Imitation dynamics in a SIR-network model with paediatric vaccination

Presented by
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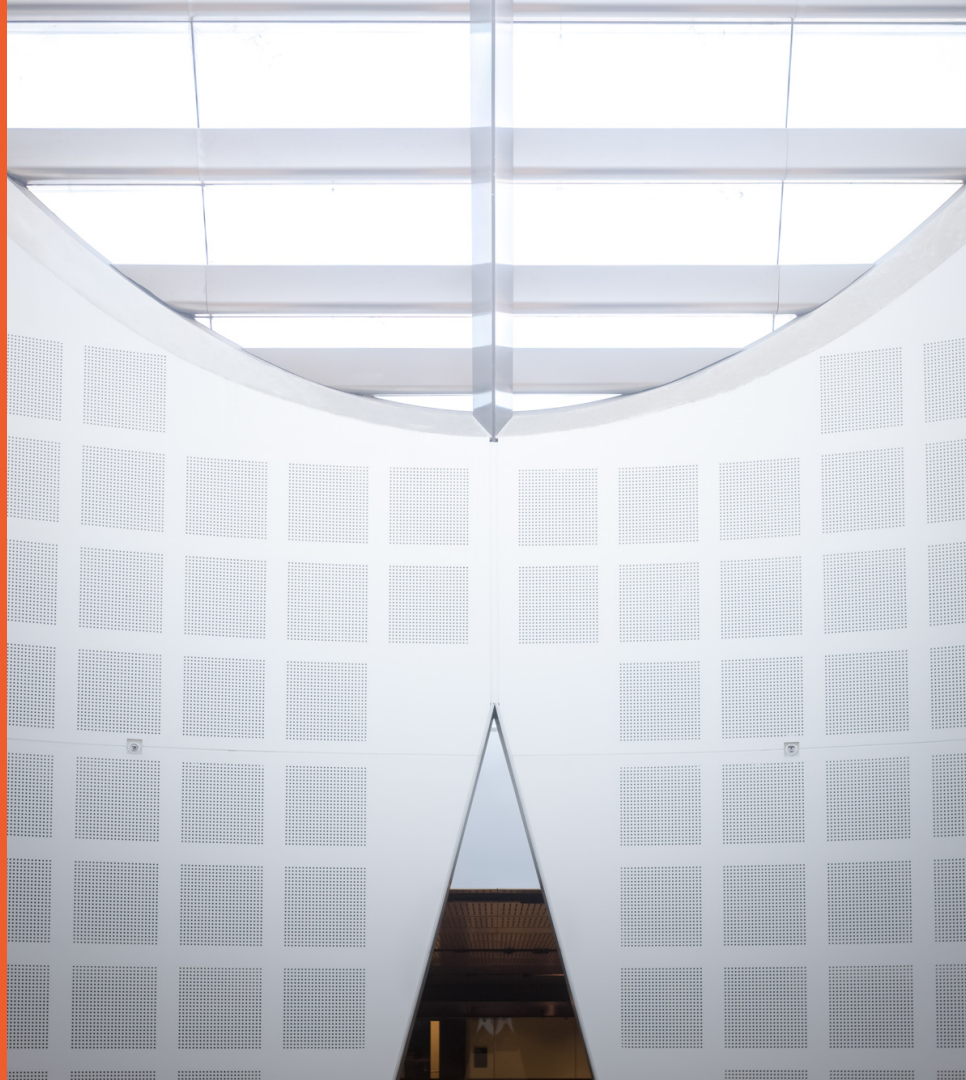

Introduction

McDonald's measles warning as sick man prompts urgent NSW Health alert across Western Sydney

Chris Hook • 7NEWS Friday, 20 September 2019 4:25 pm

Measles warning as woman diagnosed in Sydney

A measles alert has been issued after a Sydney woman, who travelled around the inner west and CBD, was diagnosed with the highly contagious virus.

- Background

- Mobility pattern
- Vaccination
- Integrated model

- 1000-node Erdos-Renyi random network

- Future research

Introduction

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Introduction

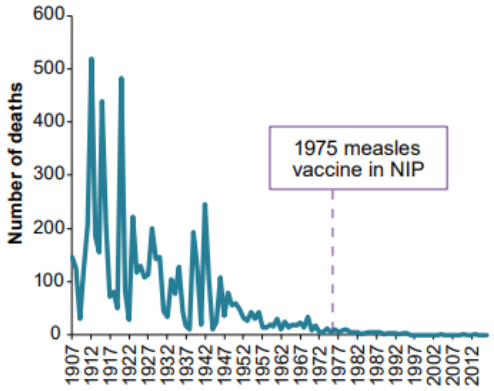
Measles:

- Highly infectious
- Recent measles alert brought from overseas

MMR (measles-mumps-rubella) vaccination:

- 93% nationwide coverage with life immunity

Is our community protected from measles?



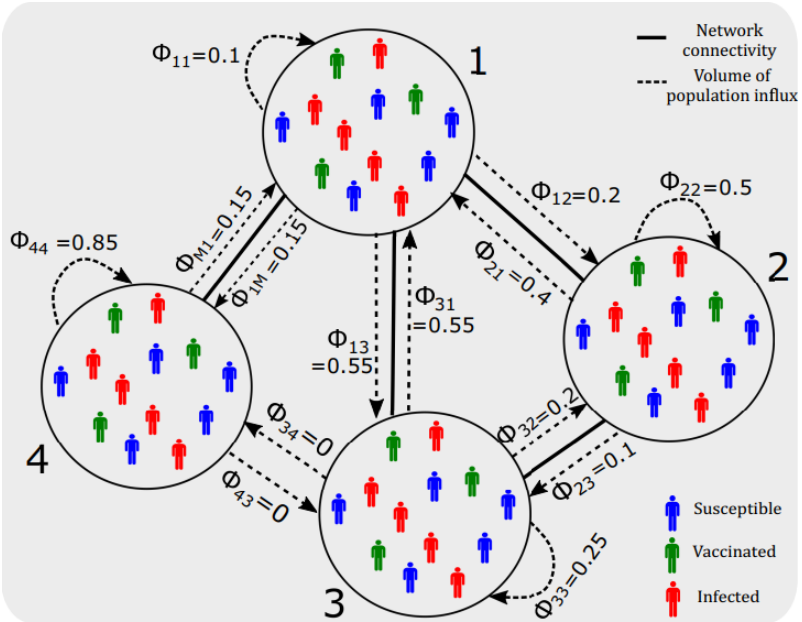
Sources: AIHW analysis of National Mortality database; AIHW 2010 GRIM books

Model: mobility pattern

Travelling pattern on network:

- Whom to meet and imitate
- Present population at destination
- Network topology defined by population influx matrix ϕ

$$\phi_{M\times M} = \begin{bmatrix} \phi_{11} & \phi_{12} & \cdots & \phi_{1M} \\ \phi_{21} & \phi_{22} & \cdots & \phi_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ \phi_{M1} & \phi_{N2} & \cdots & \phi_{MM} \end{bmatrix}$$



Schematic of a sample travelling network

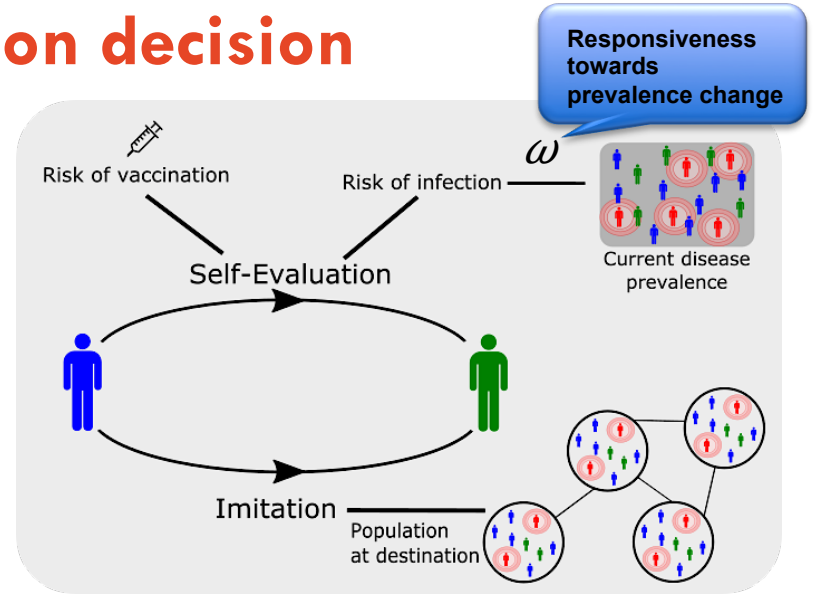
Model: voluntary vaccination decision

Self-evaluation

- Risk of vaccination
  - Low-risk, constant parameter
- Risk of infection
  - Current disease prevalence at destination I

Imitation

- Other people's decision
- κ: how quickly people imitate



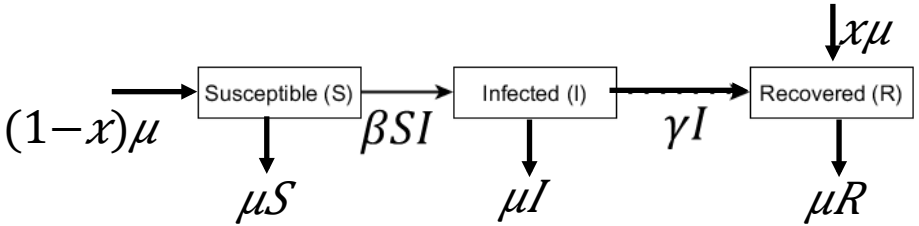
Schematic of the decision making process

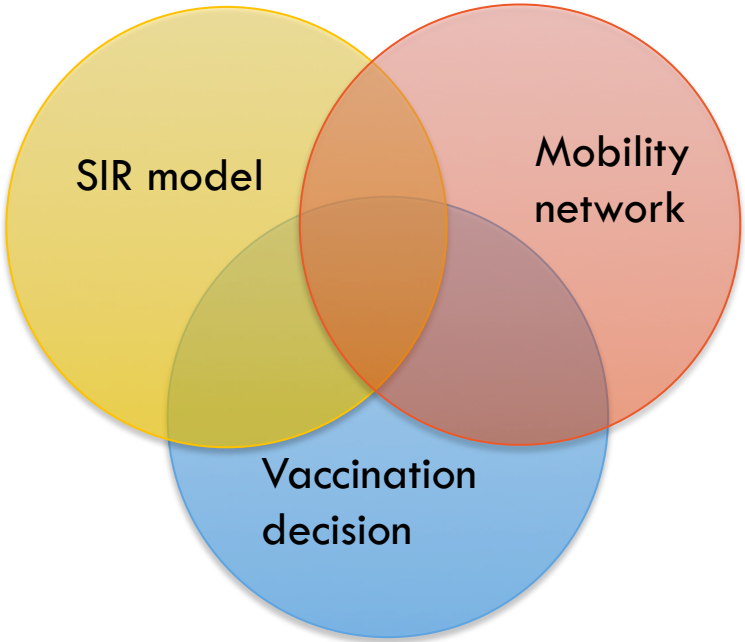
$$\dot{x}_i = \kappa(1 - x_i) \sum_{j=1}^{M} \phi_{ij}(-1 + \omega I_j) \sum_{k=1}^{M} \phi_{kj} x_k$$

Model: integrated model

SIR model with vaccination:

- Susceptible(S) –Infected(I)-Recovered(R)
- Vaccinate newborns (x)





Model: integrated model

SIR model with vaccination:

- Parameters of interest:
  - Vaccine failure rate (ξ)
  - Individual's responsiveness (ω)

How does individual behaviour affect aggregate epidemic dynamics?

Unsuccessful vaccination

unvaccinated

New infection

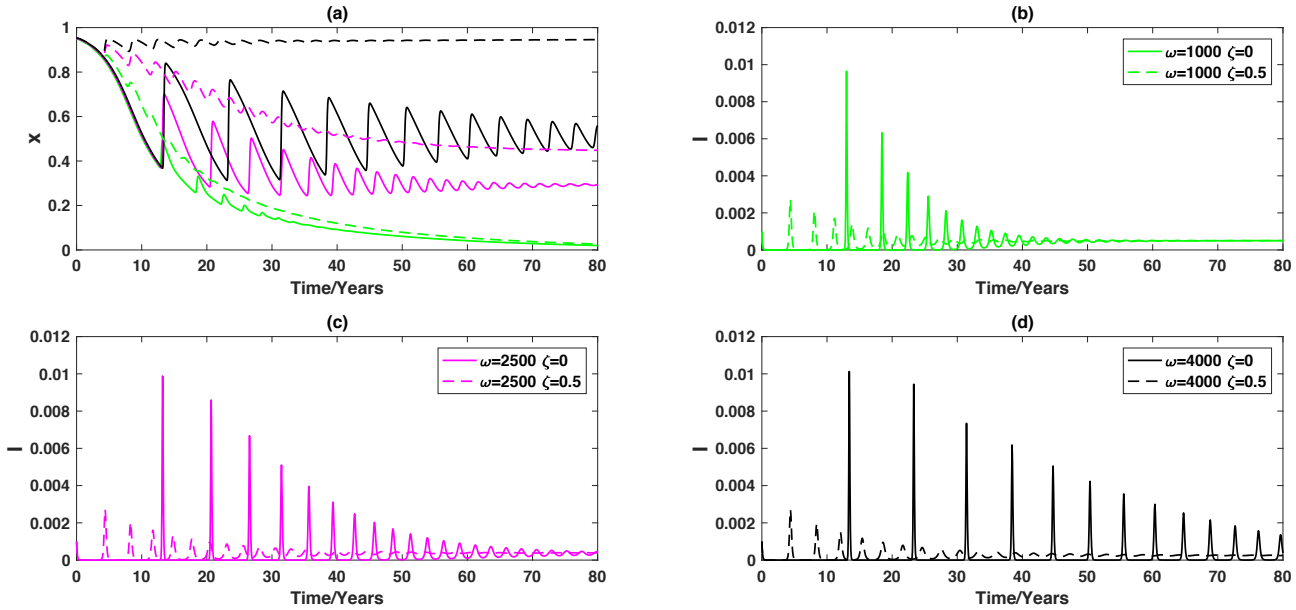
$$\dot{S}_i = \mu[\zeta x_i + (1 - x_i)] - \sum_{j=1}^{M}\sum_{k=1}^{M} \beta_j \phi_{ij} \frac{\phi_{kj} I_k}{\epsilon_j^p} S_i - \mu S_i$$

$$\dot{I}_i = \sum_{j=1}^{M}\sum_{k=1}^{M} \beta_j \phi_{ij} \frac{\phi_{kj} I_k}{\epsilon_j^p} S_i - \gamma I_i - \mu I_i$$

$$\dot{R}_i = \mu(1 - \zeta) x_i + \gamma I_i - \mu R_i$$

$$\dot{x}_i = \kappa(1 - x_i) \sum_{j=1}^{M} \phi_{ij}(-1 + \omega I_j) \sum_{k=1}^{M} \phi_{kj} x_k$$

Results: 1000-node Erdos-Renyi random network

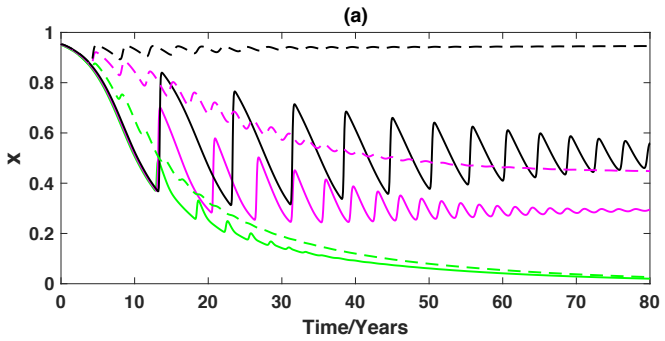


Three values of ω

"Herd immunity" at the start

(a) vaccine uptake (b)- (d) disease prevalence. Initial conditions: S_0=0.05, I_0=0.001, x_0=0.95. Same initial conditions applied to all nodes.

Results: 1000-node Erdos-Renyi random network



(a) vaccine uptake.
Black: ω=4000
Purple: ω=2500
Green: ω=1000

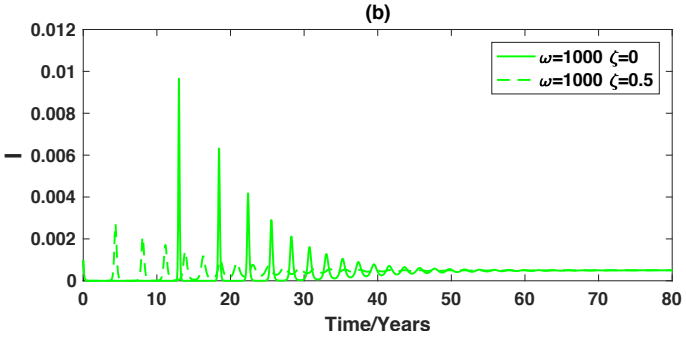
Vaccine uptake:

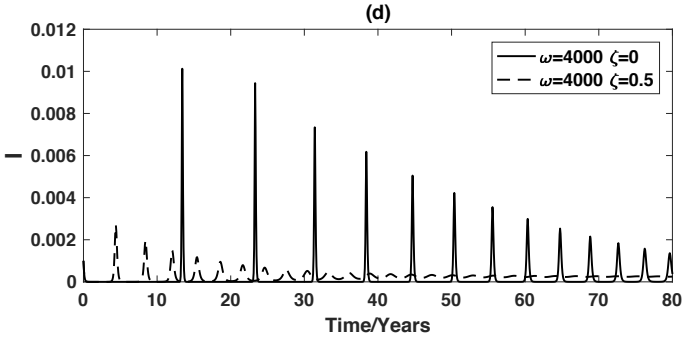
- Three distinctive equilibria
  - Damped oscillation if individuals are sufficiently responsive
  - Unresponsive individuals remain unvaccinated
- Low vaccine efficacy leads to high vaccine uptake (false "herd immunity")

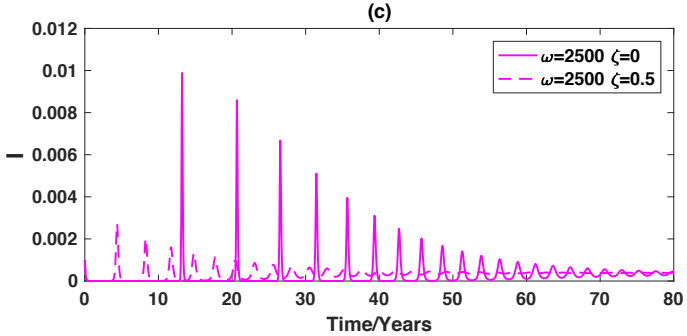
Results: 1000-node Erdos-Renyi random network

Disease prevalence:

- Pre-mature peaks at low vaccine efficacy
  - Promotes vaccine coverage







Conclusion

- Individual behaviours:
  - Responsive individual: damped oscillation; higher vaccination uptake
  - Unresponsive individuals: vaccine skeptics remain unvaccinated
- Highly effective vaccines defer epidemic peak but also increases severity
- Full length paper:

S. L. Chang, M. Piraveenan, M. Prokopenko, (2019). The effects of imitation dynamics on vaccination behaviours in SIR-network model, *Int. J. Environ. Res. Public Health, 16(14):2477*

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