# Quantifying dynamics of SARS-CoV-2 transmission suggests that epidemic control is feasible through instantaneous digital contact tracing

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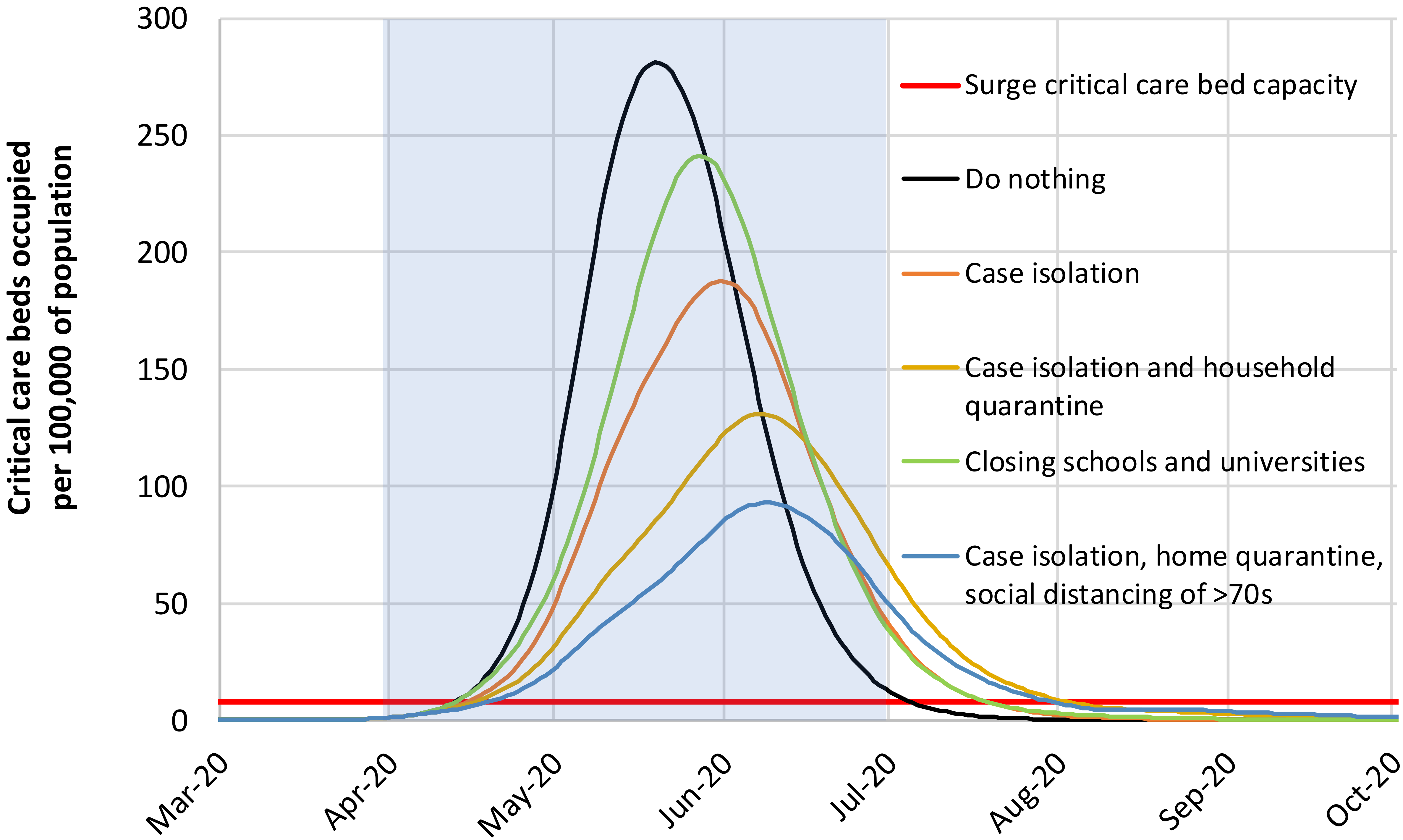
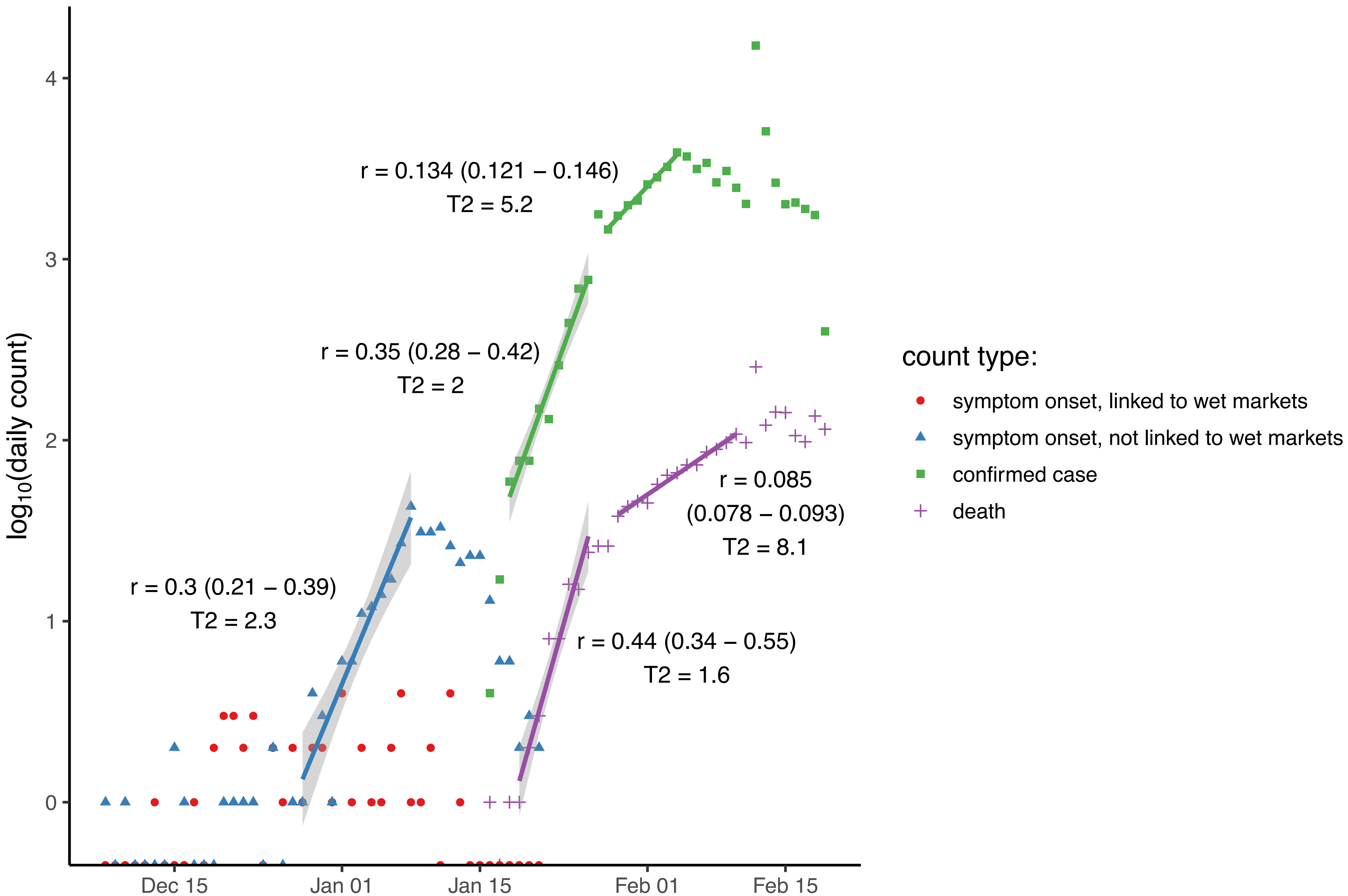
# COVID-19 impact on ICUs

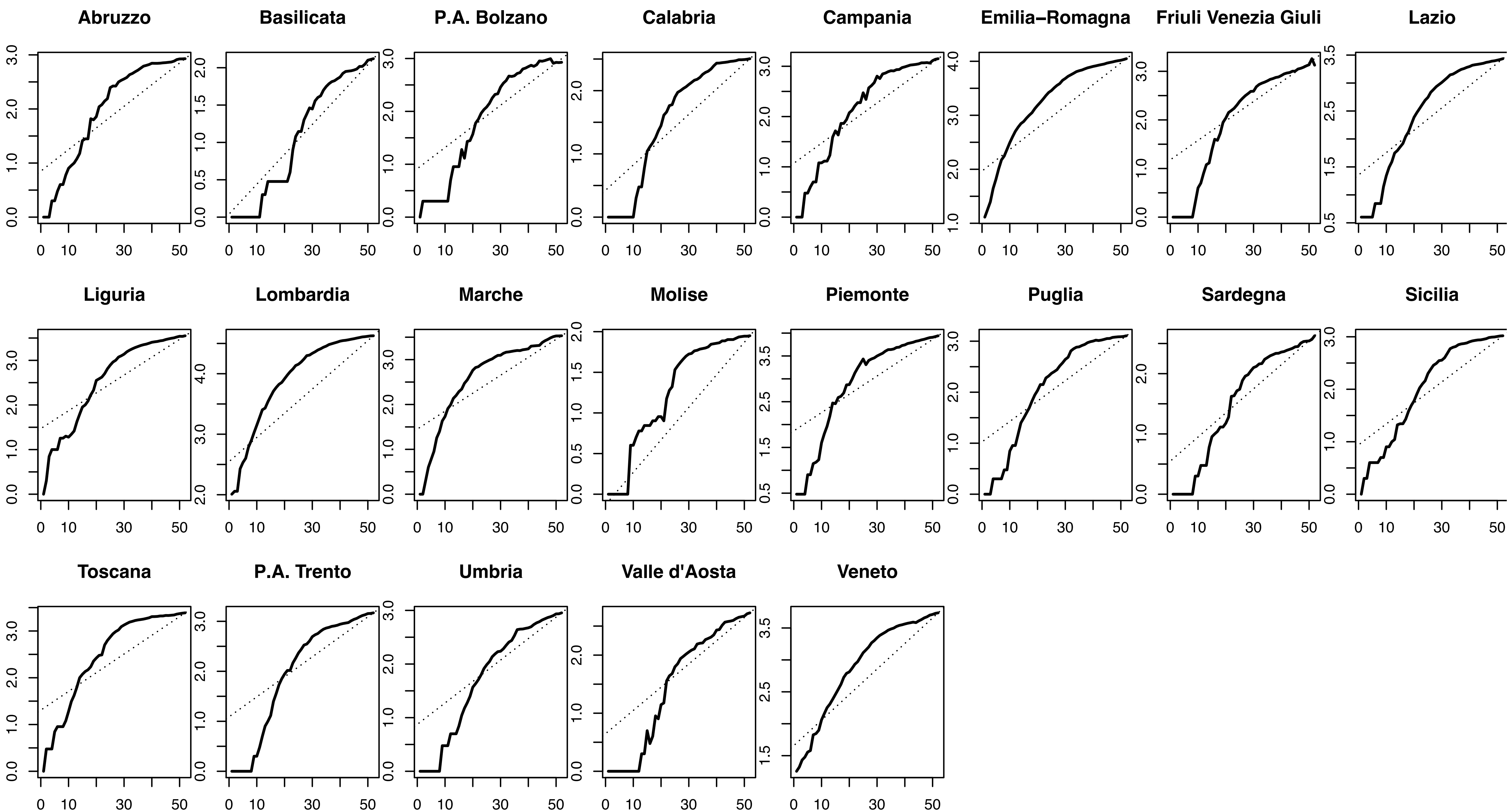
## (Imperial College report 9, Ferguson et al)



# Doubling times in China …



# … and Europe



Abruzzo
Basilicata
P.A. Bolzano
Calabria
Campania
Emilia–Romagna
Friuli Venezia Giuli
Lazio
Liguria
Lombardia
Marche
Molise
Piemonte
Puglia
Sardegna
Sicilia
Toscana
P.A. Trento
Umbria
Valle d'Aosta
Veneto

# An epidemiological classification of transmission modes for SARS-CoV-2

- Symptomatic (after symptom onset)
- Pre-symptomatic (before symptom onset)
- Asymptomatic (no symptom onset, or very mild symptoms)
- Environmental (fomites, ventilation systems…)

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  *~10-20% ?*

# Incubation period and generation time

- Incubation period:

  how long it takes to develop symptoms

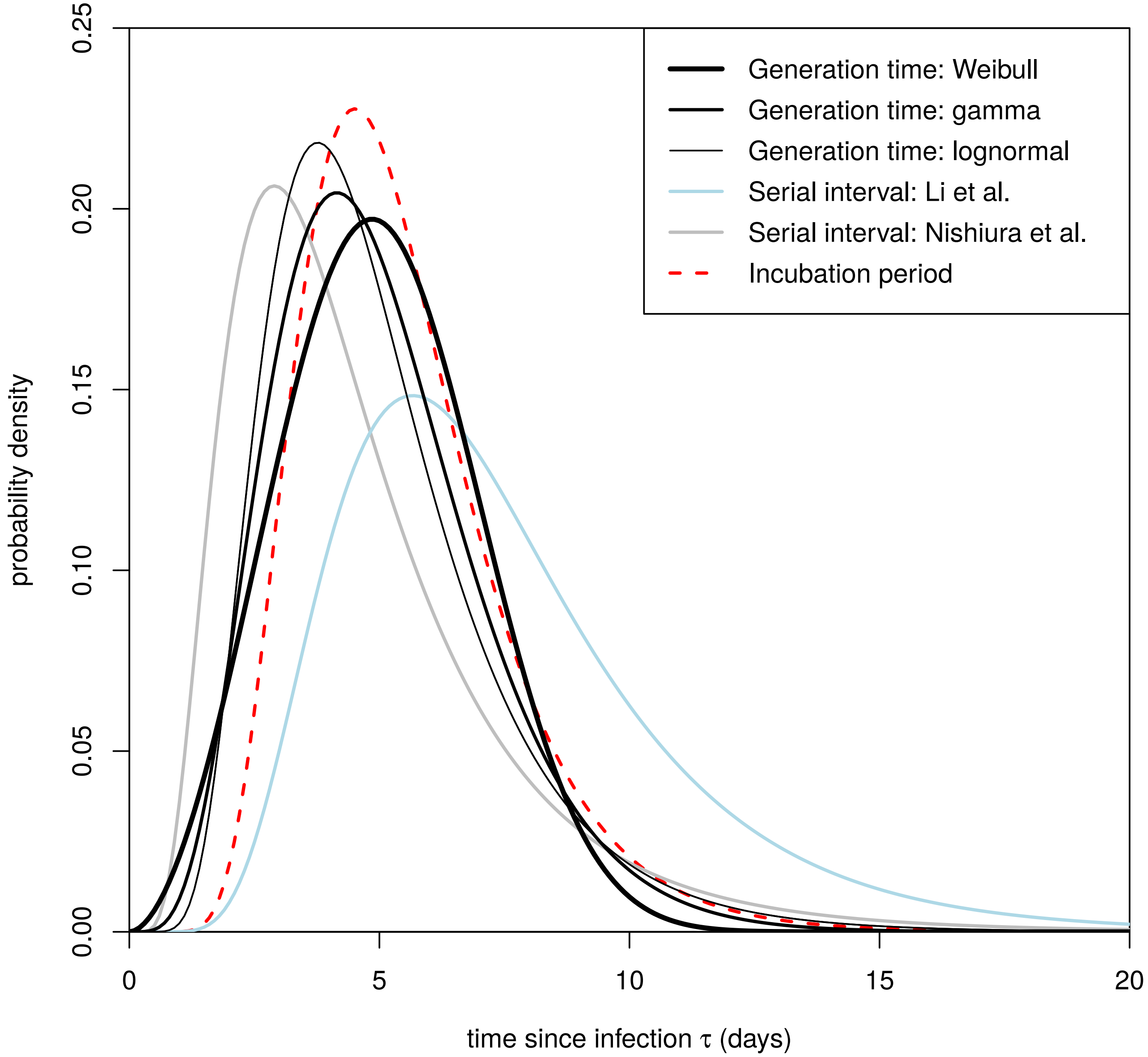
versus

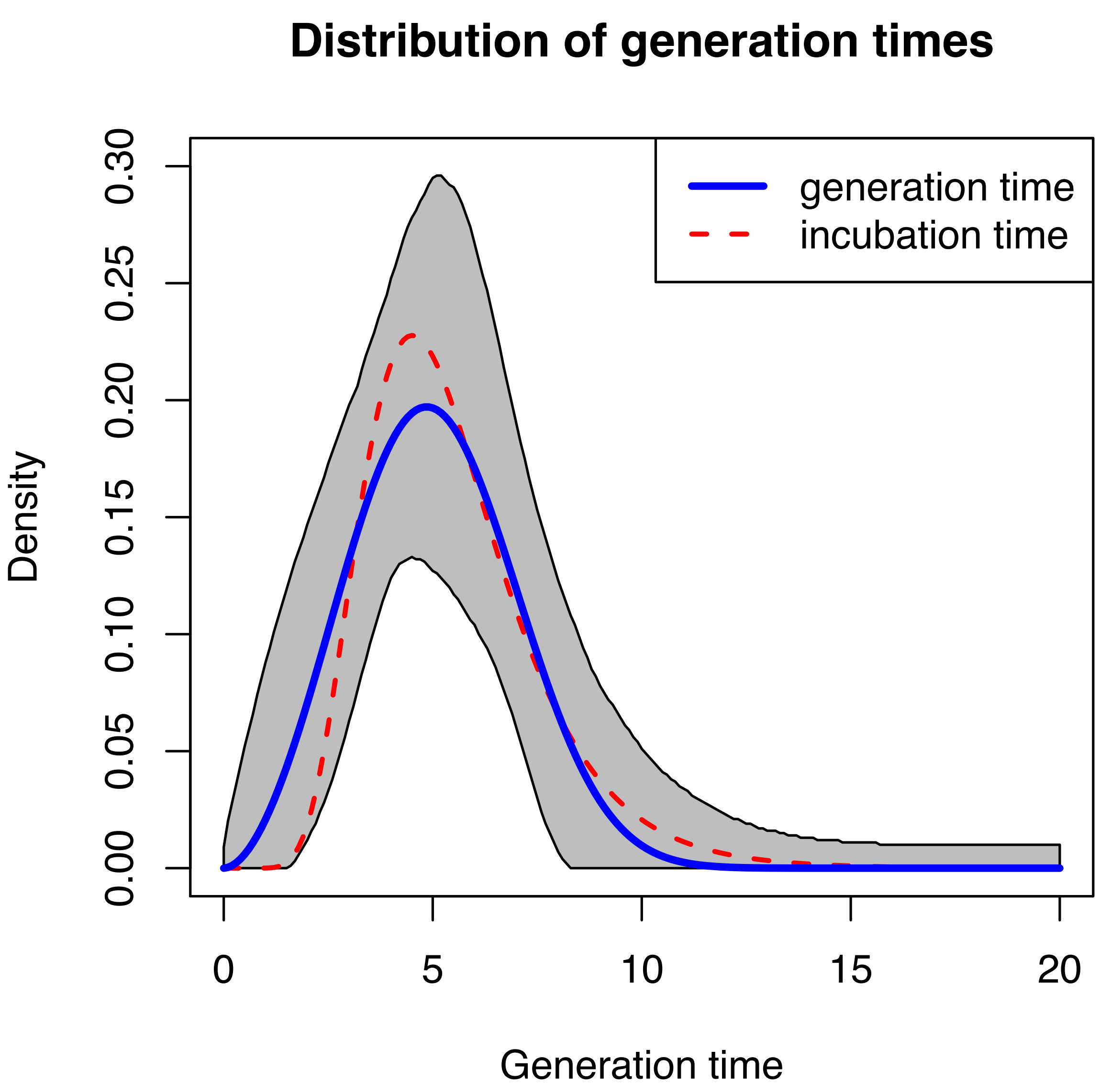
- Generation time (serial interval):

  how long it takes to transmit the disease

# Inference of generation time distribution

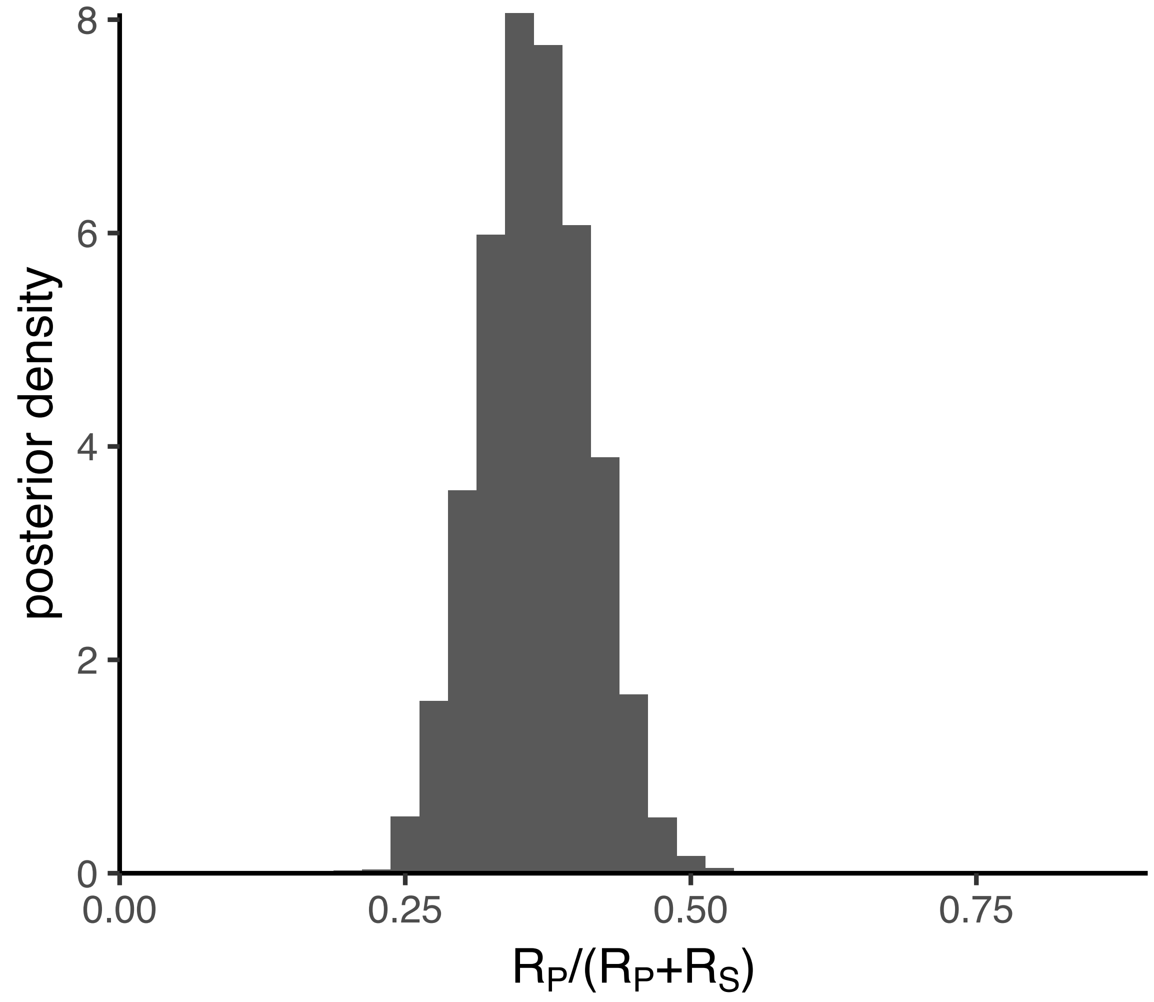
Maximum Composite Likelihood estimate
from *times of exposure* and *onset of symptoms* for infector-infected pairs

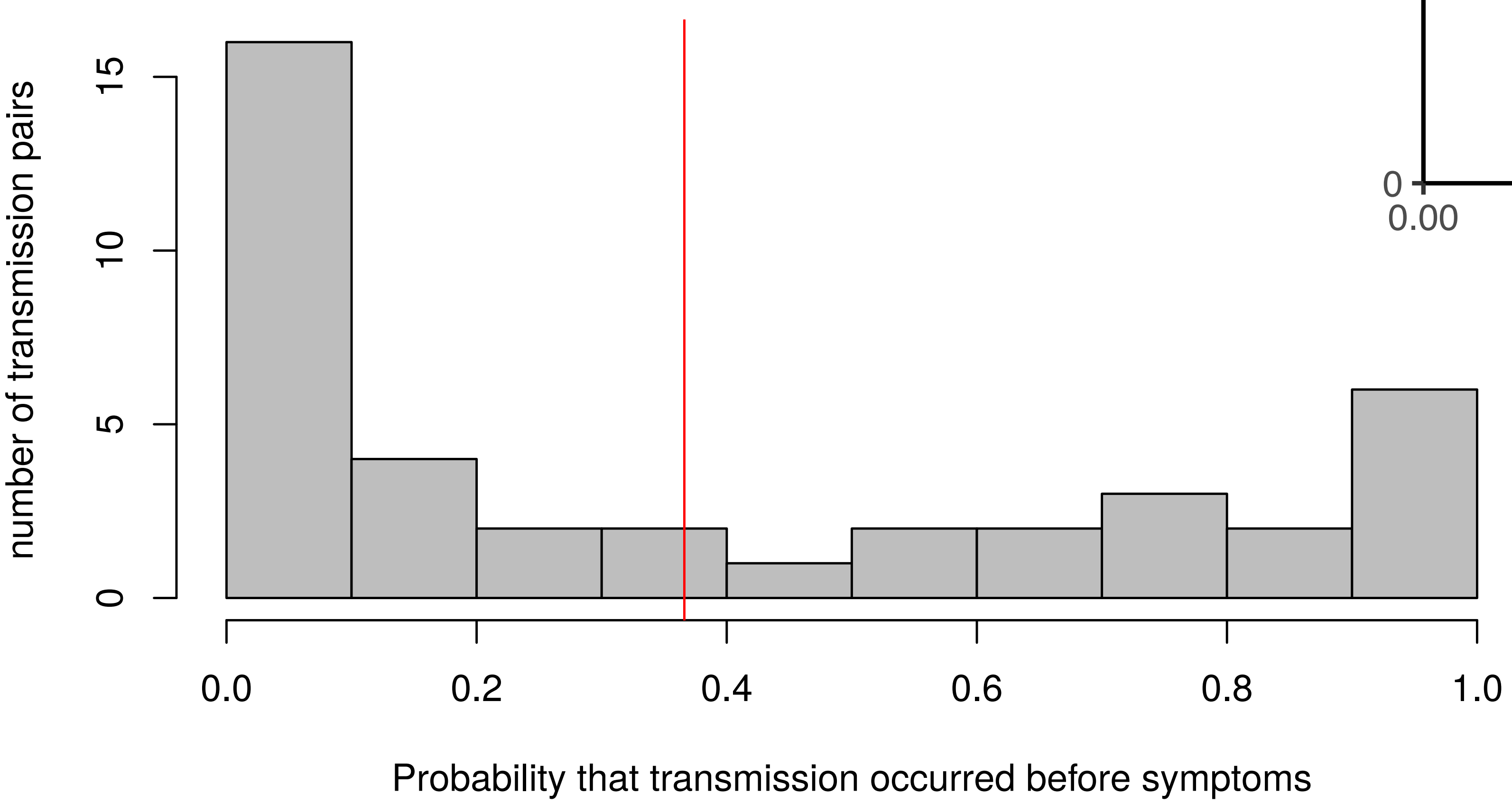


# Pre-symptomatic transmission

*About 30-45%*
*of all transmissions*
*from symptomatic cases*
*are pre-symptomatic*



# How to reach epidemic control: the reproduction numbers $R_0$ and $R_{eff}$

- $R_0$ : average number of infections caused by an infected individual in a naive population
- $R_{eff}$ : average number of infections caused by an infected individual in the presence of interventions

The critical condition to control the epidemic is $R_{eff}<1$

# Euler-Lotka equation

Classical renewal equation

$$I(t) = \int_0^\infty I(t-\tau)\beta(\tau)d\tau,$$

*Infectiousness*

Exponential ansatz with growth rate *r*

Classical Euler-Lotka equation

$$R_0 = 1/\int_0^\infty e^{-r\tau}w(\tau)d\tau$$

*Generation time distribution*

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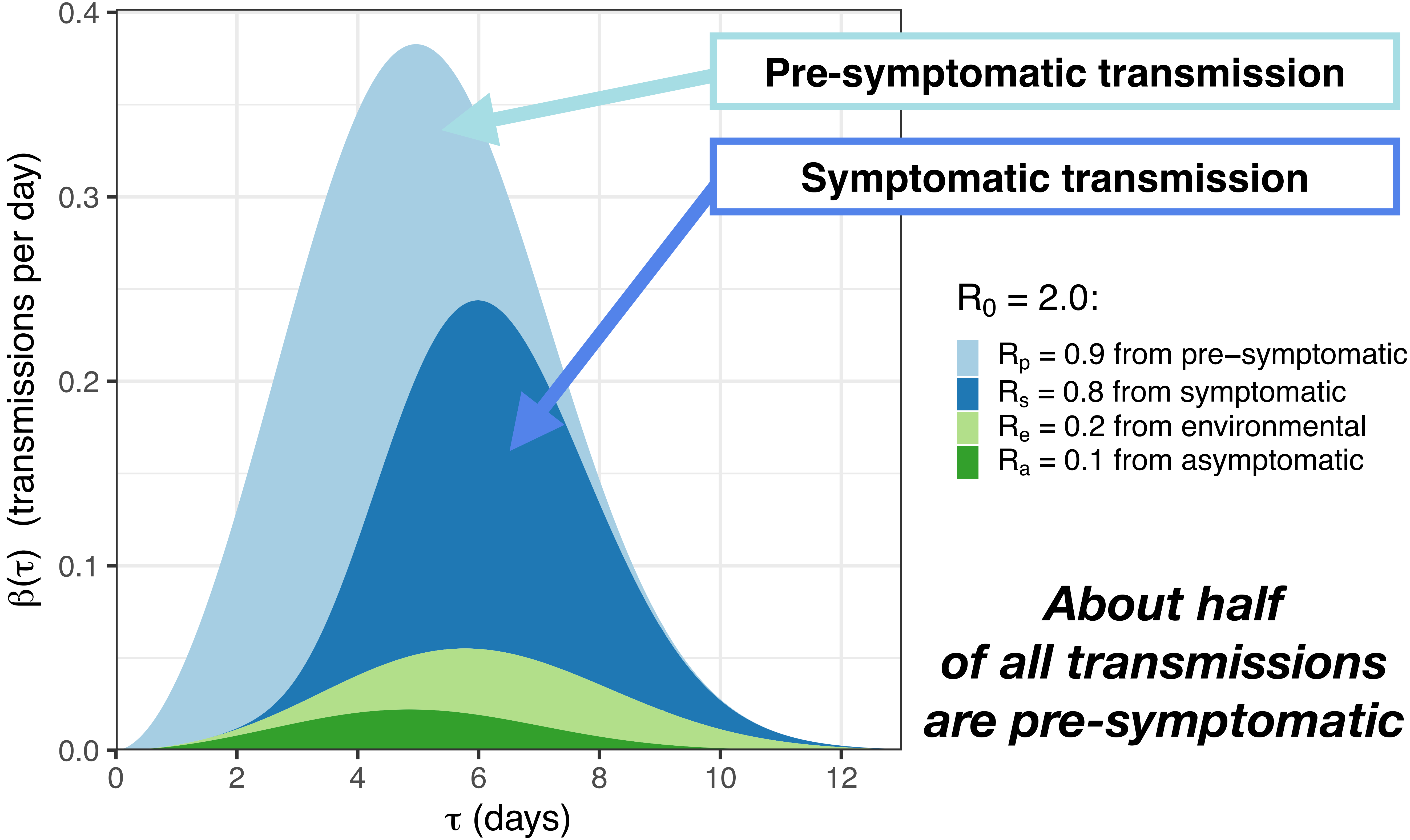
Decomposition of *infectiousness* (versus time post infection):

$$\beta(\tau) = \underbrace{P_a x_a \beta_s(\tau)}_{\text{asymptomatic}} + \underbrace{(1 - P_a)(1 - s(\tau))\beta_s(\tau)}_{\text{pre-symptomatic}} + \underbrace{(1 - P_a)s(\tau)\beta_s(\tau)}_{\text{symptomatic}} + \underbrace{\int_{l=0}^{\tau} \beta_s(\tau - l)E(l)dl}_{\text{environmental}}$$

# Decomposition of infectiousness




***About half of all transmissions are pre-symptomatic***

# Generalised Euler-Lotka equation for contact tracing

Kermack-McKendrick equations for chains of infections with contact tracing:

(Fraser el al PNAS 2004)

$$\frac{\partial Y(t,\tau,\tau')}{\partial t} + \frac{\partial Y(t,\tau,\tau')}{\partial \tau} + \frac{\partial Y(t,\tau,\tau')}{\partial \tau'} = 0$$

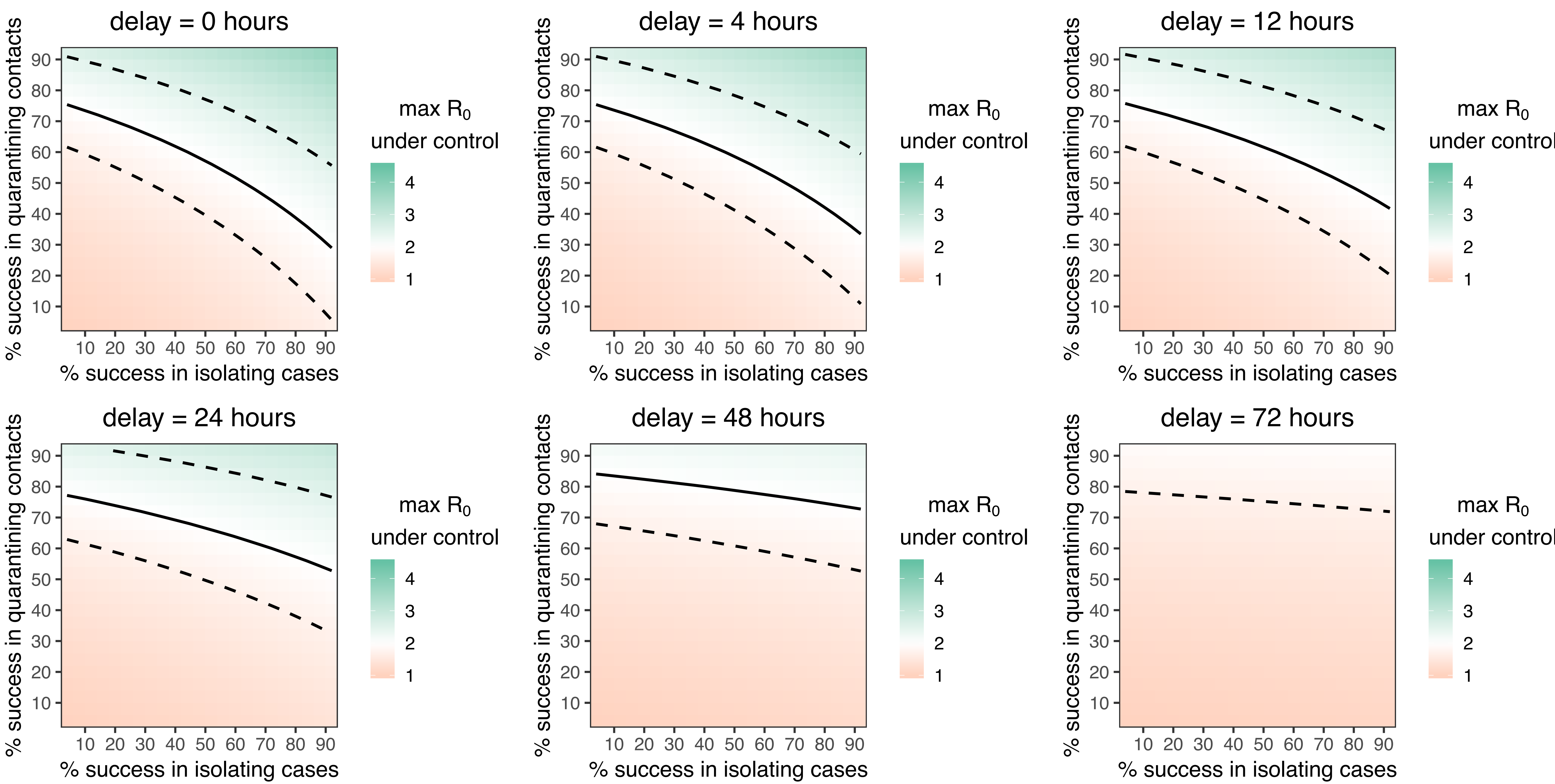
$$Y(t,0,\tau) = \beta(\tau)\,(1-\epsilon_I s(\tau)) \int_\tau^\infty \left(1 - \epsilon_T + \epsilon_T \frac{1-s(\tau')}{1-s(\tau'-\tau)}\right) Y(t,\tau,\tau')d\tau'$$

*Efficiency of isolation / contact tracing & quarantine*

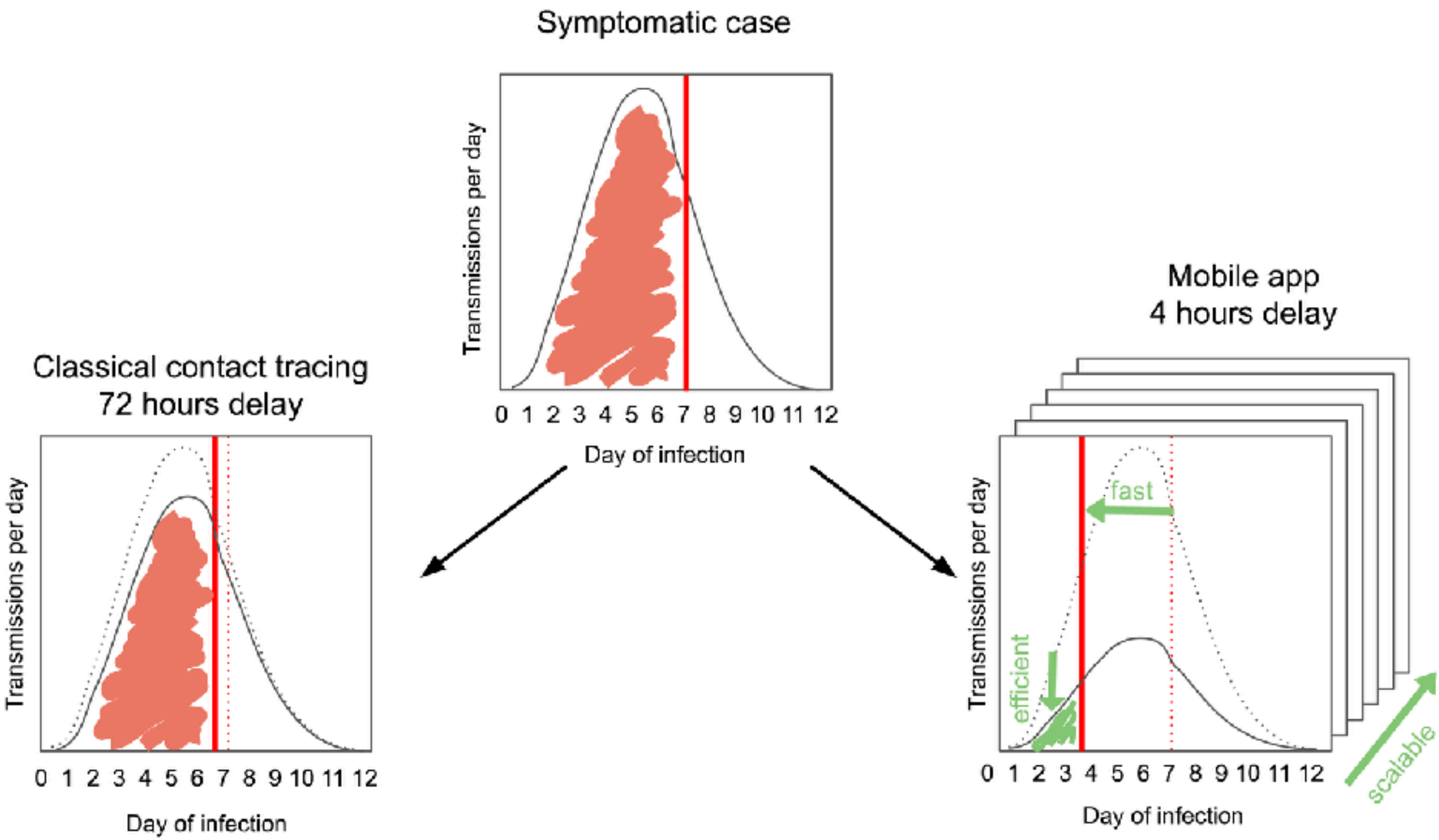
The generalised (functional) Euler-Lotka equation corresponds to the eigenvalue equation (with eigenvalue 1) for this operator:

$$\mathcal{N}_r y = e^{-r\tau}\beta(\tau)\,(1-\epsilon_I s(\tau)) \int_0^\infty \left(1 - \epsilon_T \frac{s(\rho+\tau)-s(\rho)}{1-s(\rho)}\right) y(\rho)d\rho$$

# Is the COVID-19 epidemic controllable via realistic contact tracing?

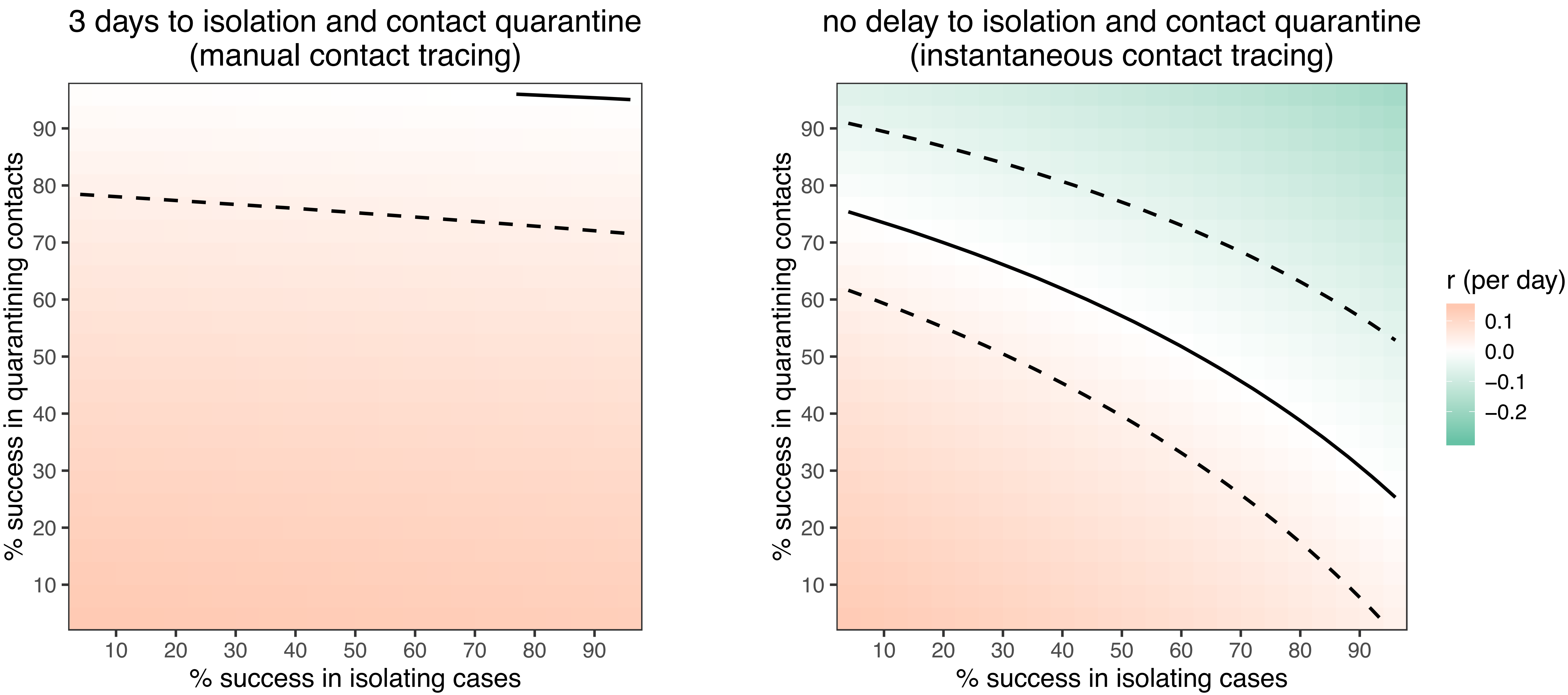


# Why instant contact tracing matters?



# Why instant contact tracing matters?

***Isolation and contact tracing can stop the epidemic only with high efficiency and short response times***



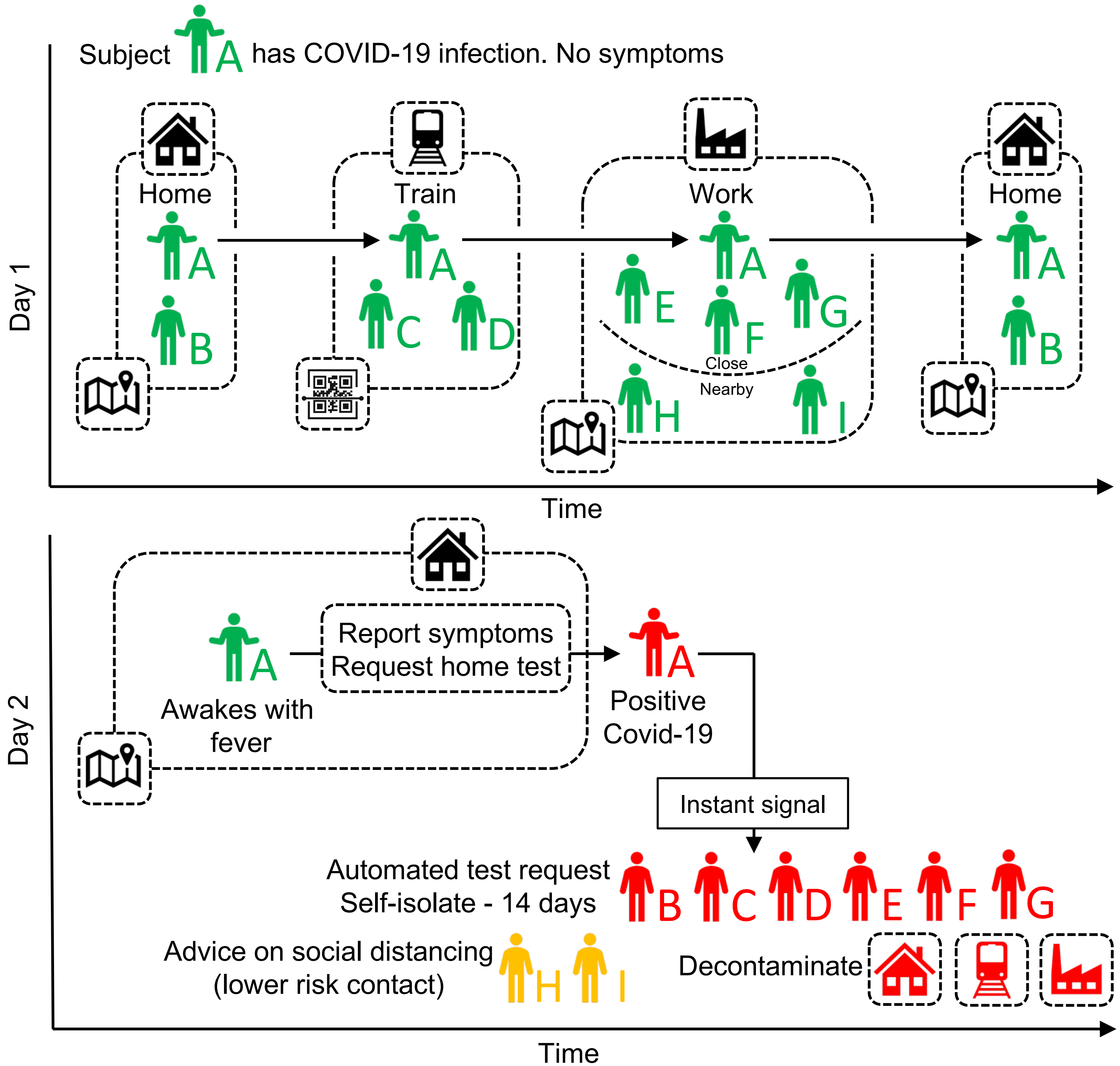
# Why digital solutions?

Tools of classical epidemiology against COVID-19:

- **Physical distancing/isolation/quarantine**
  - Either insufficient or high social&economic costs
- **Mass screening/testing + contact tracing**
  - Hard to scale for a rapid response (HR, lab capacity)
- **Vaccination**
  - Development/trial phase + time to scale production

Alternative digital technologies are needed for a **fast, scalable** response

# A mobile app for instant contact tracing



# Useful at all phases of the epidemic

- Prevent initial spread
- “Smart lockdown” to keep to economy afloat
- “Smart exit” from lockdown to prevent a second peak
- Control residual spread

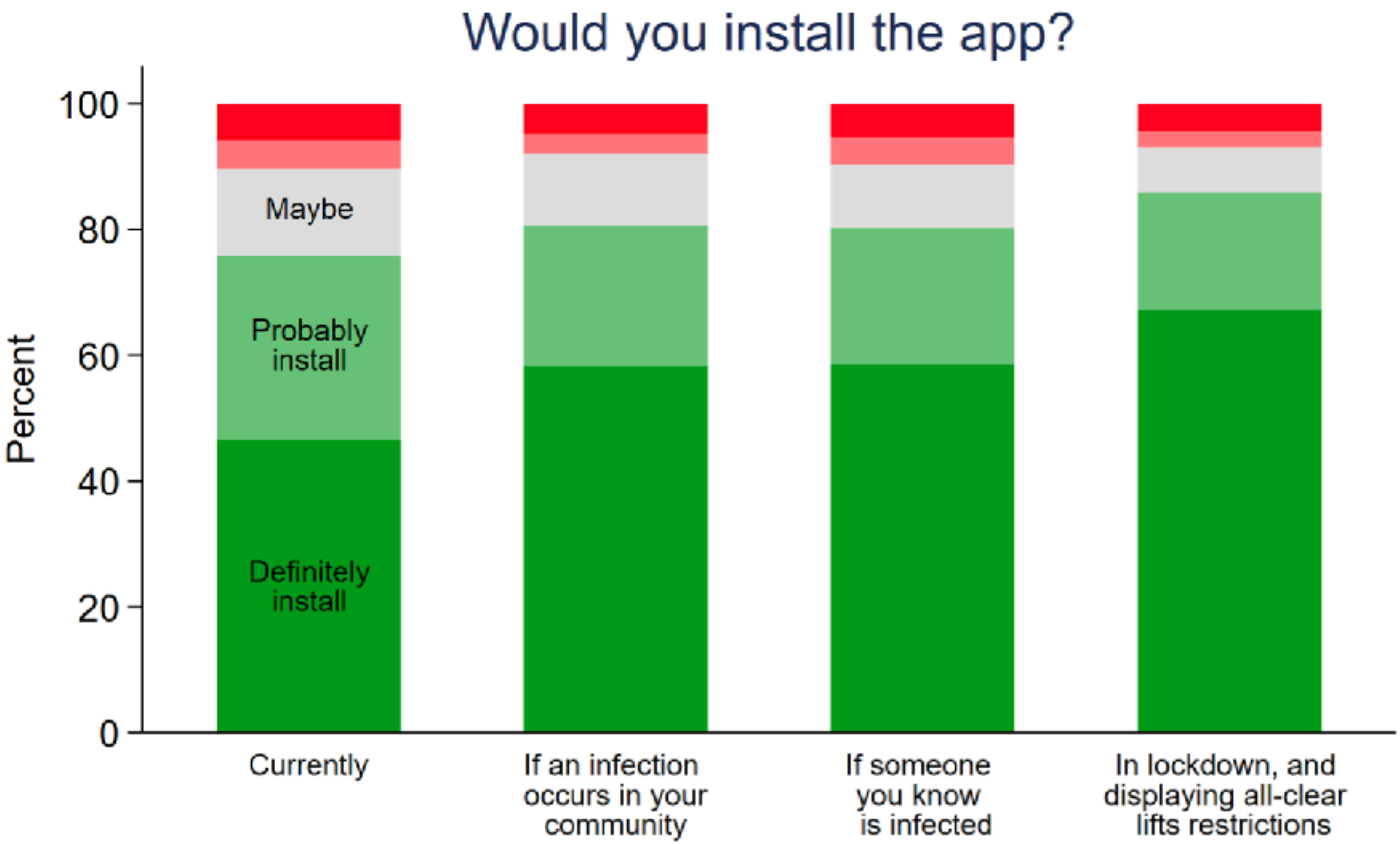
# Challenges

- Limitations in smartphone coverage and contact technologies (Bluetooth Low Energy). Integration of multiple approaches?
- >50% uptake required at population level
- Compliance with app recommendation to “stay at home” is key
- Scale-up of diagnostic testing across Europe is needed
- Some degree of physical distancing could still be required for the fast-growing European epidemic
- ***Iterative improvements of app back-end and front-end, as well as the science and technology behind app tracing***

# Ethical issues

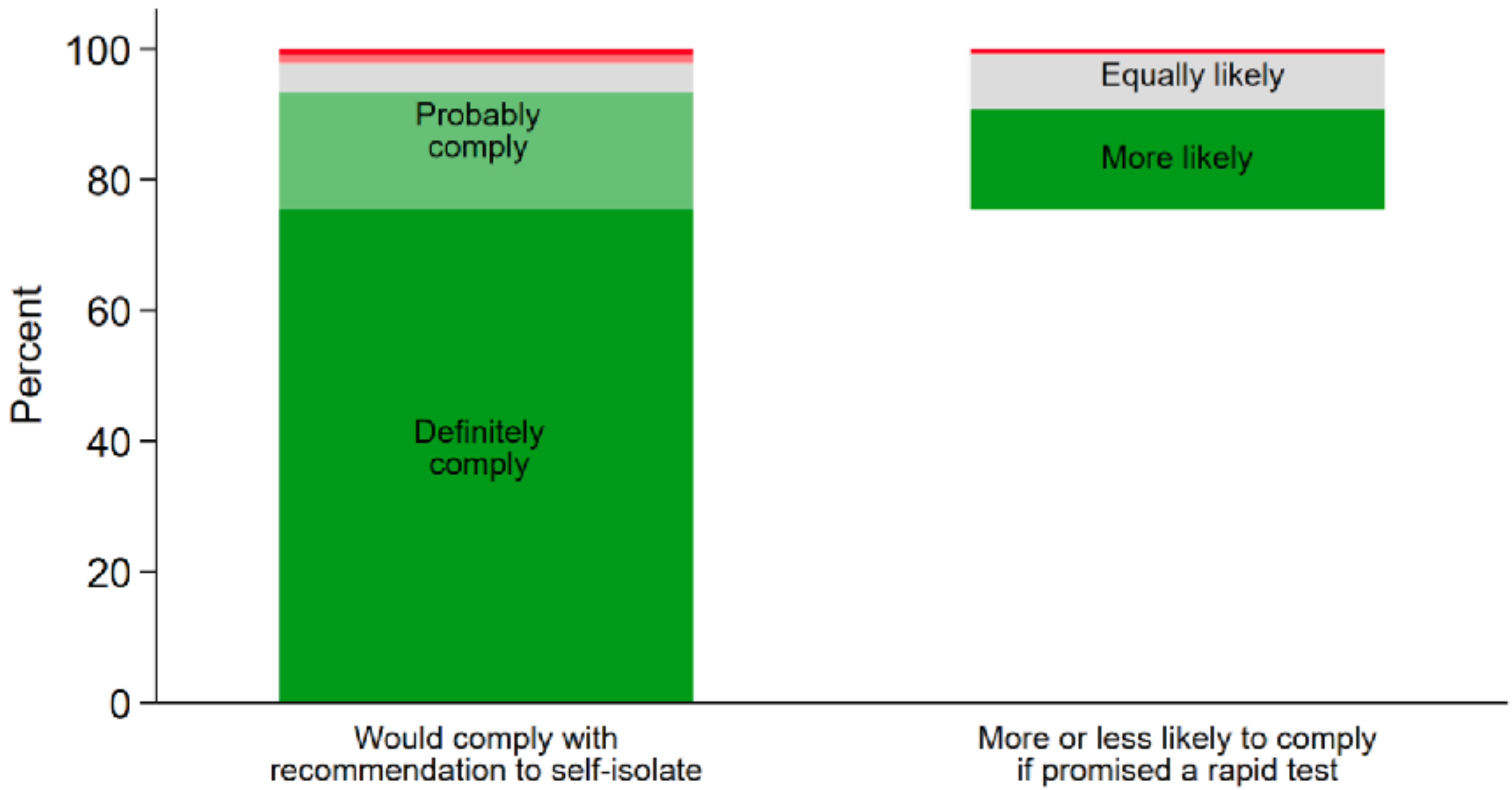
- Building trust and confidence at every stage
- privacy and data usage concerns at the forefront
- adopting a transparent and auditable algorithm
- careful consideration of digital deployment strategies to support specific groups, such as health care workers, the elderly and the young
- deployed with individual consent

# Challenges: voluntary uptake



# Challenges: voluntary uptake

## Compliance with app recommendation to self-isolate



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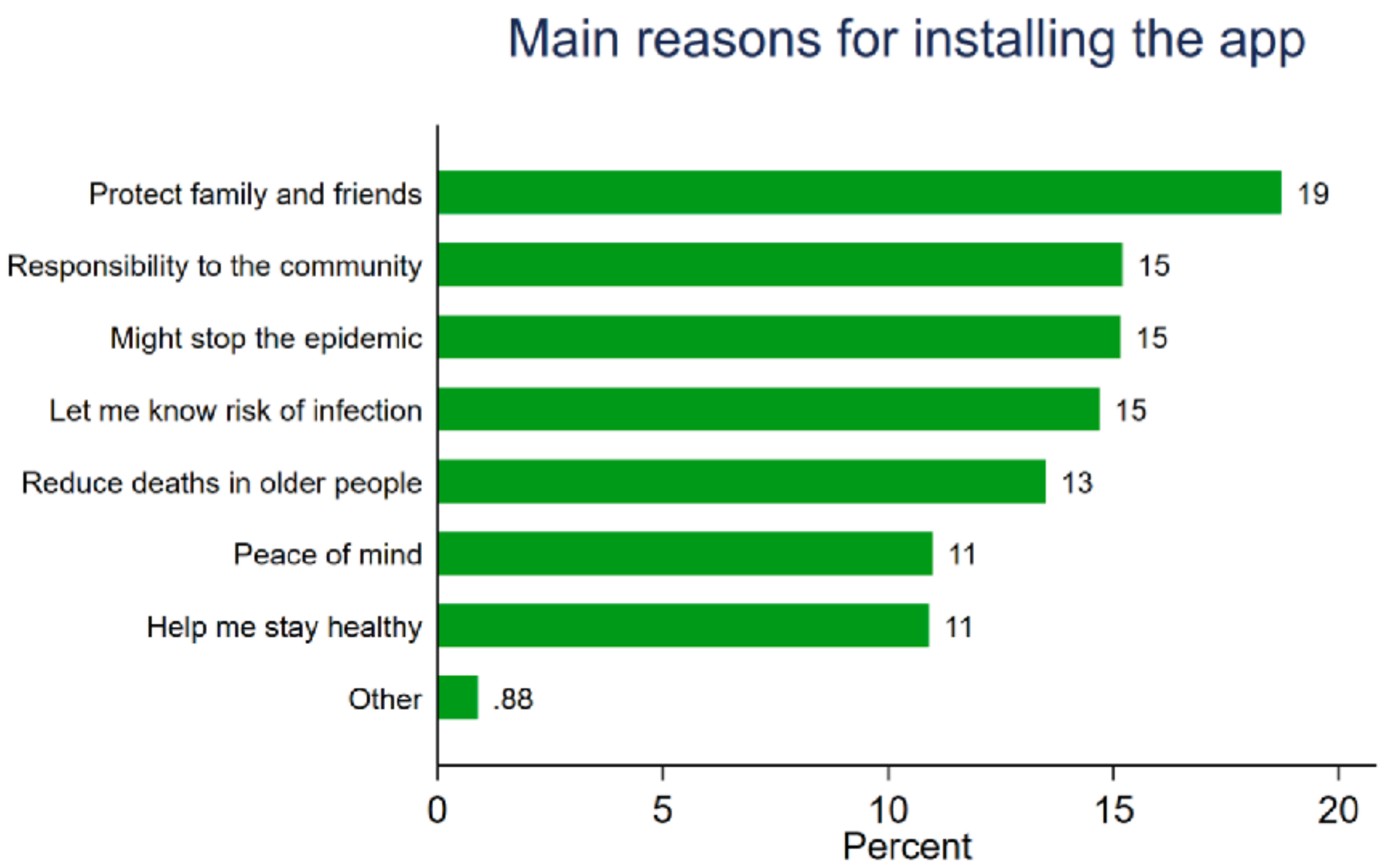

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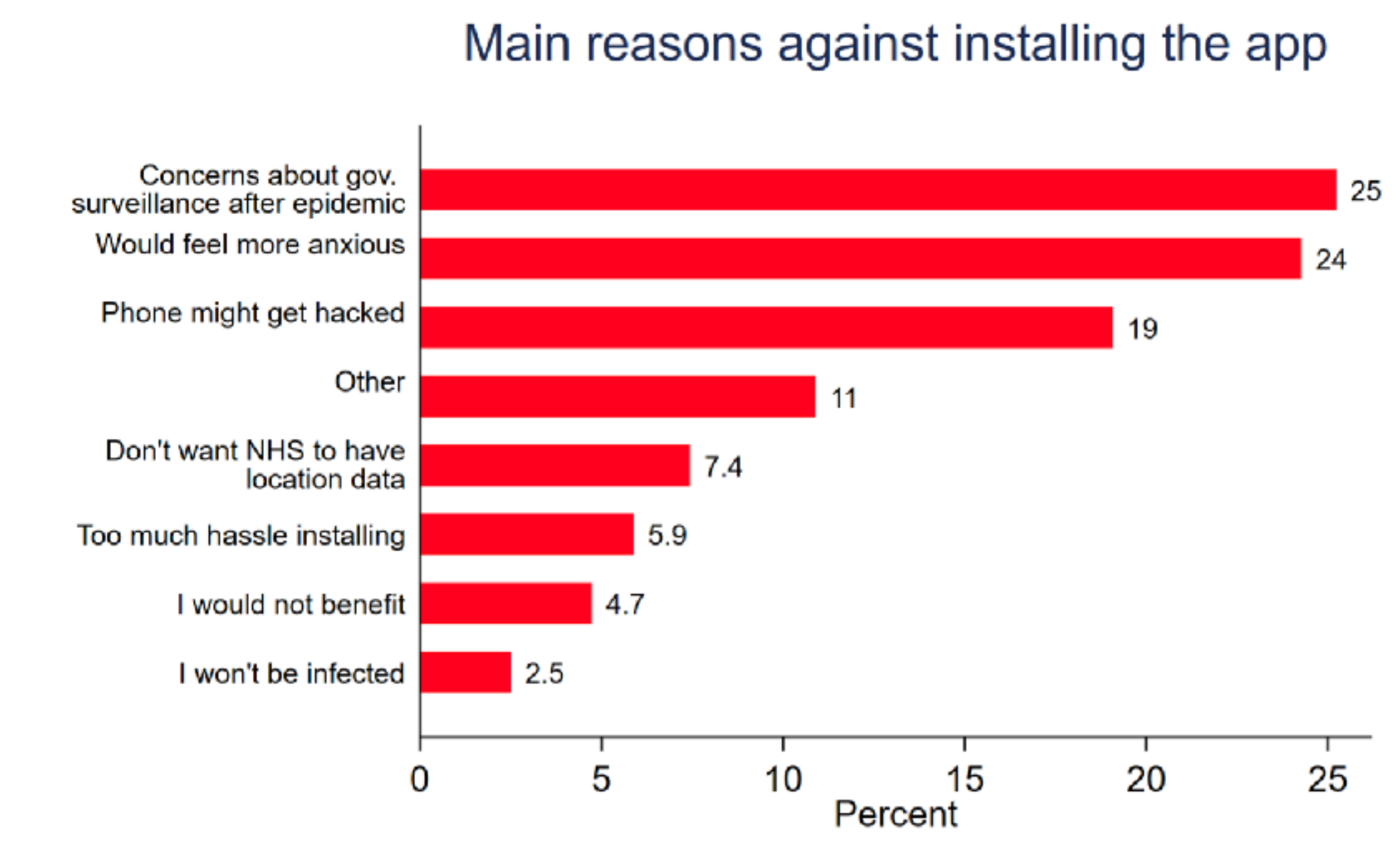

# Recent developments

- Many privacy-preserving projects across the world - now mostly concentrated in two main consortia for Europe and North America (PEPP-PT and TCN)

- Bluetooth Low Energy as common choice of technology (hence interoperability/roaming possible)

- Much movement at European level, different countries at different stages

- Recent Google/Apple announcement: embedding contact tracing APIs in the OS. Technical and political pros and cons.

# What can you do?

- App-based contact tracing could potentially control the epidemic and should be at the core of epidemic response.
  ***Optimised contract-tracing algorithms? Learning from contact networks?***

- It should not be a stand-alone solution!
  Must be part of an integrated strategy (with epidemiological surveillance, risk forecast, geolocation of hot spots, local lockdowns…).
  ***Interplay with other interventions?***

- Widespread diagnostic testing is critical

- Physical distancing still important

- Please support European governments and institutions in their efforts towards app-based contact tracing within an integrated strategy of epidemic control

Based on: *Ferretti, Wymant et al, Science 2020*

Find out more about our research here:

***http://www.coronavirus-fraser-group.org***


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