Practical considerations for estimating the effective reproductive number, $R_t$

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Practical considerations for measuring the effective reproductive number, Rt

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Outline

Choose wisely: Accuracy of common methods

Two definitions of $R_t$

Challenges when working with imperfect data

Back-calculating times of infection
Specifying the generation interval
Accounting for uncertainty
Why estimate $R_t$?

Is the epidemic growing, shrinking or holding steady?
Assess policy effects
Why estimate $R_t$?

Is the epidemic growing, shrinking or holding steady?
Assess policy effects

On average, how many new infections will a single individual cause?
Analyze transmission chains.

Instantaneous reproductive number

Case reproductive number
Instantaneous reproductive number
Methods of Cori et al. and Bettencourt & Ribeiro

Arrows show times at which infectors and infectees appear in the time series.

\[ R_{inst}^t = \frac{I_t}{\sum_{s=1}^{t} I_{t-s} w(s)} \]

New infections at time \( t \)

Number and current infectiousness of individuals infected in the previous generation

Case reproductive number
Method of Wallinga & Teunis

\[ R_{case}^t = \sum_{u \geq t} R_{u}^{inst} w(u - t) \]

Synthetic data from an SEIR model in which the transmission rate falls, then rises.
Estimate instantaneous $R$

Estimate instantaneous $R$  

**Cori et al.**

- Exact
- instantaneous $R$
- case $R$

Fit to infections

**Wallinga & Teunis**

Fit to infections

Estimate instantaneous $R$

Bettencourt & Ribeiro

Estimate instantaneous $R$

Cori et al.

Exact

- instantaneous $R$

- case $R$

Estimate case $R$

Wallinga & Teunis

Fit to

- infections

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Challenges when working with imperfect data
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$R_t$ measures transmission at time $t$. Lagged observations must be adjusted.

Observed data reflect past transmission events.
Simple methods do not accurately recover the latent infection curve

Longer and more variable delays pose a greater challenge
Better approaches

1. Infer times of infection from observations using deconvolution methods adapted from signal and image processing

2. Estimate $R_t$

   Goldstein et al. PNAS. 2009.

Treat times of infection as a latent state while estimating $R_t$
Imperfect observation

$R_t$ estimation methods assume all infections are observed.

$R_t$ estimates will remain accurate if the fraction of infections observed does not change over time. But even in this best-case scenario, **CIs will not include uncertainty from imperfect observation.**

Estimates will be biased if the fraction observed changes over time.
Caution when using serial interval estimates to parameterize the generation interval!

1. The serial interval can be negative, but the generation interval cannot.
   
   Ganyani et al. *Eurosurveillance*. 2020

2. The observed serial interval tends to decrease as an epidemic progresses. The intrinsic generation interval does not.
   
Conclusions

Choose an appropriate estimation method.

Times of infection must be inferred from lagged observations.

Estimate the generation interval carefully.

Beware spurious precision and propagate all sources of uncertainty.
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