A Bayesian approach to assess the spread of COVID-19 using an extended SEIRD model with implicit quarantine mechanism

Applications in Brazilian locations

Diego T. Volpatto[1], Anna Claudia M. Resende[1], Lucas dos Anjos[1], João Vitor O. Silva[1], Claudia M. Dias[2], Regina C. Almeida[1], Sandra M. C. Malta[1]

[1]Laboratório Nacional de Computação Científica (LNCC)

[2]Universidade Federal Rural do Rio de Janeiro (UFRRJ)

SMB 2020 Annual Meeting

Laboratório Nacional de Computação Científica

UFRRJ
UNIVERSIDADE FEDERAL RURAL DO RIO DE JANEIRO

Agenda

1 COVID-19 in Brazil

Brazil's non-pharmaceutical interventions (NPIs)

- Moderate social distancing measures
- Weak quarantine policies
- Lack of vaccines/medicines
- Underreporting and undertesting

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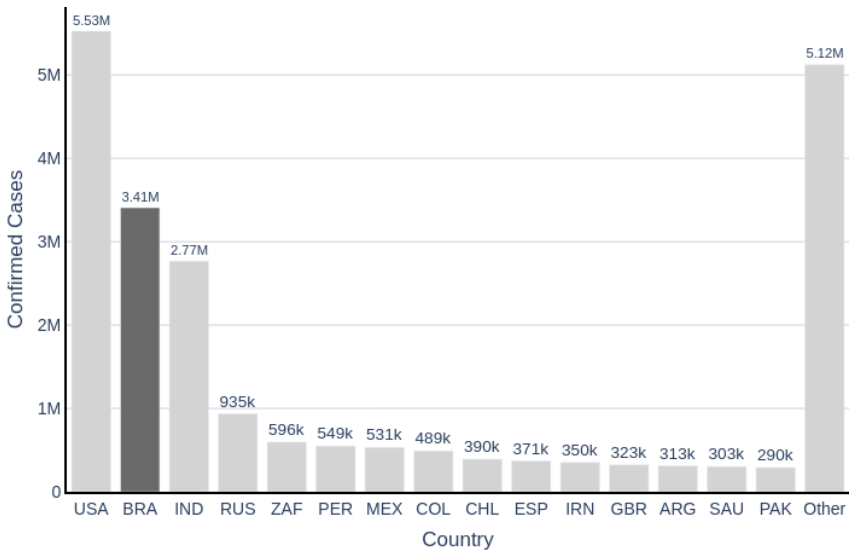
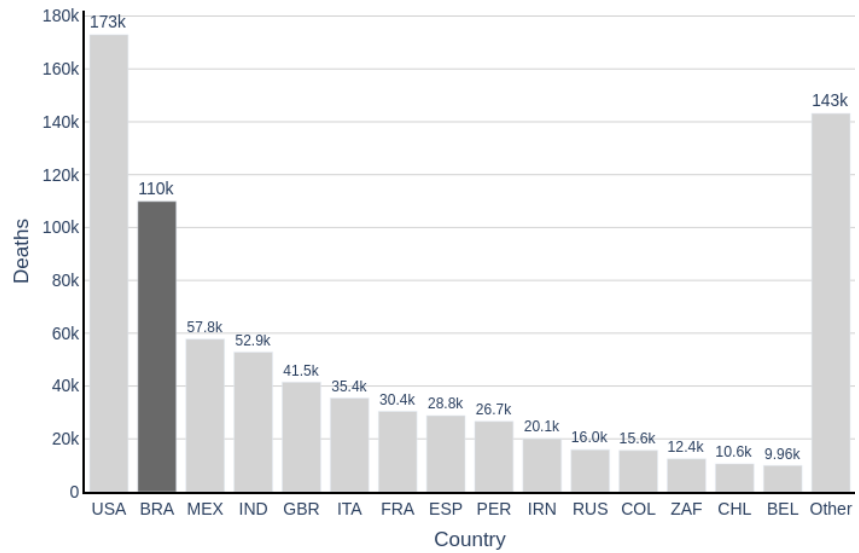
Date: 19/08/2020



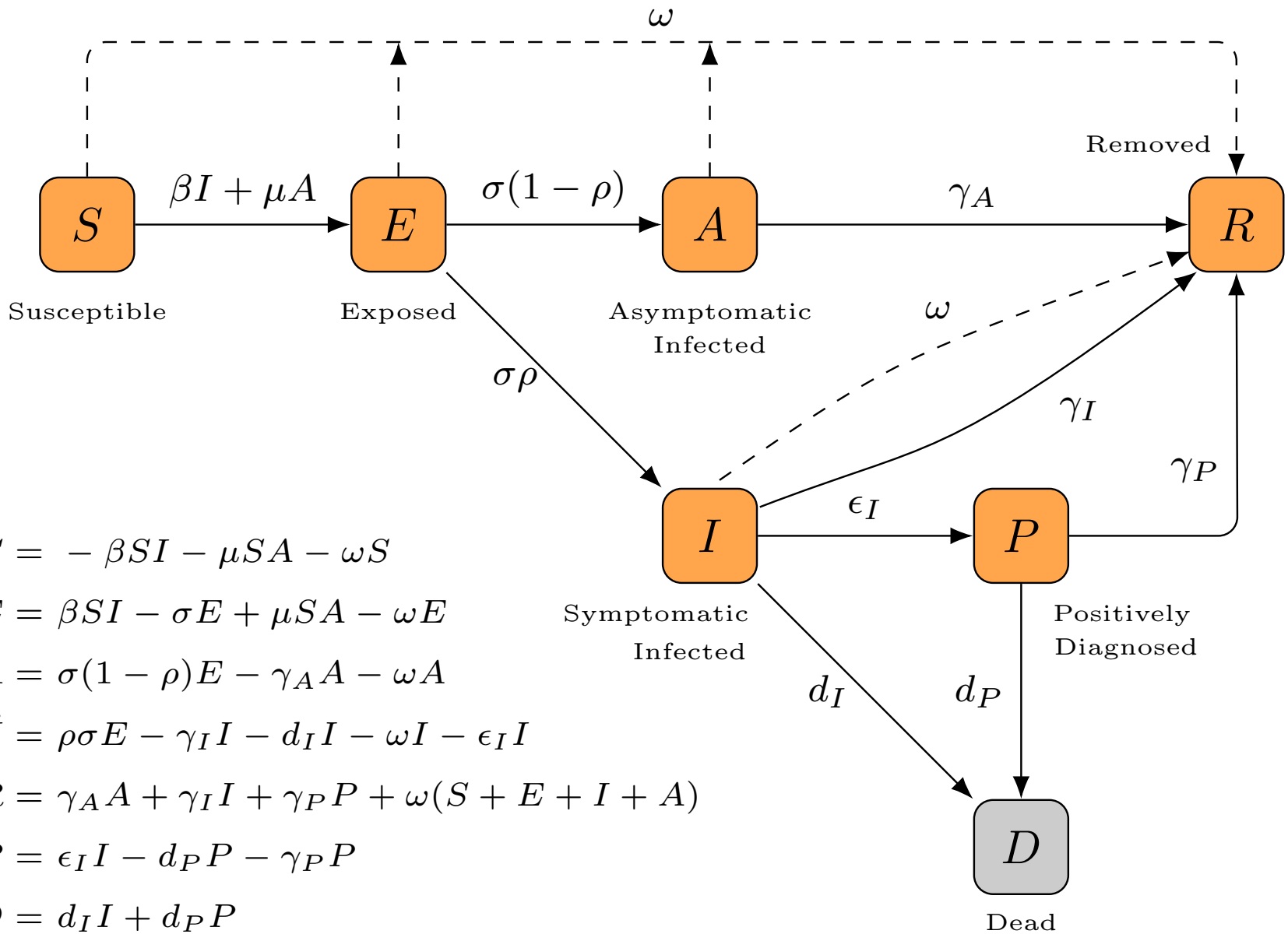


These numbers are in "human beings" unit!!!

- The question that comes to mind: **What we could do as scientists?**
- Forecasting is really hard! What if it does not match with reality afterward?
- Understanding is the "key" to open the "door" of actions
- With understanding of a phenomenon, you can **advise**!
- Our general goal: to **advise** (not forecast!) based on **scientific evidence**
- Our specific goal: to advise about NPIs and, more specifically, about **quarantine policies**

2 An extended SEIRD model

- Models are **simplifications/approximations** of reality
- *"All models are wrong, but some are useful"* (attributed to G. Box)
- Modeling goals: understanding some **features of reality** (not all!)
- **This work** $\rightarrow$ To understand the effect of **quarantine** on COVID-19 spreading in **Brazil (country)** and **Rio de Janeiro state**



$$\dot{S} = -\beta SI - \mu SA - \omega S$$
$$\dot{E} = \beta SI - \sigma E + \mu SA - \omega E$$
$$\dot{A} = \sigma(1-\rho)E - \gamma_A A - \omega A$$
$$\dot{I} = \rho\sigma E - \gamma_I I - d_I I - \omega I - \epsilon_I I$$
$$\dot{R} = \gamma_A A + \gamma_I I + \gamma_P P + \omega(S + E + I + A)$$
$$\dot{P} = \epsilon_I I - d_P P - \gamma_P P$$
$$\dot{D} = d_I I + d_P P$$

3 Sensitivity and Uncertainties

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Sensitivity analysis goals

- How changes in model factors affect QoIs?
- Assess model factors' importance
- Help to understand how the model response to perturbations

Effective Reproduction number

$$\text{QoI}_1(t) = \mathcal{R}(t)$$

Normalized squared sum

$$\text{QoI}_2(t) = \sqrt{C(t)^2 + D(t)^2}$$

- Enhanced **Elementary Effects method** (Campolongo et al., 2007) using `SALib`
- Factors' distributions: $\theta_i \sim \mathcal{U}(0.5\bar{\theta}_i, 1.5\bar{\theta}_i)$

- Fitting parameters ($\boldsymbol{\theta}$): $\{\beta = \mu, d_I, d_P, \omega\}$ and $\{\sigma_C, \sigma_D\}$
- Noise on data: $\mathcal{N}(0, \sigma_C^2)$ e $\mathcal{N}(0, \sigma_D^2)$
- Observed quantities C and D:

Likelihood function

$$\pi_{\text{like}}(\boldsymbol{y}|\boldsymbol{\theta}) = \prod_{j \in \{C,D\}} \frac{1}{\sigma_j \sqrt{2\pi}} \exp\left(-\frac{1}{2} \sum_{i=1}^{n} \left(\frac{y^{(j)}(t_i) - y^{(j)}_{\text{model}}(t_i)}{\sigma_j} \right)^2 \right)$$

- Bayesian calibration: CATMIP (*Cascading Adaptive Transitional Metropolis in Parallel*) from `PyMC3`

4 Results

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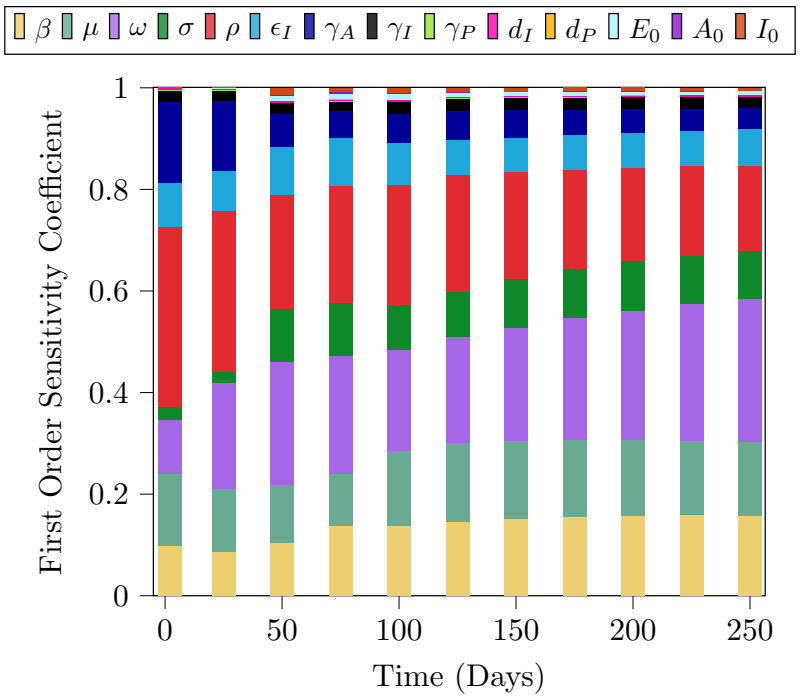
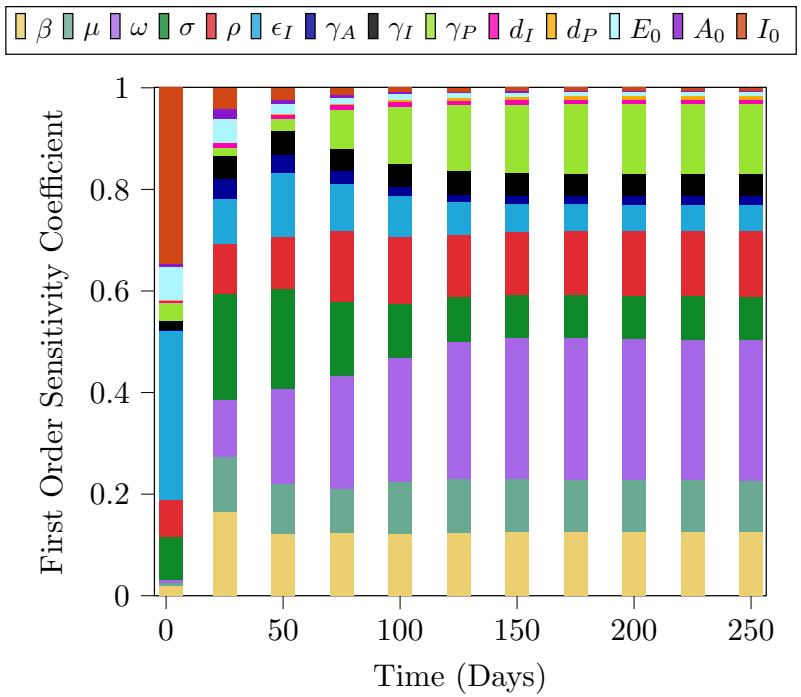
- Data for model calibration:
  - **Brazil (Health Ministry)**: `https://covid.saude.gov.br/`
  - RJ state: `https://covid19br.wcota.me/`
  - Data range: March-May (approximately 2 months)
- Code:
  - Open Source
  - Code and Data available at:
    `https://doi.org/10.5281/zenodo.3865730`

- Sensitivity measures here: normalized mean of the absolute overall factor influence on QoI for different times



$\mathrm{QoI}_1(t)$



$\mathrm{QoI}_2(t)$

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Quarantine scenarios - what happens if...

1. Relaxation of quarantine policy before infection peak:
   - Abrupt release
   - Progressive relaxation
2. Relaxation of quarantine policy after infection peak:
   - Abrupt release
   - Progressive relaxation

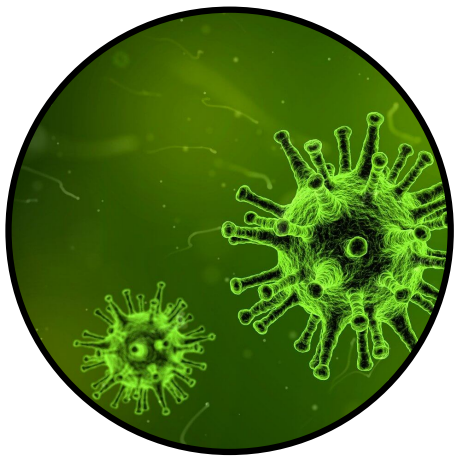
Removal/quarantine rate

$$\omega_r = \omega e^{-\lambda(t-t_d)}$$

Decay constant: $\lambda = \ln 2 / t_{1/2}$;

Release day: t_d;

COVID-19



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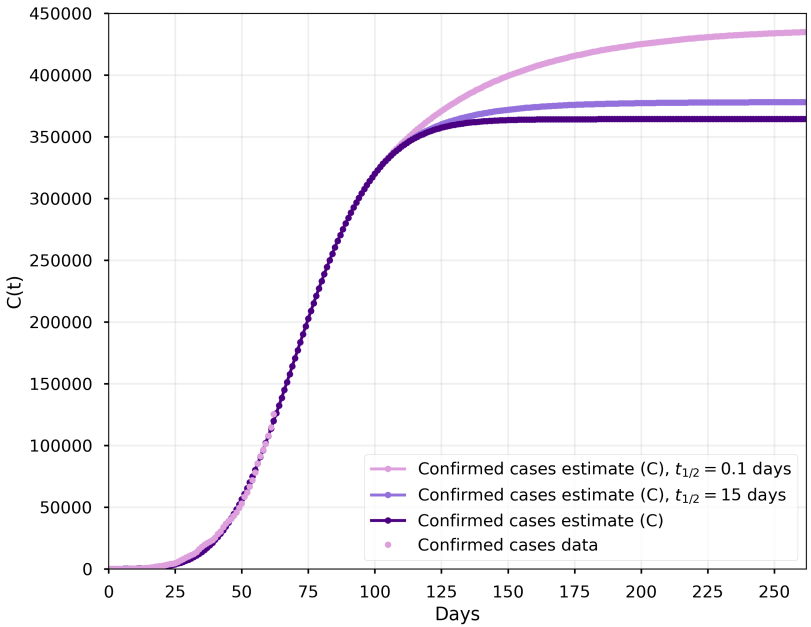
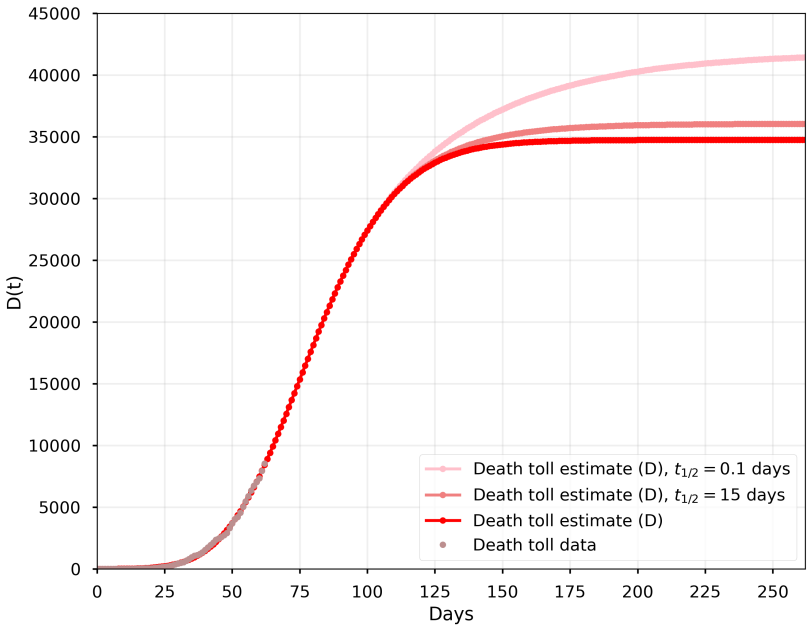
Relaxation after infection peak (disease spreading under control)



Confirmed cases



Death toll

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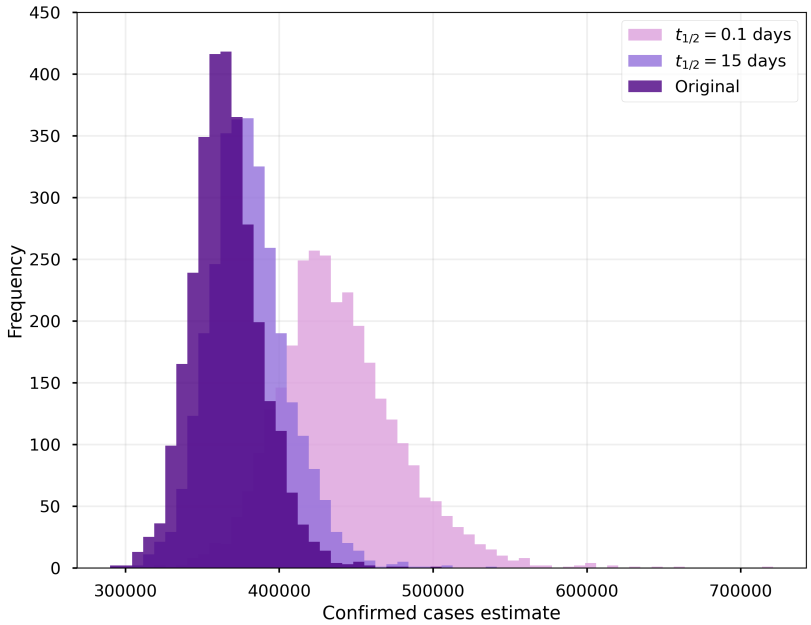
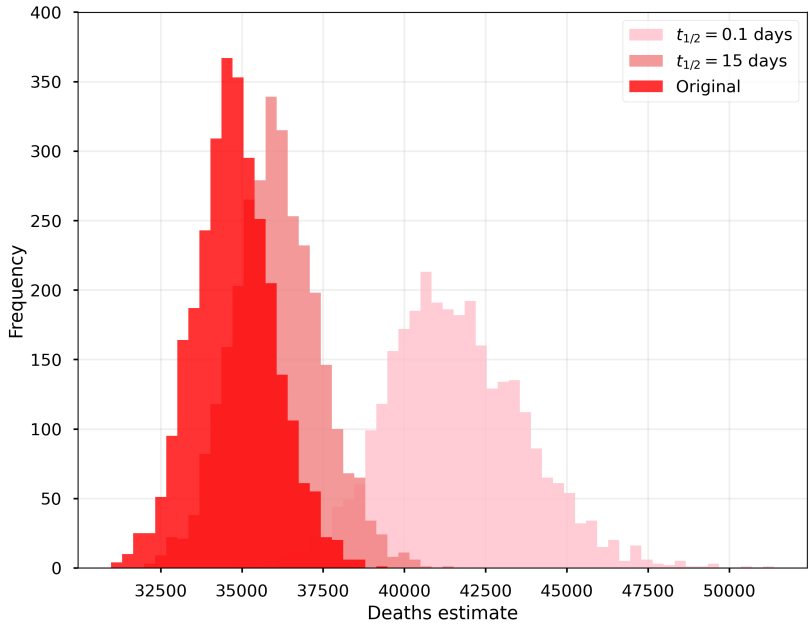
When disease spreading ends...

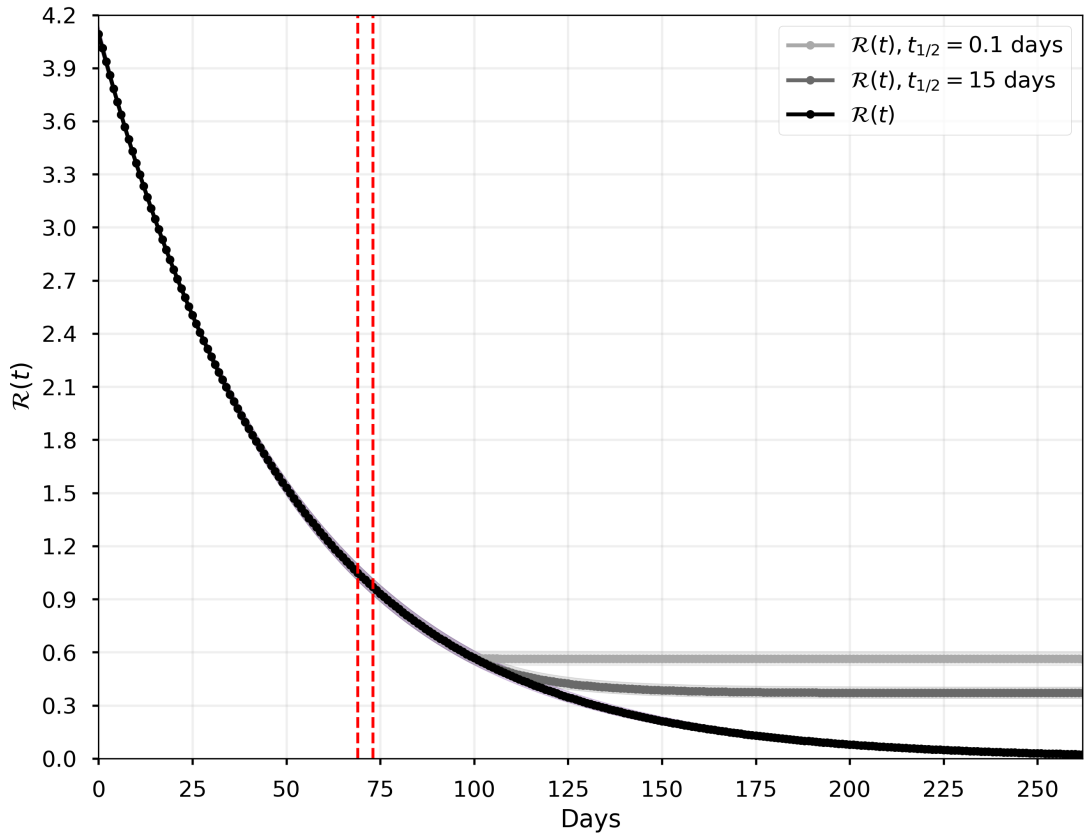


Confirmed cases



Death toll

Effective Reproduction number: relaxation implies in a longer time to disease eradication



What if quarantine policy relaxation is applied without disease control evidence?

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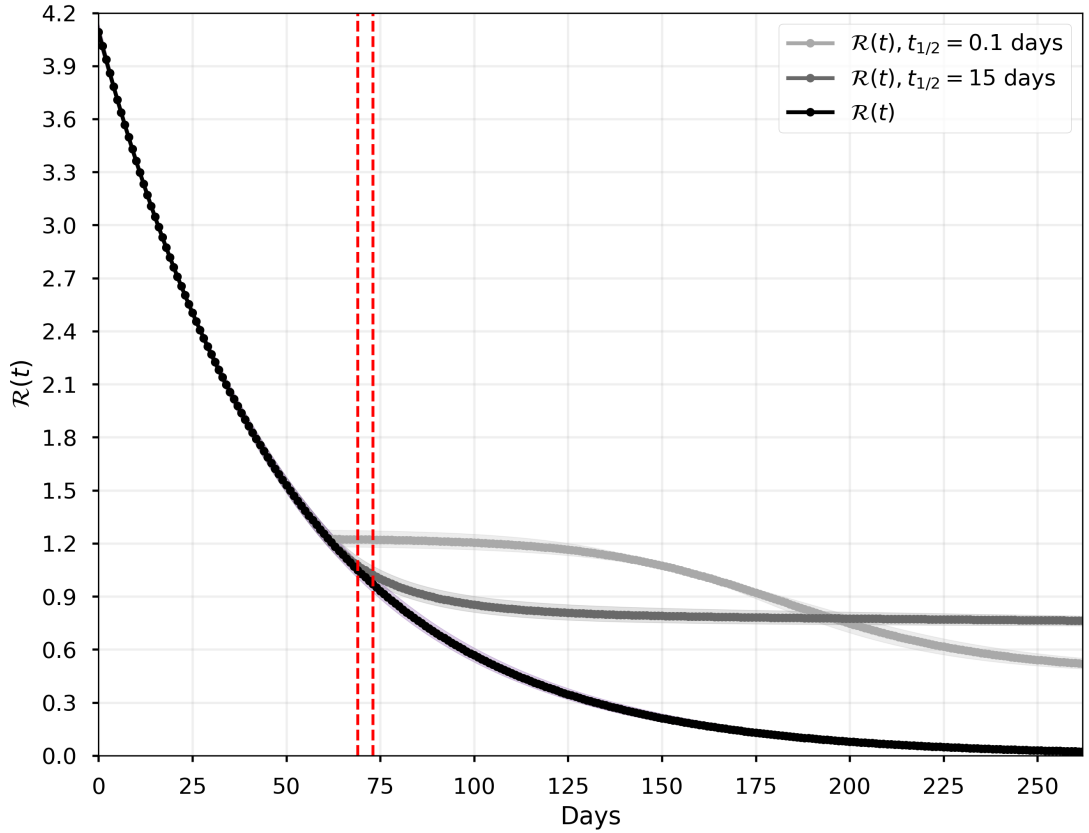

Higher $\mathcal{R}(t)$ for an even longer period, requiring more time to reach $\mathcal{R}(t) \leq 1$

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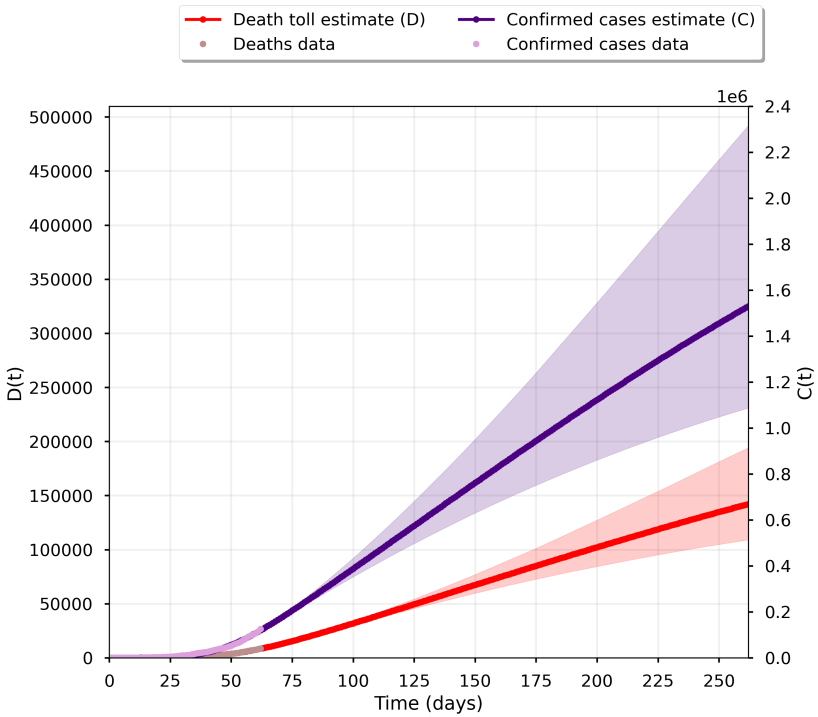
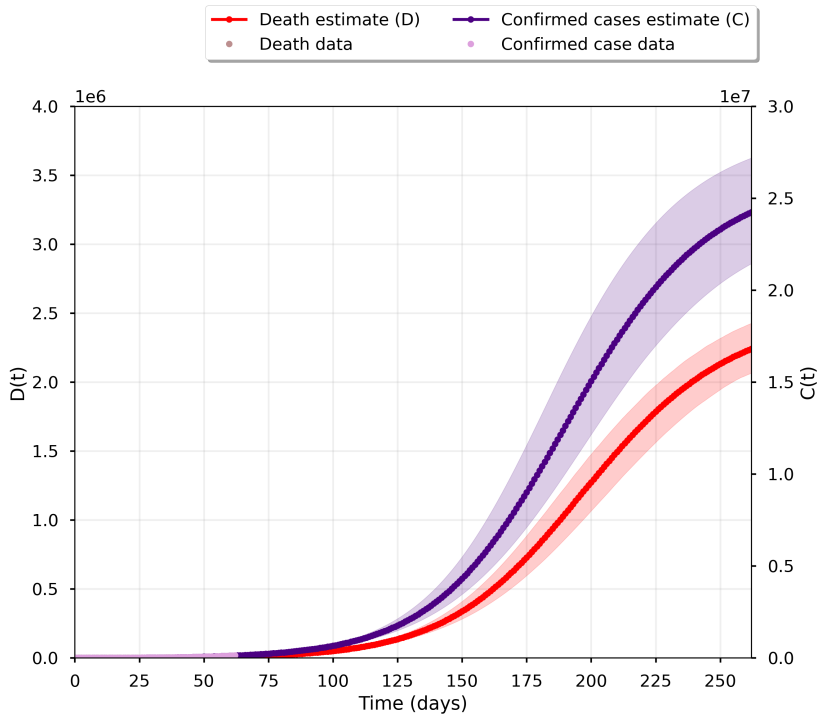
A terrible scenario is achieved regardless of quarantine policy relaxation strategy



Progressive relaxation



Abrupt relaxation

5 Concluding Remarks

Concluding Remarks

Main results (and recommendations)

- Sensitivity analysis suggests that NPIs parameters ($\beta + \mu$ and ω) are the most influential in the disease dynamics
- Results show that the maintenance of quarantine policy can help to control the spreading
- "Decision timing" plays a fundamental role, even when the "almost under control"
- Uncertainties increase in worse scenarios, making the disease control diagnosis more difficult to detect

Thank you and stay safe!

Check out our preprint: "Spreading of COVID-19 in Brazil: Impacts and uncertainties in social distancing strategies"

volpatto@lncc.br