Must Whatever Goes up Come Down? Mortality Gradients in the Emergence of COVID-19

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Theoretical Background

- Fundamental cause theory states that mortality gradients persist even if proximal causes of death change
- COVID-19 (like other recent EIDs) 1st emerged with an inverted social gradient in mortality that later reversed & went in expected direction
- Existing theory = mortality gradients are produced by differential uptake of interventions that are introduced to prevent/treat the disease
- What about the role of pre-existing disease-agnostic inequities?

Motivation

- Historical uniqueness of COVID-19
  - Initially introduced to higher SES geographies
  - Interventions adopted ***contemporaneously*** with wider spread
  - No empirical evidence to disentangle their effects from pre-existing inequities

1. What were the relative contributions of ***disease-specific interventions*** and ***disease-agnostic pre-existing inequities*** to the production of COVID-19 mortality gradients?
2. How could more equitable distribution of these interventions have counteracted the effects of these pre-existing inequities?

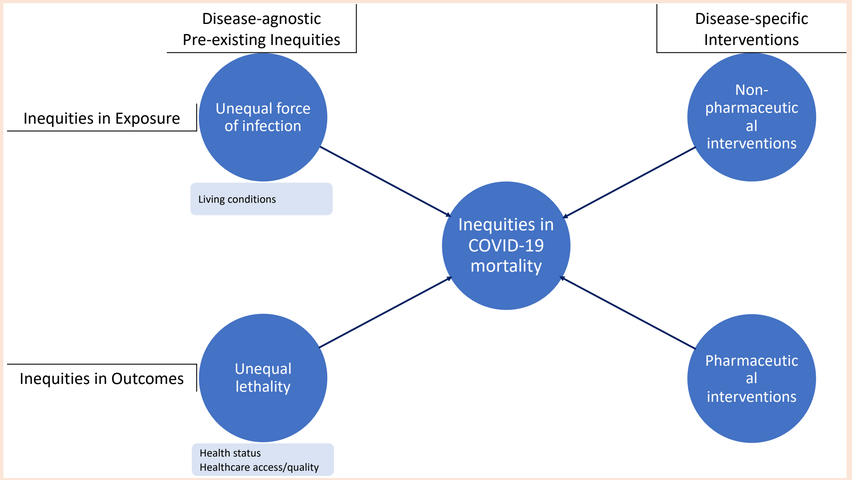


Figure 1: Pathways to COVID-19 mortality gradients.

Approach: Creation of a model world for looking at social gradients in mortality under ***counterfactual scenarios***.

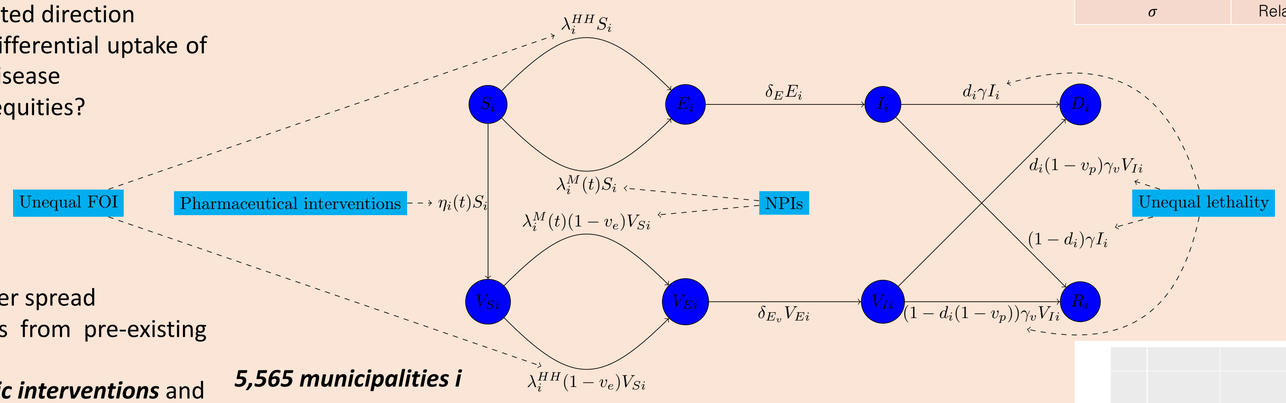
a) No interventions
b) Interventions distributed as in real world
c) Interventions distributed more equitably

Setting: Emergence of COVID-19 in Brazil.

- 1st study of spatiotemporal dynamics of mortality gradients
  - National in scope
  - Fine-grained geographic scale
  - Mechanistic model using real-world data- informed parameters

1st mechanistic model of pathways to EID mortality gradients

Methods



5,565 municipalities i

Figure 2: Model diagram.

Table 1: Model compartments.

Compartment	Description
S_i	Susceptible (unvaccinated)
E_i	Exposed (unvaccinated)
I_i	Infectious (unvaccinated)
V_{S_i}	Susceptible (vaccinated)
V_{E_i}	Exposed (vaccinated)
V_{I_i}	Infectious (vaccinated)
R_i	Recovered
D_i	Deceased
N_i	Total population

Household/mobility-independent force of infection

$$\lambda_i^{HH} = \tau_{HH}(\overline{HHsize_i} - 1)\frac{I_i + \sigma V_{I_i}}{N_i}$$

Extra-household/mobility-related force of infection

$$\lambda_i^M(t) = \kappa_M(1 + \Delta M_i(t)) \sum_j \omega_{ij} \frac{I_j + \sigma V_{I_j}}{N_j}$$

Table 4: Parameterization of pathways.

	Pre-existing inequities	COVID-specific interventions
Unequal exposure	<u>Pre-existing living conditions</u> Mean residents per household ($\overline{HHsize_i}$) *2010 Census*	<u>Social distancing NPIs</u> Proportional change in movement ($\Delta M_i(t)$) *Facebook Movement Range Maps*
Unequal outcomes	<u>Pre-existing health/healthcare conditions</u> Infection fatality rate (d_i) *SIM/state epidemiological bulletins*	<u>Vaccination</u> Rate of vaccine administration per day ($\eta_i(t)$) *SI-PNI*

Model implementation & output analysis

1. Start with 10 exposed cases in São Paulo
2. Run for 26 weeks
   - Deaths stochastic, everything else deterministic

Outcome = weekly deaths by municipality, D_{iw}

3. Adjust for age distribution/intra-municipality inequality: NB regression

$$log(D_{iw}) = log(PY_{iw}) + \alpha_w + W \times X_{ik}^T \beta_{kw} + u_{iw}$$

4. Obtain predicted weekly mortality rates by municipality

Measuring inequality from model output

- Weekly relative concentration index of mortality
- Measurement of SES = PC1 of social vulnerability index (urban infrastructure, human capital, income/work), municipal HDI & racial makeup

Parameter	Description
v_e	Vaccine efficacy
v_p	Vaccine protection against death
$\delta_{E_v}^{-1}$	Latent period of vaccinated (days)
γ_v^{-1}	Infectious period of vaccinated (days)
σ	Relative infectiousness of vaccinated

Table 3: Vaccination-related parameters.

Table 4: Remaining model parameters.

Parameter	Description	Value (mean)
ω_{ij}	Mobility (commuting) matrix	Municipality-specific
δ_E^{-1}	Latent period (days)	2.9
γ^{-1}	Infectious period (days)	7
τ_{HH}	Household secondary attack rate	.166
κ_M	Mobility-dependent transmission rate	.063
R_0	Basic reproduction number	3.1

Preliminary Results

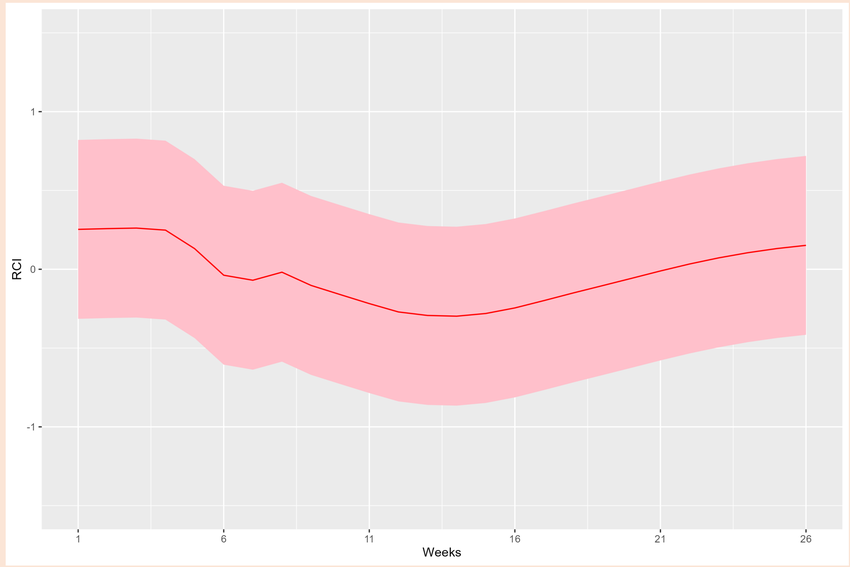


Figure 3: Simulated RCI of COVID-19 mortality in Brazilian municipalities (baseline scenario with no interventions).

- RCI > 0 indicates mortality more concentrated in higher SES municipalities
- Mortality starts concentrated in higher SES municipalities
- Moves to lower SES municipalities as disease spreads, before reversing (as supply of suseptibles depleted)

Next steps

- Counterfactual model scenarios with interventions
  1. NPIs only
  2. Vaccination only
  3. Both
  4. More equitable distribution of the above
- Obtain flight data & model as a stochastic migration process
- Add additional controls to regression model/robustness checks
  1. Region/state fixed effects
  2. Pre-covid mortality
  3. Bolsonaro vote share
  4. Spatial autocorrelation