Reading group session, Jorge X. Velasco-Hernández

Angulo et al, RSIF 2021

Criteria for epidemic outbreaks---objective eradication of infection

$$R_0 > 1$$

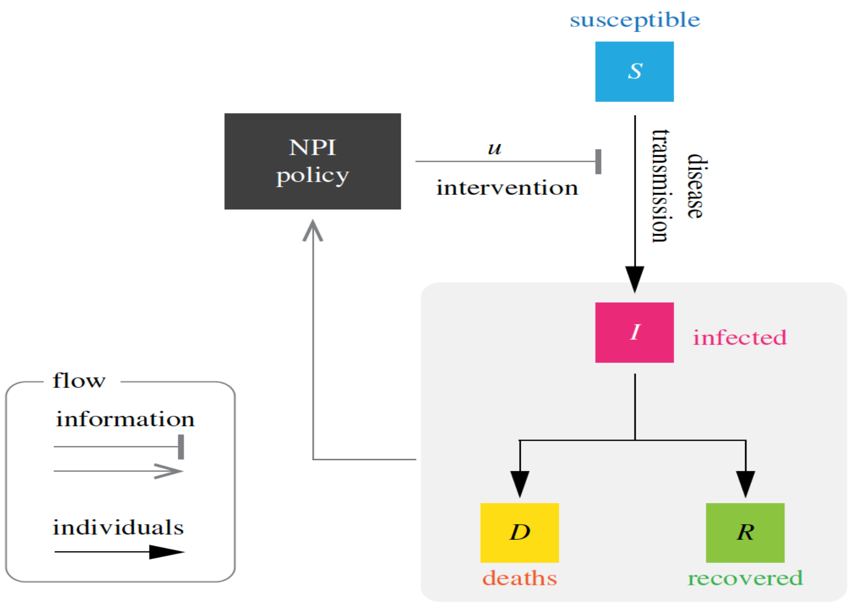
$$R_0 \leq 1$$

Not necessary for mitigation: behavioral and economic objectives: is it possible a similar guideline?

$$S' = -\beta(1-u)SI,$$
$$I' = \beta(1-u)SI - \gamma I,$$
$$R' = \gamma I$$

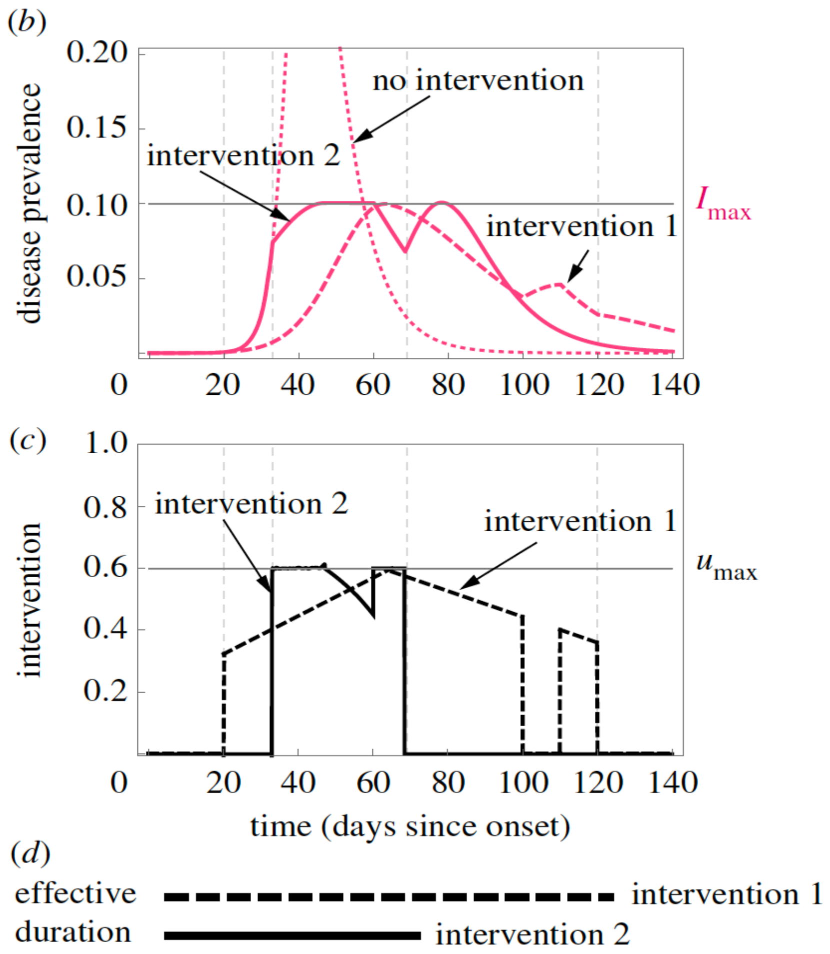
Modeling non-pharmaceutical interventions (NPI)

(a)



Optimal NPI must:
minimize application period (economic, societal costs)
maximum (desired) prevalence must not be exceeded (public health)

Optimal strategy depends on the state of system
Reproduction number below 1, sufficient but not necessary.
Depends on maximum desired prevalence (I_{max}).
Intervention must start before I_{max} is reached (not seeking $R_0 < 1$).



$$(S, I) \in [0,1]^2 \qquad 1 - u, u_{\max}$$

reduction on effective contact rate

$$I(t) \le I_{\max} \qquad u, u_{\max} \in [0,1], u \in [0, u_{max}]$$

is an admissible control

Optimal admissible is $u^*(S(t), I(t))$ required at time t (*now*) to:
minimize intervention period.
maximum (desired) prevalence is not exceeded in future
Aim is mitigation

Optimal depends on state of system

Safe zone Δ: largest set in state space such that for any given time t_1 $(S(t_1), I(t_1)) \in \Delta$, we can put $u = 0$, and still have $I(t) \leq I_{max}$ for all $t \geq t_1$

$$\Delta = \{(S, I) : I \leq \Phi_{R_0}(S)\}$$

$$\Phi_R(S) = \begin{cases} I_{\max}, & \text{for } \leq \frac{1}{R} \\ I_{\max} + \frac{1}{R}\left(\log RS + 1 - RS\right), & \text{otherwise.} \end{cases}$$

Want: to steer (S_0, I_0) into Δ in minimal time keeping $I \leq I_{max}$

An optimal intervention exists if and only if (S_0, I_0) satisfies $I_0 \leq \Phi_{R_c}(S_0)$.

$$u^*(S, I) = \begin{cases} 0, & \text{for } (S, I) \in \Delta \cup W \\ 1 - \frac{1}{R_c S}, & \text{for } I = \Phi_{R_c}(S) \text{ and } S^* < S < R_c^{-1}, \\ u_{\max}, & \text{otherwise.} \end{cases}$$

Controlled reproduction number

$$R_c = (1 - u_{max})R_0$$

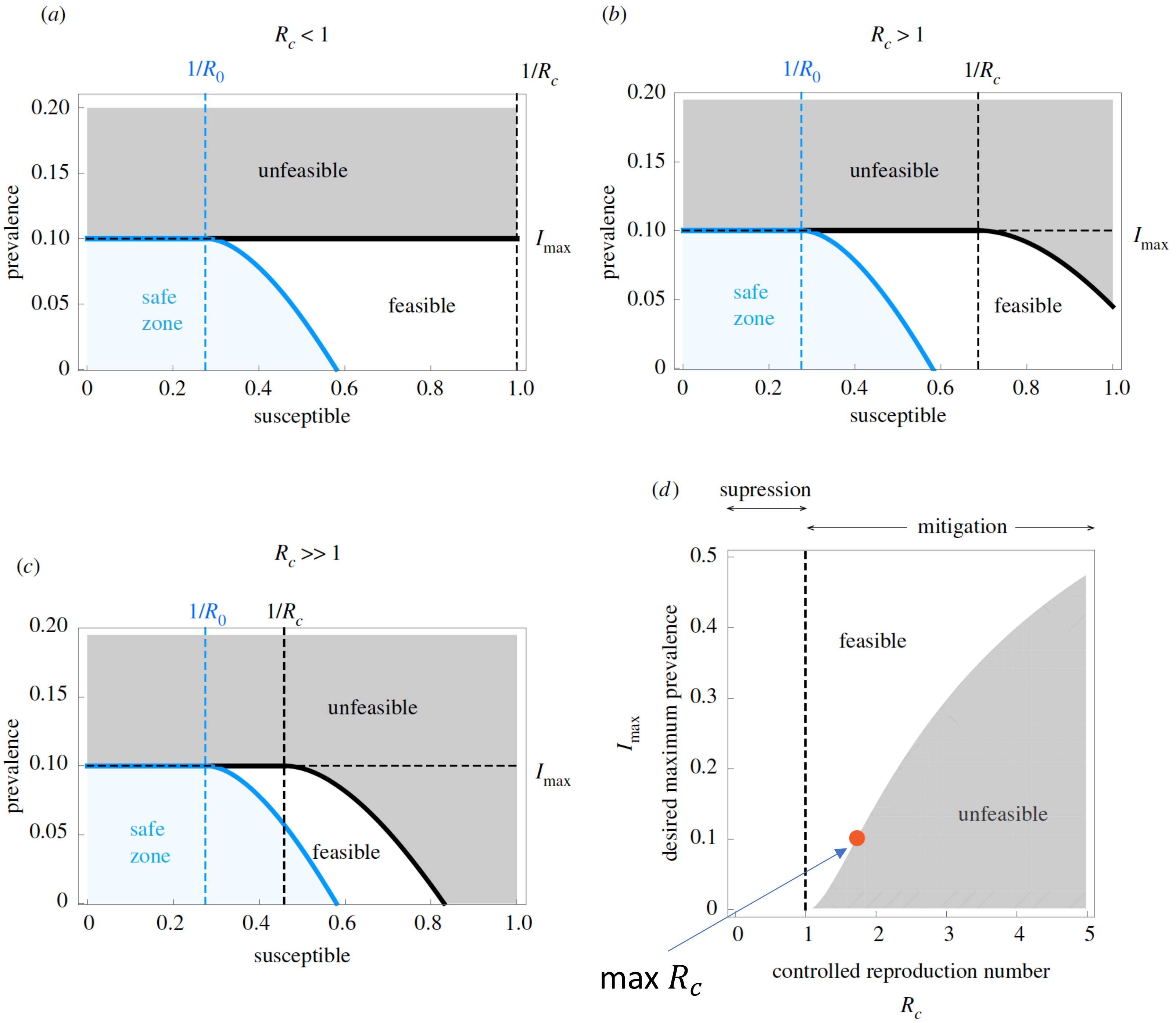
$R_c < 1$, eradication
$R_c > 1$, mitigation still feasible

Maximum reduction that *admissible* interventions can achieve

For $S_0 \to 1$, NPI exist, $I(t) < I_{max}$:

$R_c < 1$ or

$$I_{\max} + \frac{1}{R_c}\log R_c - (1 - \frac{1}{R_c}) \geq 0$$

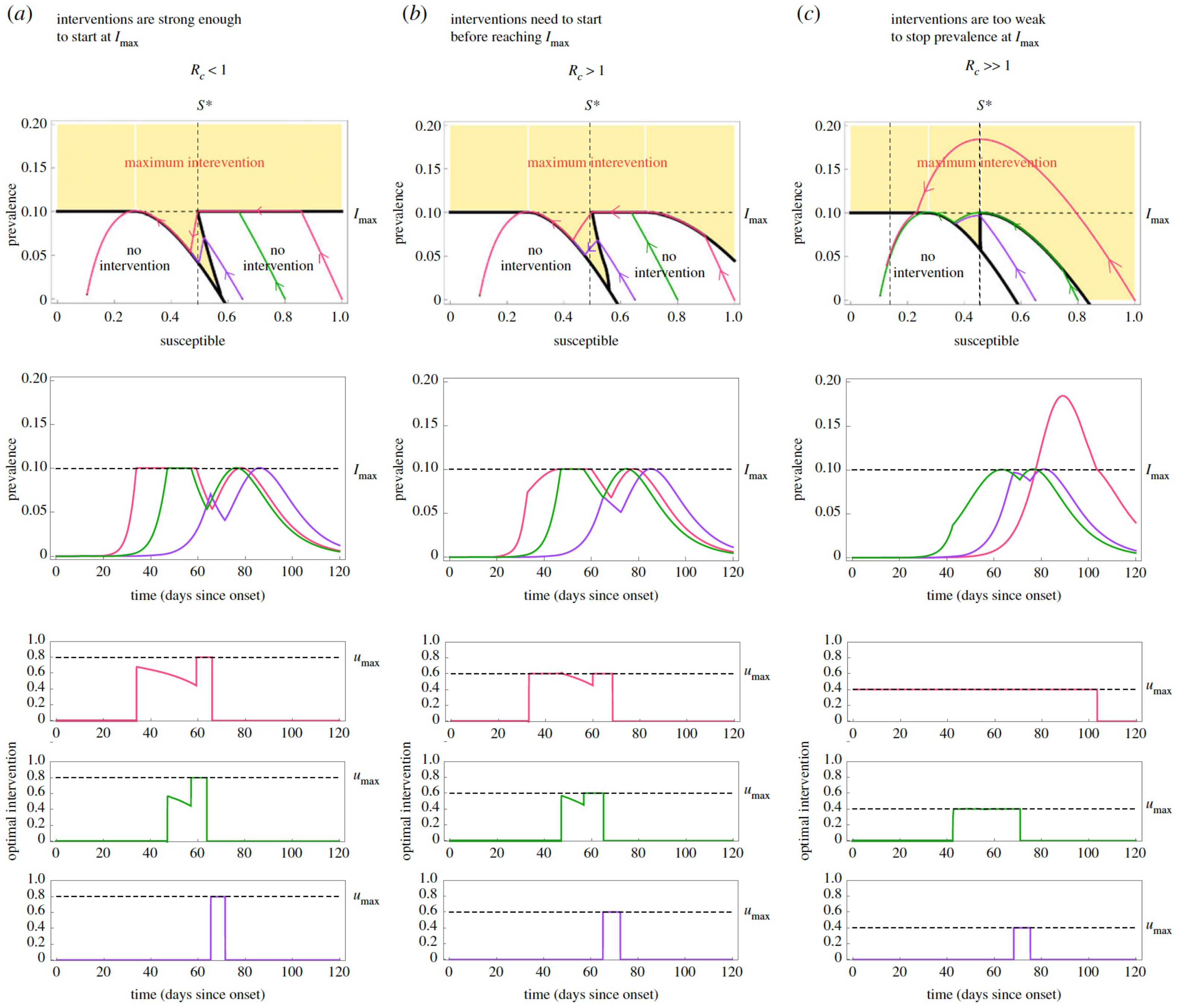


Scenarios:

- Interventions until I_{max} is reached
- Early interventions
- Ineffective interventions

In general (case $R_c > 1$):

- no intervention
- maximum strength interventions
- gradual decrease of interventions
- maximum intervention to safe zone



Behaviour and infectious diseases

- Human behavior underutilized in epidemiology before CoVID
- Data scarcity
- Underdeveloped computational technologies.

- Behavioral dynamics during pandemic
  - Social distancing.
  - Mask wearing.
  - Vaccine hesitancy.

- Research and data for models and simulations.

- Need: computational models, artificial intelligence and machine learning techniques that bridge human behavior knowledge and traditional epidemiological theory and models.

- Role of heterogeneity
- Static unweighted networks
- Weighted dynamic networks
- Waning immunity on network models
- Approximation of epidemic processes on networks
- Effect of network properties
- Networks and data
- Design network-based interventions

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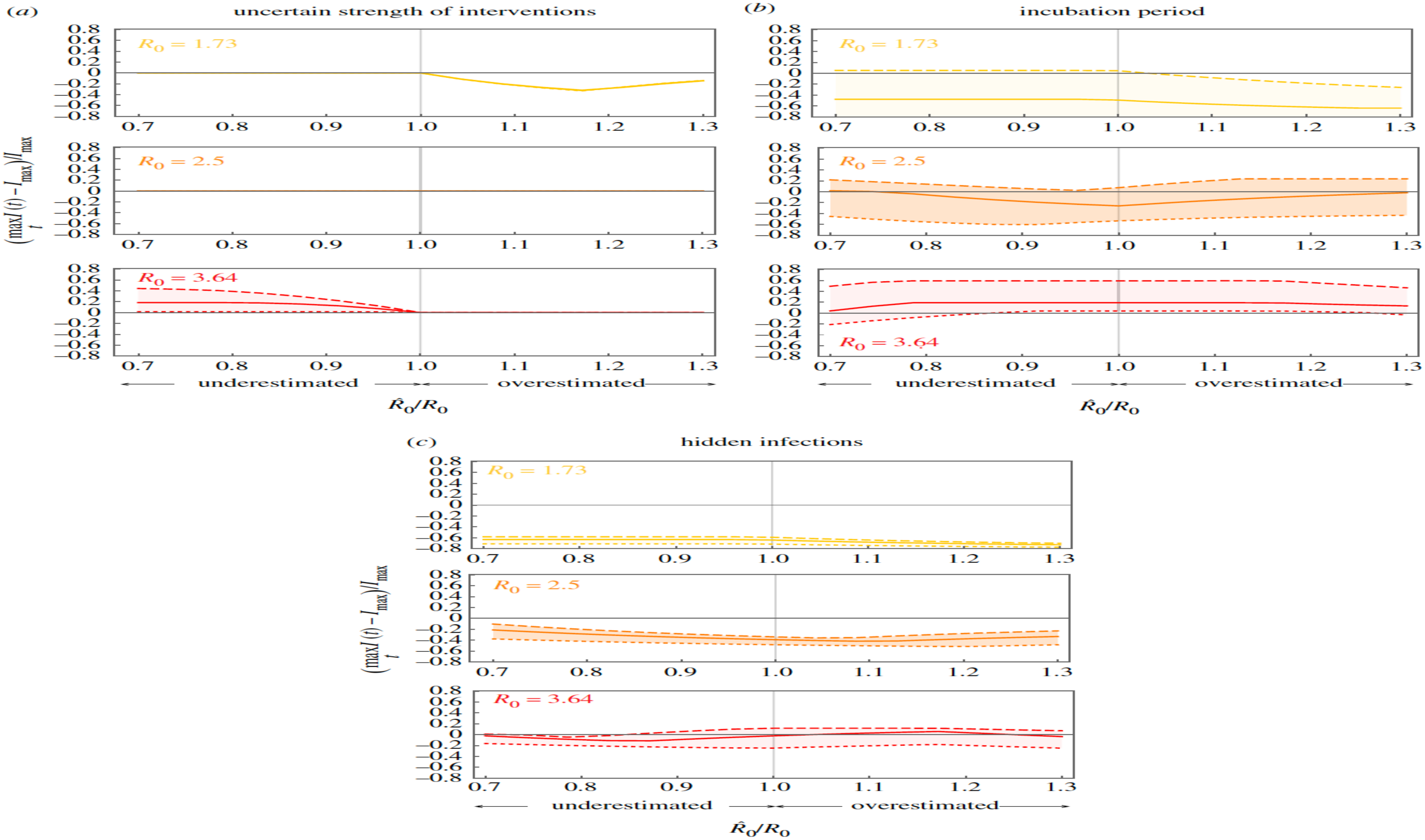
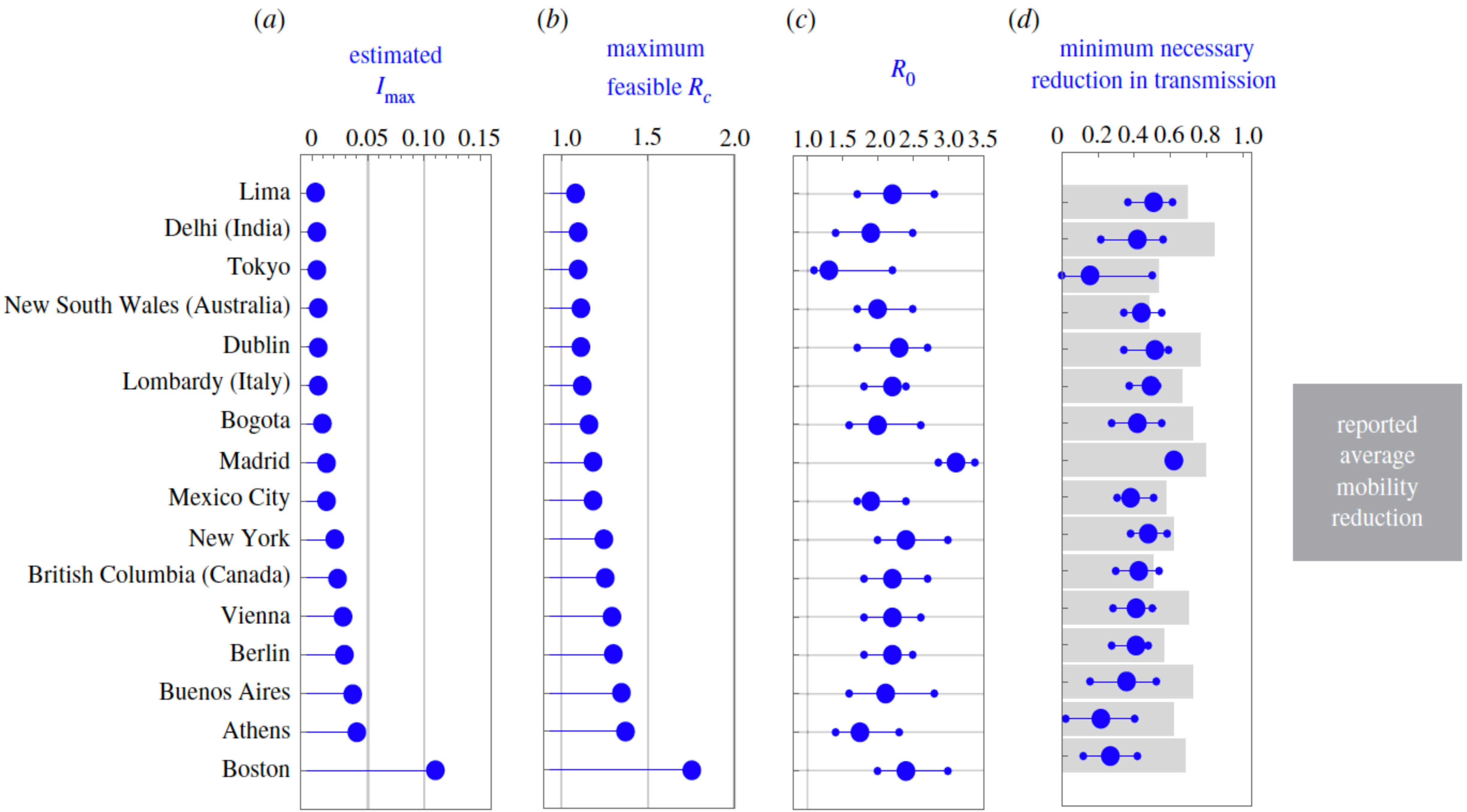
Challenges in Modelling Infectious Disease Dynamics: Preface



(a)
uncertain strength of interventions
(b)
incubation period
(c)
hidden infections
$R_0 = 1.73$
$R_0 = 2.5$
$R_0 = 3.64$
$(\max_t I(t) - I_{max})/I_{max}$
underestimated
overestimated
$\hat{R}_0/R_0$



(a)
estimated
I_{max}
0
0.05
0.10
0.15
(b)
maximum
feasible R_c
1.0
1.5
2.0
(c)
R_0
1.0
1.5
2.0
2.5
3.0
3.5
(d)
minimum necessary
reduction in transmission
0
0.2
0.4
0.6
0.8
1.0
Lima
Delhi (India)
Tokyo
New South Wales (Australia)
Dublin
Lombardy (Italy)
Bogota
Madrid
Mexico City
New York
British Columbia (Canada)
Vienna
Berlin
Buenos Aires
Athens
Boston
reported
average
mobility
reduction