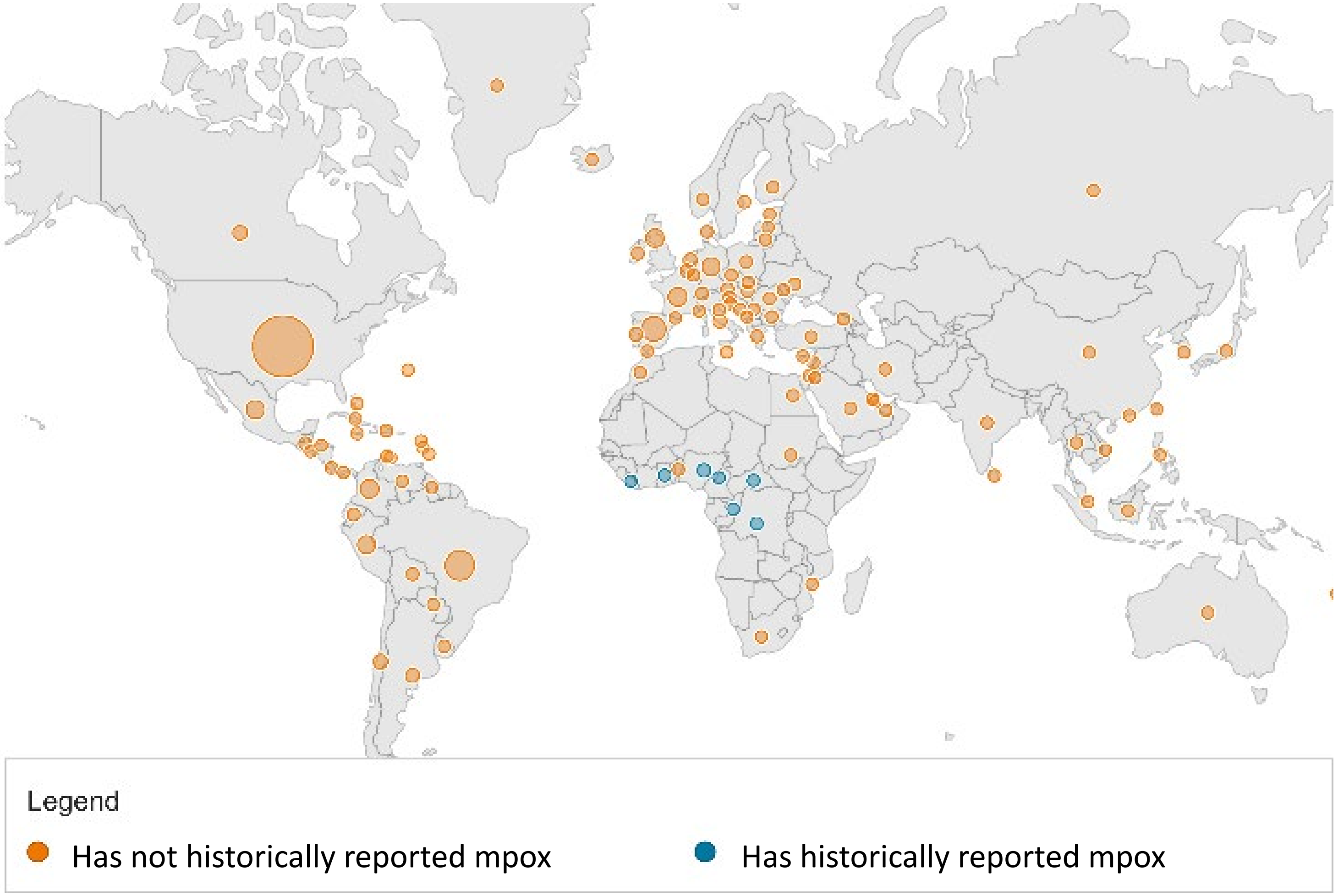
- Past outbreaks – casual close contact – $\mathcal{R}_0 < 1$



https://www.cdc.gov/poxvirus/monkeypox/response/2022/world-map.html

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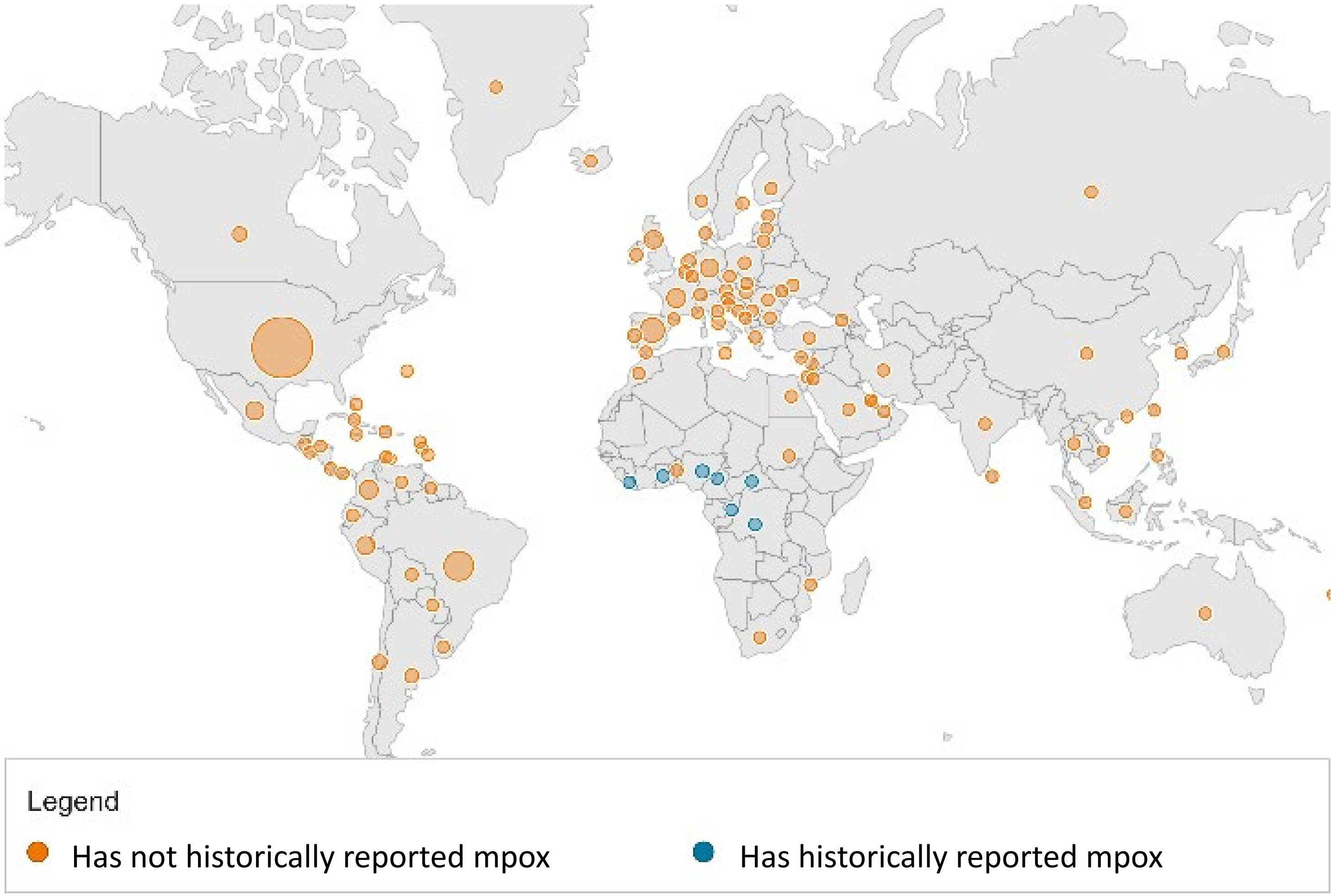
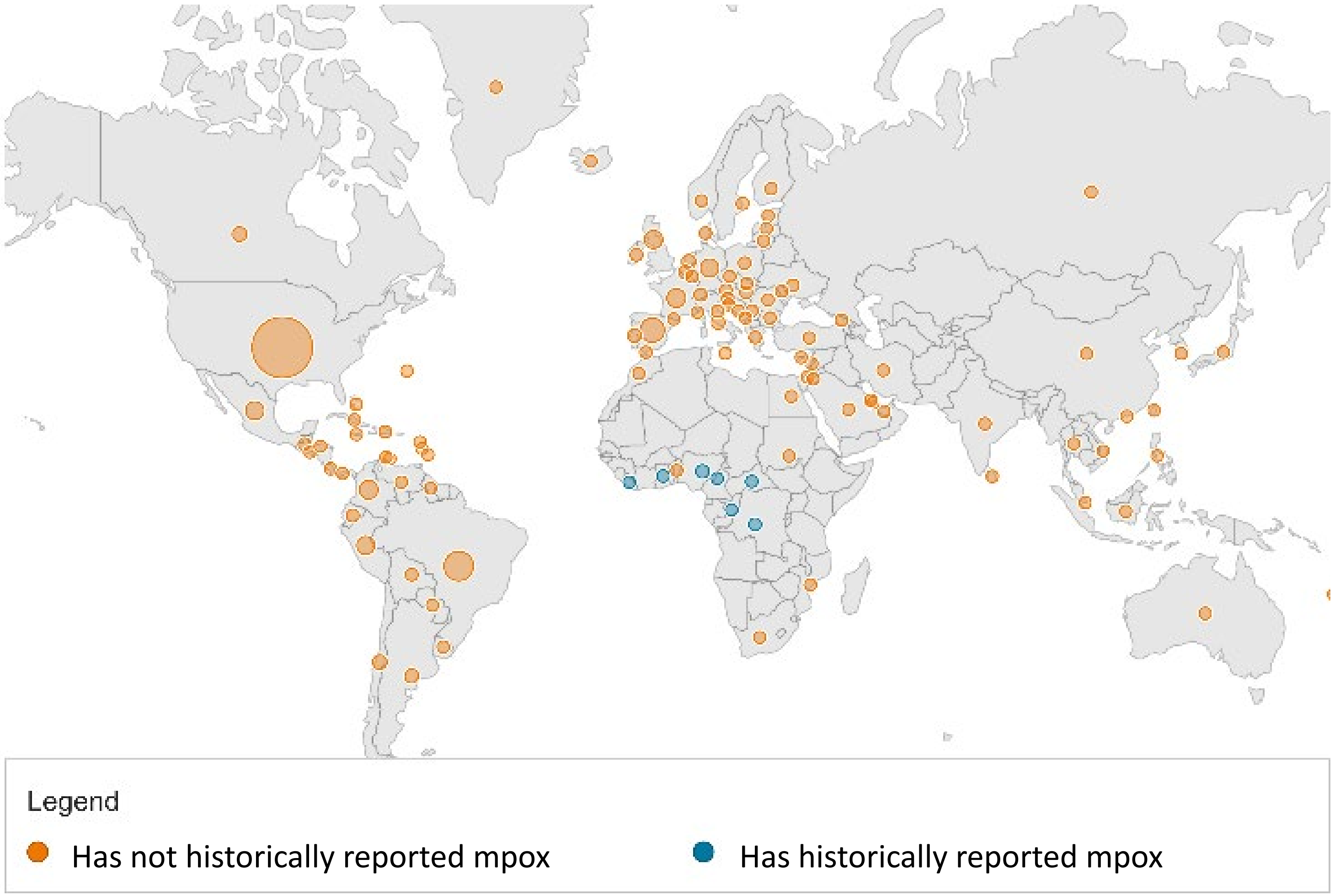
- Past outbreaks – casual close contact – $\mathcal{R}_0 < 1$
- Latest outbreak – sexual contact – $\mathcal{R}_0 > 1$



https://www.cdc.gov/poxvirus/monkeypox/response/2022/world-map.html

- Past outbreaks – casual close contact – $\mathcal{R}_0 < 1$
- Latest outbreak – sexual contact – $\mathcal{R}_0 > 1$
- Sexual transmission – dominant



https://www.cdc.gov/poxvirus/monkeypox/response/2022/world-map.html

If there are multiple modes of transmission, then the one which is most likely to expose you to a transmission event is the dominant mode of transmission.

1

Casual Transmission $\mathcal{R}_0 < 1$

2

Sexual Transmission $\mathcal{R}_0 > 1$

3

Combined model of casual and sexual transmission

1

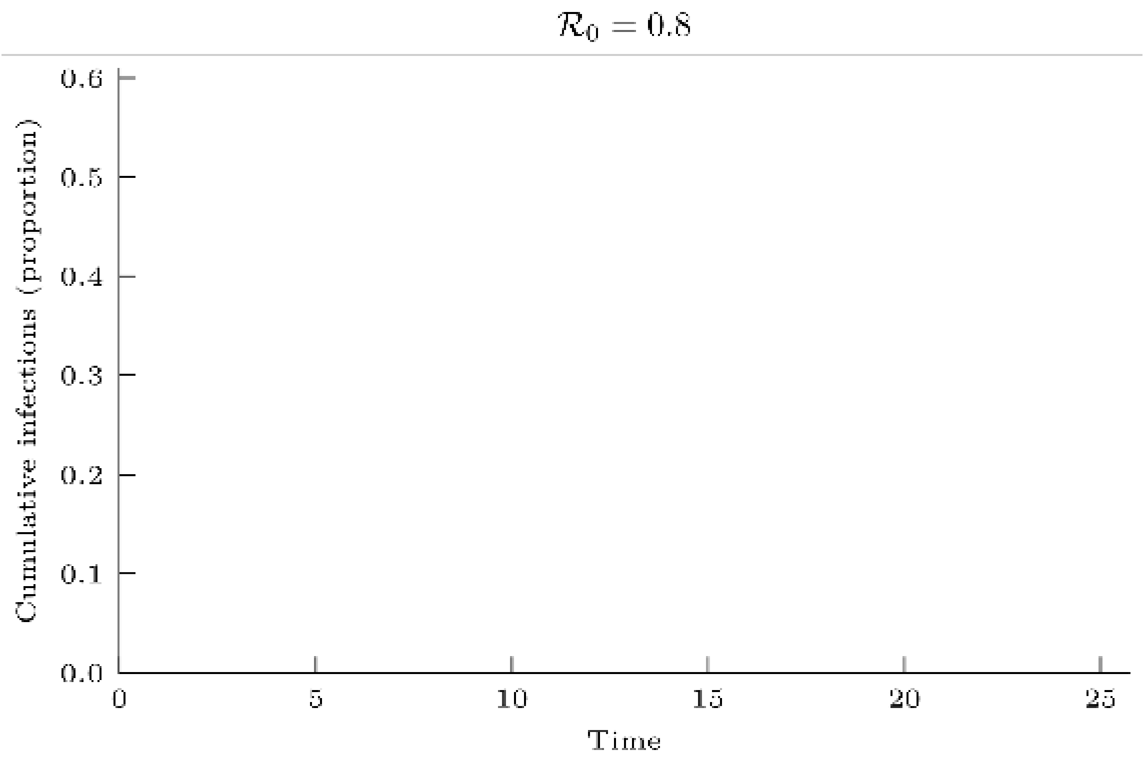
Casual Transmission
$\mathcal{R}_0 < 1$

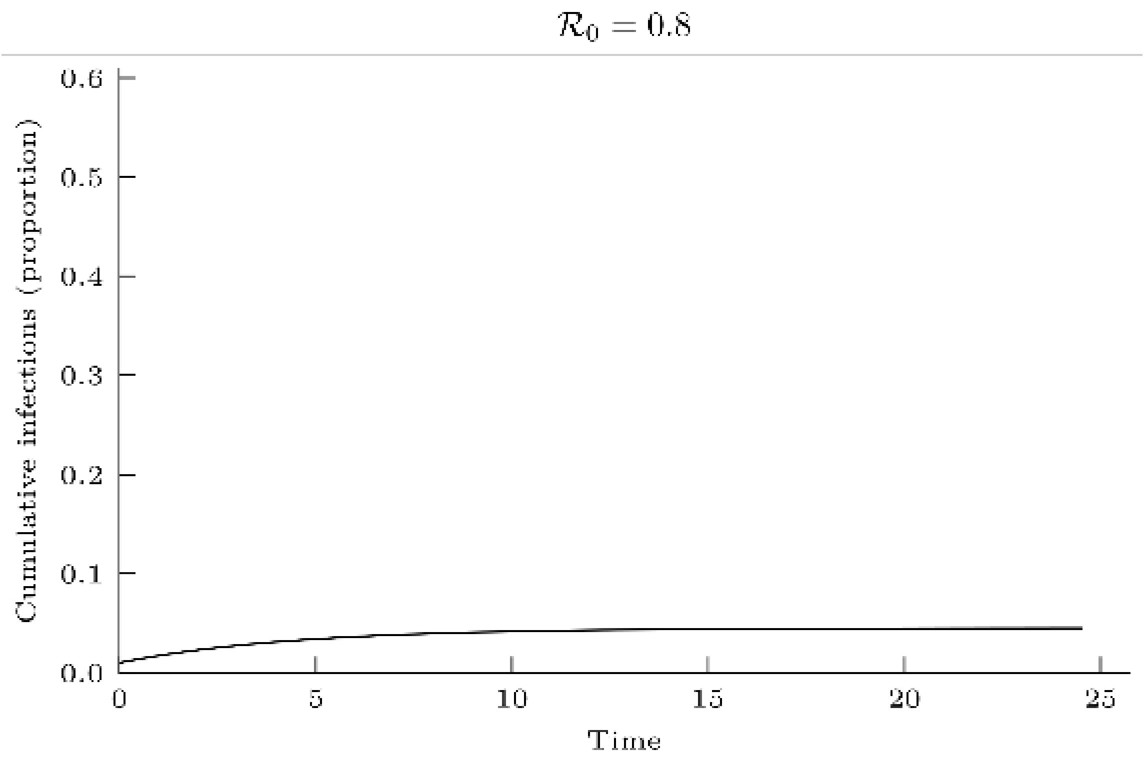
2

Sexual Transmission
$\mathcal{R}_0 > 1$

3

Combined model of casual and sexual transmission


$\mathcal{R}_0 = 0.8$
Cumulative infections (proportion)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
Time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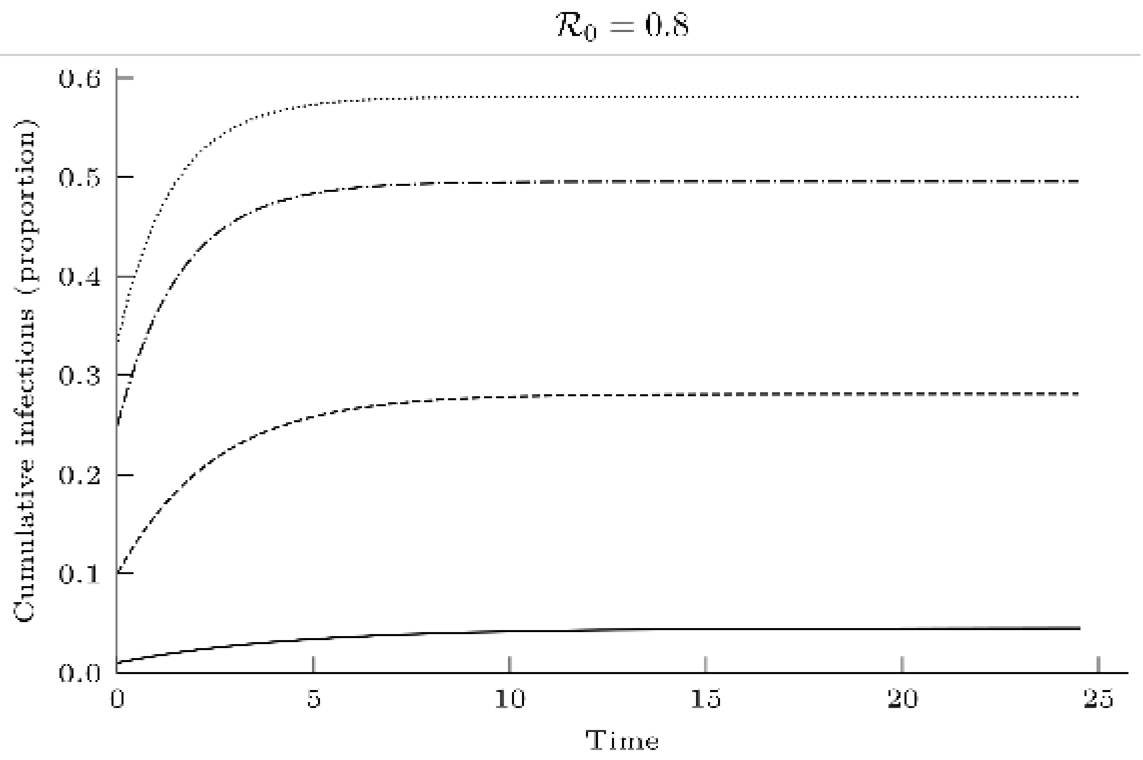


Start with many active infections – get many new infections

1

Casual Transmission $\mathcal{R}_0 < 1$

2

Sexual Transmission $\mathcal{R}_0 > 1$

3

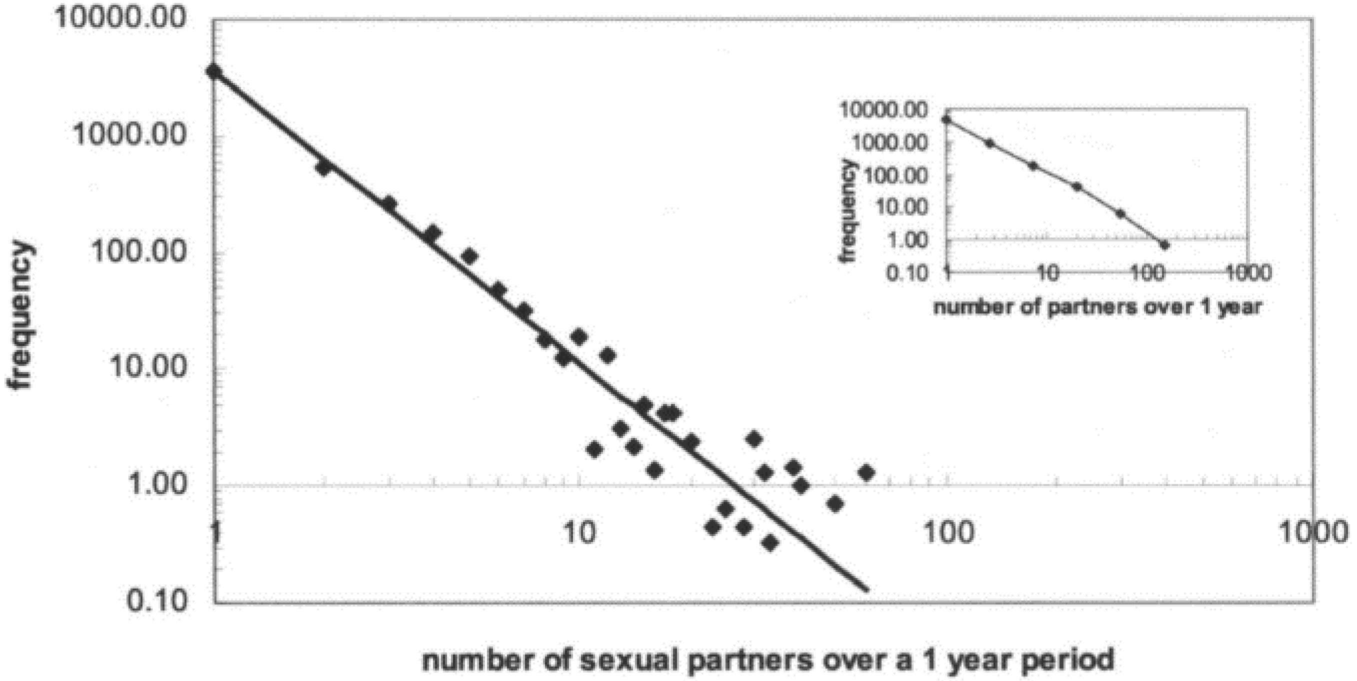
Combined model of casual and sexual transmission

JOURNAL ARTICLE

Scale-Free Networks and Sexually Transmitted Diseases: A Description of Observed Patterns of Sexual Contacts in Britain and Zimbabwe

ANNE SCHNEEBERGER, CATHERINE H. MERCER, SIMON A. J. GREGSON, NEIL M. FERGUSON, CONSTANCE A. NYAMUKAPA, ROY M. ANDERSON, ANNE M. JOHNSON and GEOFF P. GARNETT

Sexually Transmitted Diseases
Vol. 31, No. 6 (June 2004), pp. 380-387 (8 pages)



Number of contacts ~ power law distributed (long tailed)

ELSEVIER

Physics Letters A

Volume 368, Issue 6, 3 September 2007, Pages 458-463

Influence of network structure on rumor propagation

Jie Zhou [a], Zonghua Liu [a, b], Baowen Li [b, c, a]

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https://doi.org/10.1016/j.physleta.2007.01.094

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Propagation and immunization of infection on general networks with both homogeneous and heterogeneous components

Zonghua Liu, Ying-Cheng Lai, and Nong Ye

Phys. Rev. E **67**, 031911 – Published 19 March 2003

EPIDEMIC DYNAMICS ON RANDOM AND SCALE-FREE NETWORKS

Published online by Cambridge University Press: **30 January 2013**

J. BARTLETT and M. J. PLANK

SIR on sexual contact network – final number of infections is smaller

1

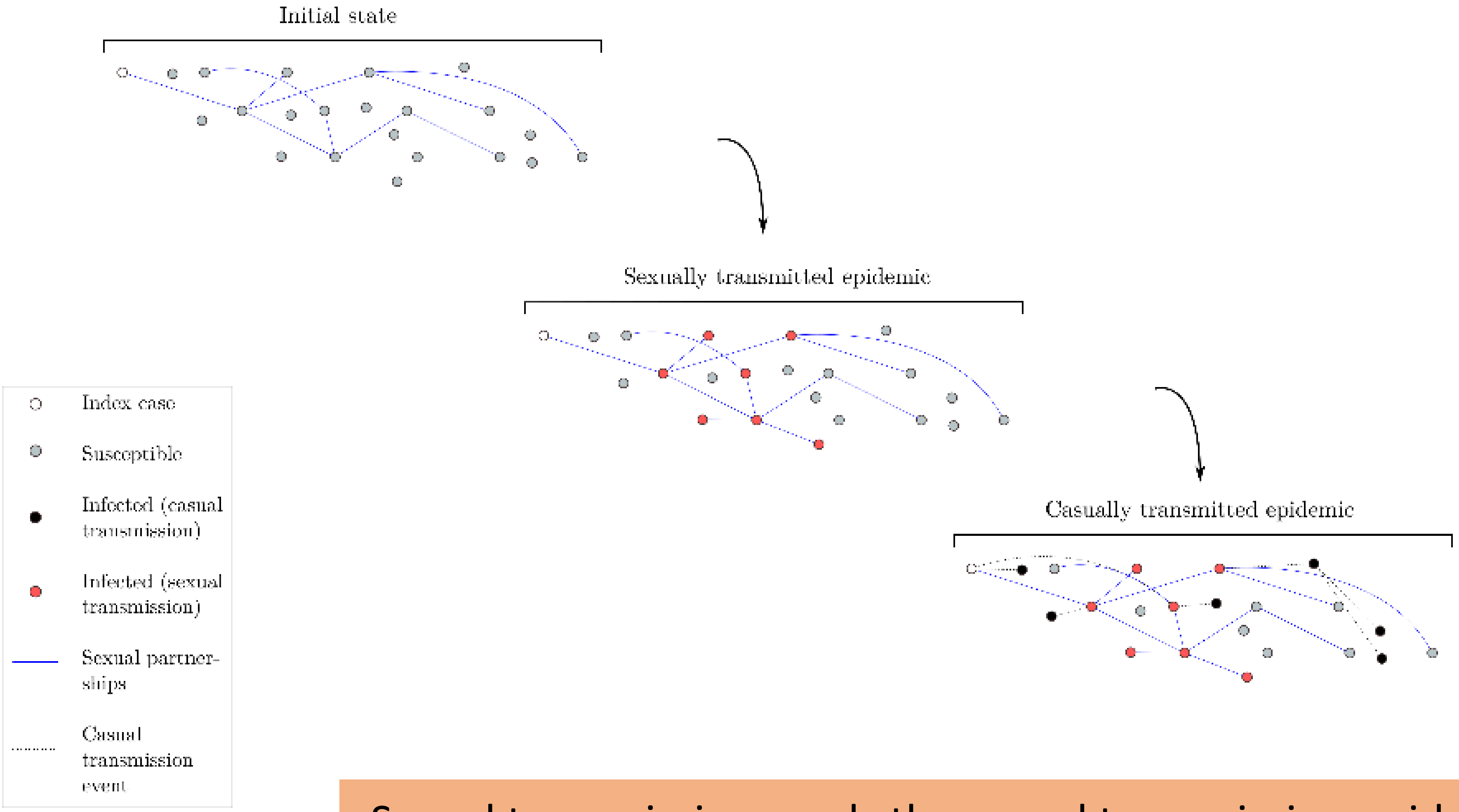
Casual Transmission $\mathcal{R}_0 < 1$

2

Sexual Transmission $\mathcal{R}_0 > 1$

3

Combined model of casual and sexual transmission



Sexual transmission seeds the casual transmission epidemic

ELSEVIER

Mathematical Biosciences
Volume 203, Issue 1, September 2006, Pages 124-136

The effect of contact heterogeneity and multiple routes of transmission on final epidemic size

Istvan Z. Kiss, Darren M. Green, Rowland R. Kao

KeAi
CHINESE ROOTS GLOBAL IMPACT

Infectious Disease Modelling
Volume 2, Issue 1, February 2017, Pages 35-55

Mathematical models of SIR disease spread with combined non-sexual and sexual transmission routes

Joel C. Miller [a, b]

Two forces of infection – from casual transmission and from sexual transmission

Two forces of infection – from casual transmission and from sexual transmission

$$\frac{\mathrm{d}S}{\mathrm{d}t} \sim -S \times (F_c + F_s)^*$$

*Calculation of this force of infection is not shown here

Two forces of infection – from casual transmission and from sexual transmission

$$\frac{\mathrm{d}S}{\mathrm{d}t} \sim -S \times (F_c + F_s)^*$$

$$\frac{S(t)}{S(0)} \sim \exp\left(-\int_0^t F_c \, \mathrm{d}\tau\right) \exp\left(-\int_0^t F_s \, \mathrm{d}\tau\right)$$

*Calculation of this force of infection is not shown here

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Two forces of infection – from casual transmission and from sexual transmission

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Probability of not getting exposed to any transmission up to time *t* =

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Two forces of infection – from casual transmission and from sexual transmission

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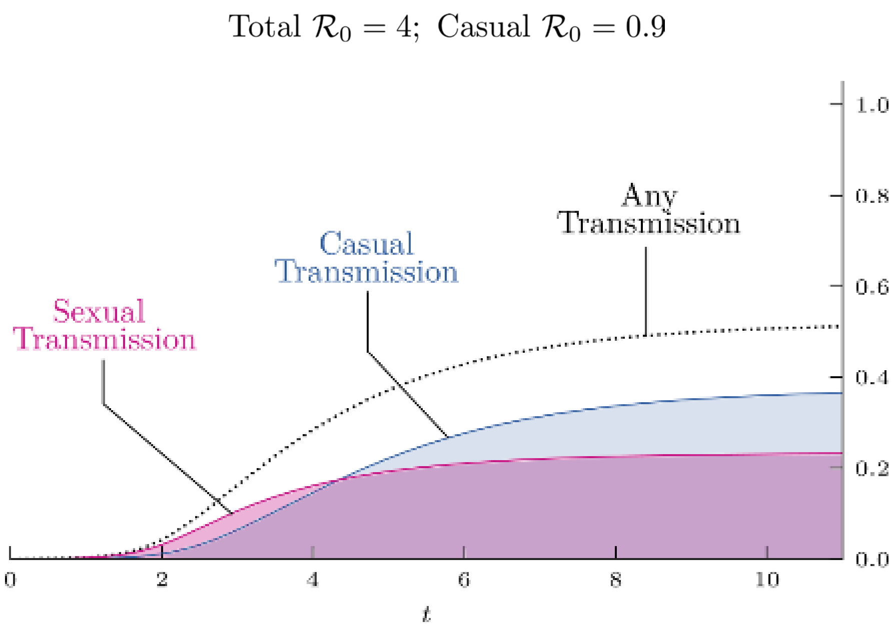
$$\frac{S(t)}{S(0)} \sim \exp\left(-\int_0^t F_c \,\mathrm{d}\tau\right) \exp\left(-\int_0^t F_s \,\mathrm{d}\tau\right)$$

Probability of not getting exposed to any transmission up to time *t* = Probability of not getting exposed to any casual transmission events up to time *t* × Probability of not getting exposed to any sexual transmission events up to time *t*

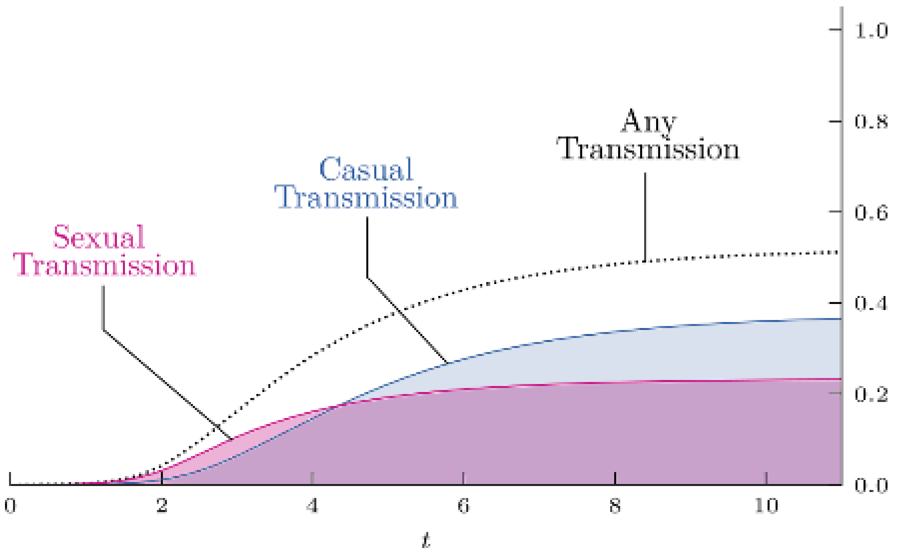
*Calculation of this force of infection is not shown here



Network 1

Casual transmission with $\mathcal{R}_0 < 1$ can become dominant as the epidemic unfolds

Total $\mathcal{R}_0 = 4$; Casual $\mathcal{R}_0 = 0.9$

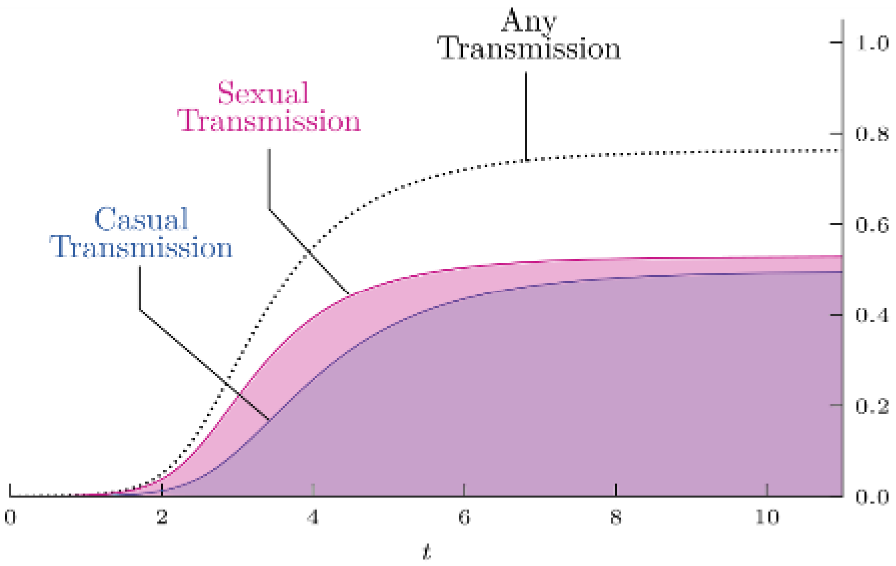


Network 1

Casual transmission with $\mathcal{R}_0 < 1$ can become dominant as the epidemic unfolds

Counter example!

Total $\mathcal{R}_0 = 4$; Casual $\mathcal{R}_0 = 0.9$



Network 2

It's really simple

- An initially non-dominant transmission mode may become dominant at the later stages of an epidemic

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- Mpox: the outbreaks died out

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- An initially non-dominant transmission mode may become dominant at the later stages of an epidemic
- Underestimation of attack rate
- Risk factors for sexually inactive individuals changes with time
- Mpox: the outbreaks died out
- Ebola, Zika and potential emerging diseases

medRxiv

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Cold Spring Harbor Laboratory BMJ Yale

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doi: https://doi.org/10.1101/2022.11.28.22282692

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