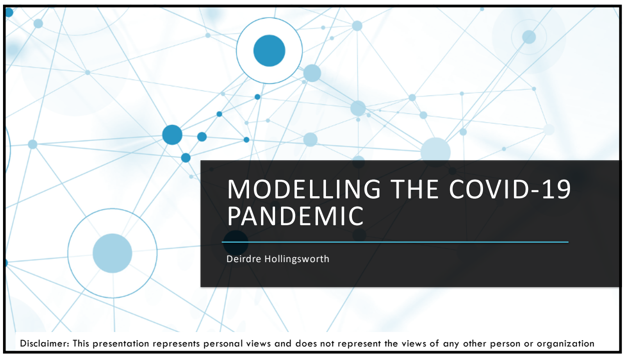
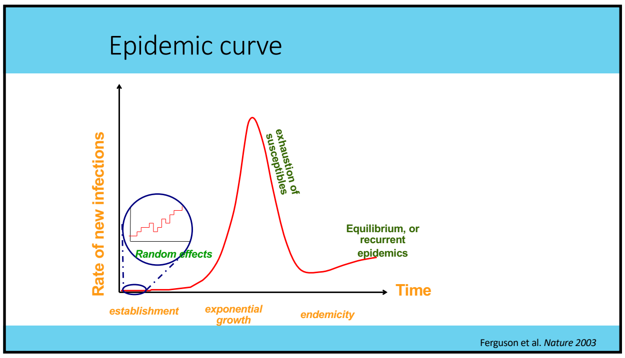
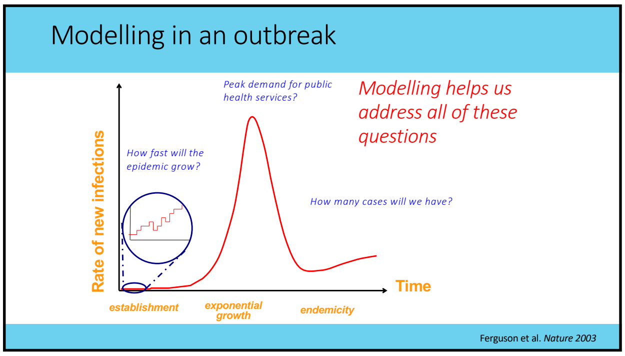

MODELLING THE COVID-19 PANDEMIC
Deirdre Hollingsworth
Disclaimer: This presentation represents personal views and does not represent the views of any other person or organization

1


Epidemic curve
Rate of new infections
Random effects
exhaustion of susceptibles
Equilibrium, or recurrent epidemics
Time
establishment
exponential growth
endemicity
Ferguson et al. Nature 2003

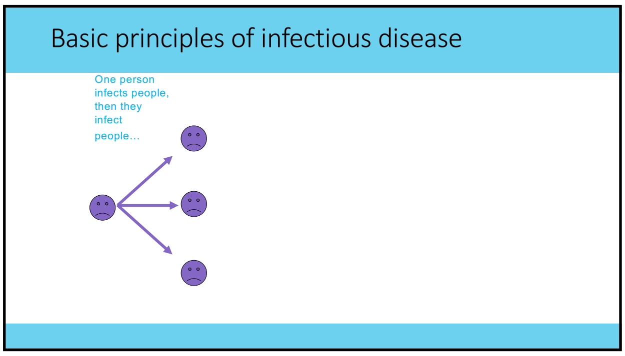
2


Modelling in an outbreak
Peak demand for public health services?
Modelling helps us address all of these questions
How fast will the epidemic grow?
How many cases will we have?
Rate of new infections
Time
establishment
exponential growth
endemicity
Ferguson et al. Nature 2003

3


Basic principles of infectious disease
One person infects people, then they infect people…

4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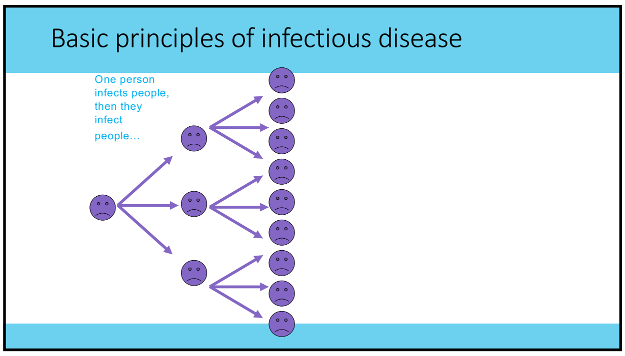
Basic principles of infectious disease
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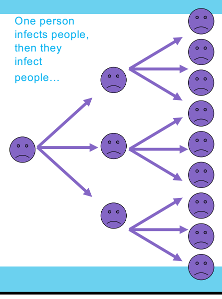
Basic reproduction number, R_0



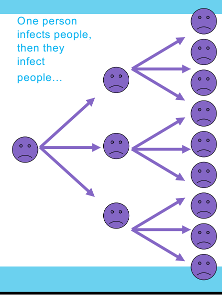
•A key *quantity* governing the dynamic of an epidemic is *how many* other people one person infects.

the ***Basic Reproduction Number*** R_0.

Anderson & May *Infectious Diseases of Humans* (1991)

7

Basic reproduction number, R_0



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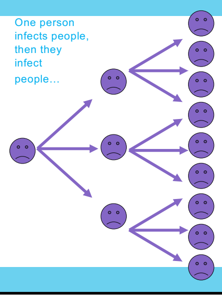
Needs to be >1 for an epidemic

Anderson & May *Infectious Diseases of Humans* (1991)

8

Basic reproduction number, R_0



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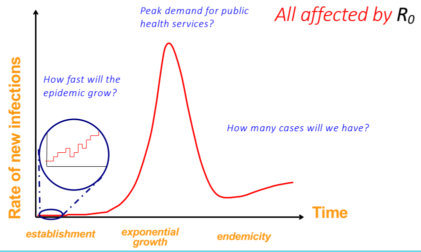
Role of R_0



All affected by R_0

Ferguson et al. *Nature 2003*

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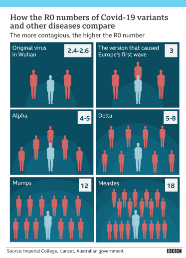
How does COVID19 compare?



- Higher than influenza, lower than measles
- Estimates of *R0* have changed through the epidemic
  - Depends on the population
  - Depends on the strain

Further reading on early estimation of *R0* https://doi.org/10.1098/rstb.2020.0264

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Drivers of the basic reproduction number

Basic reproduction number: Average number of people a single infectious individual infects in a wholly susceptible population

$$R_0 = T\ c\ D$$

- T: Probability of transmission per contact
- c: Contact rate – e.g. how many contacts are being made per day
- D: Duration of infectiousness

Note: This is for a homogeneous population. For different model assumptions the details will be different

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Reducing reproduction number

Probability of transmission per contact

Duration of infectiousness

Reproduction number – number of infections per infectious individual at time t (excluding immunity)

$$R_t = T\ c\ D$$

Contact rate – e.g. how many contacts are being made per day

Note: This is for a homogeneous population with no immunity. For different model assumptions the details will be different

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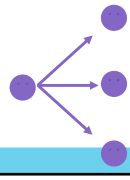
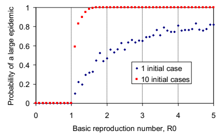
Why is the reproduction number important?

- Probability of an outbreak
  - Probability of extinction for this branching process is $1/R_0$
  - Probability of an outbreak is $1\text{-}1/R_0$



For k initial cases $(1\text{-}1/R_0)^k$



Stochastic processes are important

Further reading:

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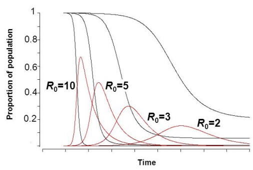
Why is the reproduction number important?

- Exponential growth rate

  $r=(R_0\text{-}1)/D$
- *Peak prevalence*

  $I_{max}=1\text{-}(1+\ln R_0)/R_0$
- *Final number infected*

  $a = 1\text{-}\exp(\text{-}R_0 a)$



Approximations from Anderson and May (1991)

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A real quantity

The importance of R_0 as a key epidemiological determinant is highlighted by models. This can lead to the mistaken impression that it is an abstract quantity that characterises models.

The reproduction number *R* is very real. Each person really does infect a number of others. At any time *t* this number really does have an average, which we call *R*(*t*). You don't need a model to measure it. If *R*(*t*)>1, the number of cases really does go up, and if *R*(*t*)<1, it really does go down.

R_0 is an abstraction in that one tries to work out what value *R* would take if there was no control (immunity or public health). If you're lucky (??) enough to watch uncontrolled epidemics starting off, then you measure R_0 without a model!

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Underlying model assumptions

Probability of transmission per contact

Duration of infectiousness

Basic reproduction number: Average number of people a single infectious individual infects in a wholly susceptible population

$$R_0 = T\ c\ D$$

Contact rate – e.g. how many contacts are being made per day

Note: This is for a homogeneous population. For different model assumptions the details will be different
Further reading: Diekmann, Heesterbeek and Britton (2012),

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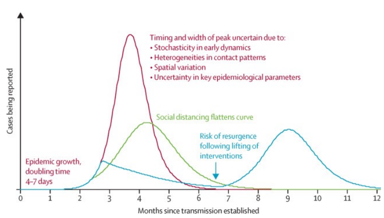
Lockdowns

- Lockdowns or social distancing may only temporarily reduce R_t
- When lifted, can be resurgence, depending on the proportion susceptible



Anderson et al. *Lancet* 2020

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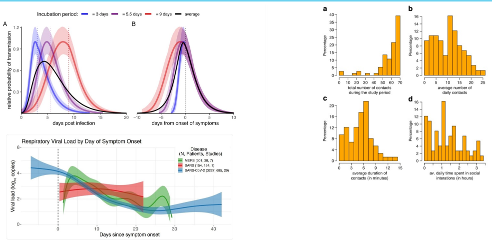
Underlying model assumptions



Further reading: https://doi.org/10.1098/rspb.2006.3754and https://www.nejm.org/doi/full/10.1056/NEJMp2016822

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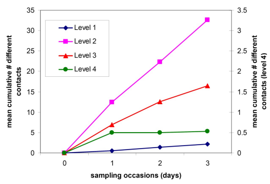
Contact patterns – types contact

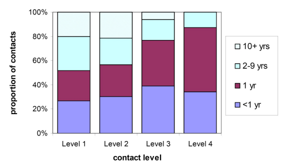


1. Physical, no conversation
2. Conversation, no physical
3. Conversation, non-sexual physical
4. Sexual contact, including kissing

Edmunds *et al* Emerging Themes in Epidemiology (2006)

21

Contact patterns – age differences



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Edmunds *et al* Emerging Themes in Epidemiology (2006), Mossong *et al* PLoS Medicine (2008)

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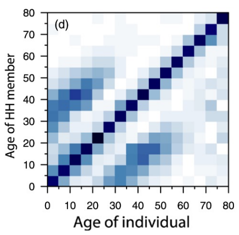
Age structured



We tend to talk with people of a similar age,

But we also live in households which cross generations

Prem et al PLOS Computational Biology 2017

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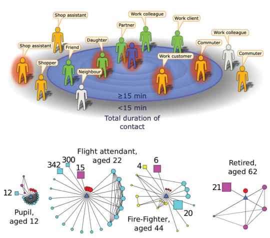
Types of contact, occupation



- How does this translate into risk?
- Key workers can be at higher risk, but also present higher risk

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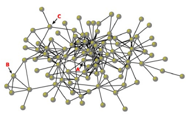
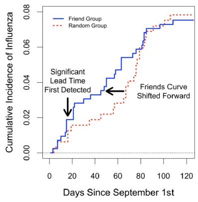
Too popular?



Friendship network of 105 students

When people nominate a friend, they tend to nominate someone more 'central' to their social network



In this study of students at Harvard, the "more popular" people acquired 'flu more quickly!

Chistakis & Fowler, PLoS ONE (2010)

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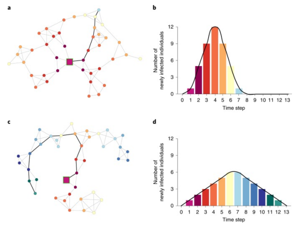
R_0 on networks - interventions

- Mean and variance of contacts affect R_0



Block et al *Nature* 2020

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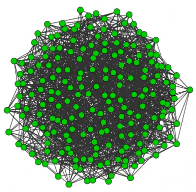
Can I just see one friend?

- The good ol' days
- Each green dot is a household
- Lines represent interactions between households
- For a new virus which can spread on these ties, life is pretty good



http://statnet.org/COVID-JustOneFriend/

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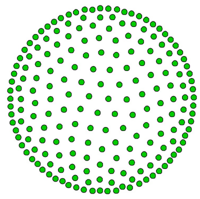
Can I just see one friend?

- Perfect isolation
- Everyone stays at home



http://statnet.org/COVID-JustOneFriend/

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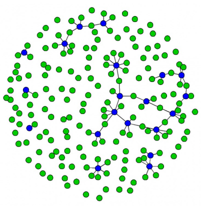
Can I just see one friend?

- Key workers (essential workers) in blue households



http://statnet.org/COVID-JustOneFriend/

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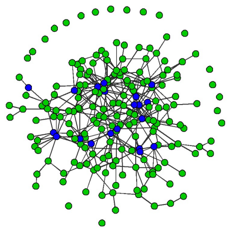
Can I just see one friend?

- An average of two people in each household see just one friend
- Start to have a connected network



http://statnet.org/COVID-JustOneFriend/

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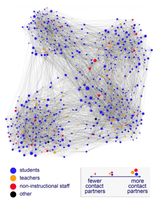
Networks

- Difficult to measure
- Demonstrate how we're all connected
- Cohorting/bubbling of classes, patients or sub-groups



https://news.psu.edu/photo/264033/2013/02/14/disease-networks

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Contact tracing and Vaccination

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Behavior and contact tracing

- Does legally enforcing isolation reduce transmission?

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Trade-offs in contact tracing

- Does legally enforcing isolation reduce transmission?
  - What if it is linked to a reduction in self-reporting?

Lucas, Davis *et al. Phil Trans Roy Soc B*, https://www.medrxiv.org/content/10.1101/2020.08.20.20178558v1

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Trade-offs in contact tracing

- Does legally enforcing isolation reduce transmission?
  - What if it is linked to a reduction in self-reporting?
- Using a branching process model, investigated this effect

Lucas, Davis *et al. Phil Trans Roy Soc B*, https://www.medrxiv.org/content/10.1101/2020.08.20.20178558v1

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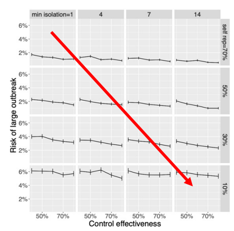

Lucas, Davis *et al. Phil Trans Roy Soc B*, https://www.medrxiv.org/content/10.1101/2020.08.20.20178558v1

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Trade-offs in contact tracing

- Does legally enforcing isolation reduce transmission?
  - What if it is linked to a reduction in self-reporting?
- Probably not

Lucas, Davis *et al.* *Phil Trans Roy Soc B*, https://www.medrxiv.org/content/10.1101/2020.08.20.20178558v1

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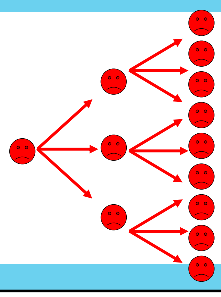
Vaccination



Each infection is dependent on previous events.

R_0=3

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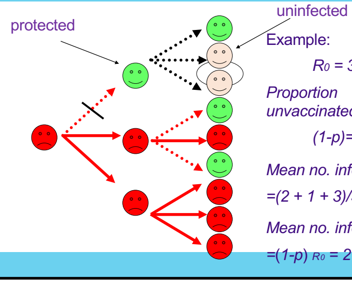
Vaccination



Example:

R_0 = 3

Proportion unvaccinated

(1-p)= 2/3

Mean no. infections

=(2 + 1 + 3)/3 = 2

Mean no. infections

=(1-p) R_0 = 2

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Vaccination

- Critical vaccination fraction
  - Vaccinate proportion, *p*, of the population
  - 1-*p* are unprotected
  - 'Effective R0' is

    R_{0v}=R_0(1-p)
  - Want this to be less than 1

    R_{0v}<1 R_0(1-p)<1

$$p > p_c = 1 - \frac{1}{R_0}$$

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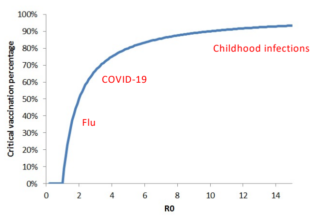
Critical vaccination threshold



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New variants

- Successful variants often increase R_0 in new ways
- Affect critical vaccination thresholds
- May be selective pressure to overcome vaccination
- Many uncertainties
- Modelling allows investigation of scenarios

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Role of modelling

- Modelling essential for
  - Bringing together disparate data sources
  - Estimating parameters
  - Providing forecasts
  - Investigating 'what-if' scenarios
- Best done in collaboration with policy makers
  - Understand your data streams
  - Understand the questions and needs
- Communication of uncertainty is challenging
  - Multiple models, and multiple parameter sets
  - Summarising information crucial
- Impacted policy, but challenges remain

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