Assessing the effectiveness of perimeter lockdowns at the urban scale: the case of Madrid

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Background

- COVID-19 pandemic happened.
- A myriad of non-pharmaceutical interventions (Perra N. Phys. Rep. 2021;913:1–52):
  - Self-protection (hygiene, face masks, quarantines...)
  - Capacity limits, tele-work, school closures.
  - Lockdowns (national, regional, urban-scale).
- Perimeter lockdowns?
  - Confinement of urban areas (district-like) under risk.
  - Rare strategy: Santiago de Chile and Madrid.

Question

Are perimeter lockdowns an effective control strategy?

Quick literature review

Santiago de Chile [Li et al. (2021)]:

- "localized lockdowns on their own are insufficient to control pandemic growth in the presence of indirect effects from contiguous neighboring areas that do not have lockdowns."
- "the epidemic is only controlled when generalized lockdowns are in place."

Madrid:

- Candel et al. (2020). (et al: includes Madrid's Public Health vice counselor) Tell and sell their management of the COVID-19 situation.
- Fontán-Vela et al. (2021): "According to our analysis, the decrease in the epidemic curve started before the impact of the perimeter lockdown could be reflected."
- García-García et al. (2022): "Our analysis suggests that the perimeter closures by Basic Health Zone did not have a significant effect on the epidemic curve in Madrid."
- Replies to Candel et al. (2020) harshly criticizing the *propaganda*.

Focus: Madrid

Our aim

- Qualitative inspection of epidemiological data from Madrid.
- Devise a general, minimal and mechanistic model of perimeter lockdowns.
- Explore under which circumstances could work.
- Understand the case of Madrid under this framework.

"Madrid es de todos. Madrid es España dentro de España. ¿Qué es Madrid si no es España?" - Isabel Díaz de Ayuso, President of Autonomous Community of Madrid.

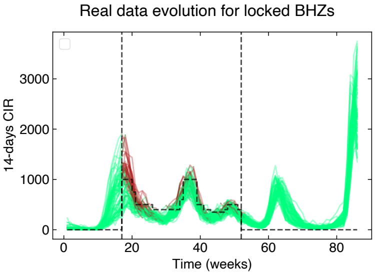
Strategy followed by Madrid

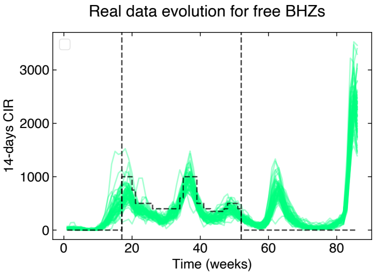
Epidemiological context: Second wave of COVID-19 building up (September 2020).

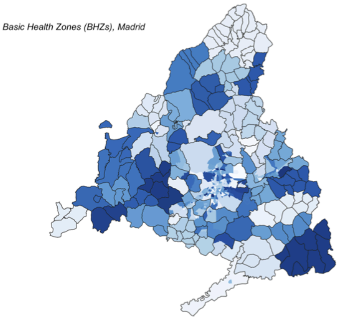
Socioeconomic context: Avoid "economic ruin".

- First round of perimeter lockdowns: September 23.
- Conditions:
  - 14 days cumulative incidence rate above 1000 cases per every 10^5 inhabitants.
  - Increasing trend.
  - Observation of community spread.
- Spatial extension: Basic Health Zones
- There were also general measures in place and disease awareness.
- Changing conditions since...

Real epidemiological time series for BHZs



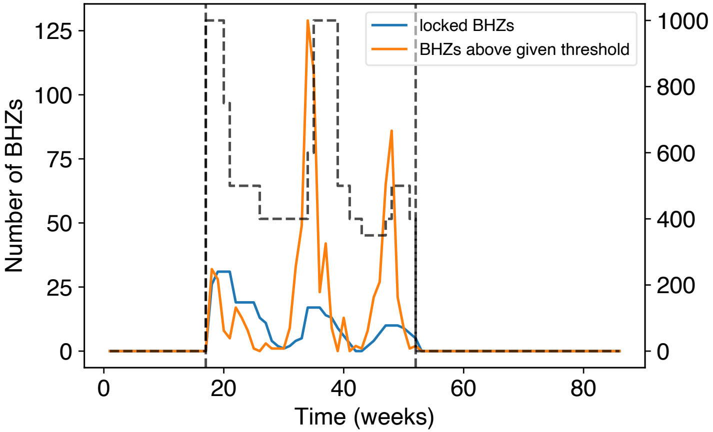




from García-García et al. (2022)

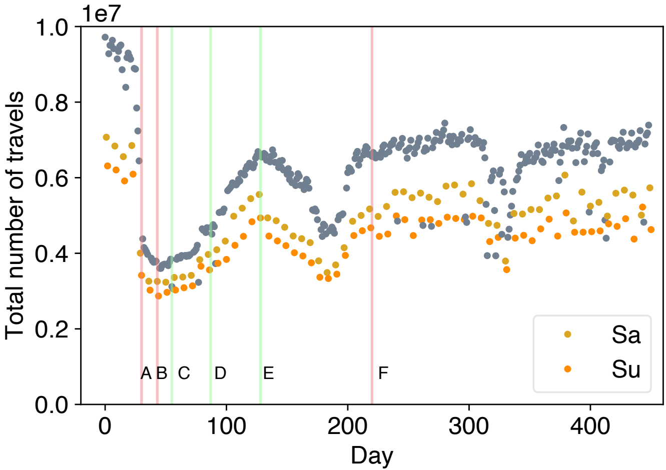
https://doi.org/10.1186/s12889-022-12626-x

Number of BHZs above threshold



- Apart from the strange moving threshold criterion...
- Huge number of free BHZs above threshold during successive waves (3rd and 4th global waves).

Real mobility data

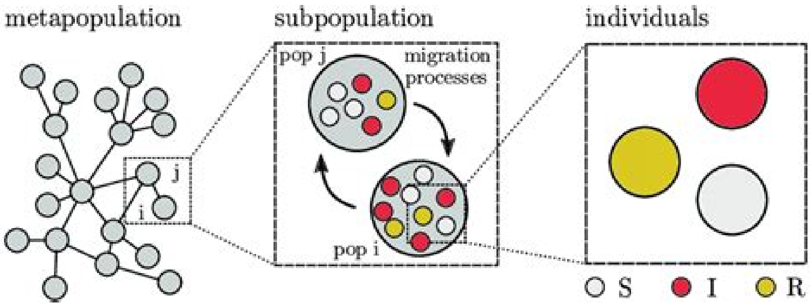


- F) marks the onset of perimeter lockdown strategy.
- Nothing seems to change in general mobility.

Lessons from Madrid's real data

- As literature shows, measures possibly introduced too late.
- Strange moving threshold criterion.
- Lots of BHZs above threshold that are not documented to be locked.
- Mobility seems unaffected by the perimeter lockdown activation.

Our framework: Metapopulation network approach



from Colizza & Vespignani (2008)

- Ideal framework for spatial epidemics.
- Epidemic spreading and people mobility are regarded as stochastic reaction-diffusion processes.
- Very important quantity: global invasion number R_*.
- Built a data-driven metapopulation model for Madrid city.

Epidemic model

Within each subpopulation the following reactions take place:

$$\boxed{S + I \to I + I} \tag{1}$$

with probability $P_i(S \to I) = 1 - (1 - R_0/(T_I N_i))^{I_i}$,

- R_0 is the basic reproduction number of the disease,
- T_I is the mean infectious time,
- N_i stands for the number of individuals in patch i, and
- I_i accounts for the number of infected individuals in such region.

$$\boxed{I \to R} \tag{2}$$

with probability $P(I \to R) = 1/T_I$.
New cases stochastically sampled from binomial distributions.
Process iterated with $\Delta t = 1$ day until absorbing state reached ($I = 0$).

Mobility model

Several approaches exist:

- Simple random walks assigning equal probability to traveling to any neighboring subpopulation.
- Degree-based travel, gravity, radiation models.
- Micro-mobility models (EPR and extensions).

Our approach here is fully data-driven:

- Data from mobility survey carried by the Spanish Ministry of Transport, Mobility and Urban Agenda. (`https://www.mitma.gob.es/ministerio/covid-19/evolucion-movilidad-big-data`)
- Build OD matrices **M**: elements contain flow of travelers from i to j.
- Diffusion rate matrices. New travelers are extracted from multinomial distributions following rates:

$$D_{ij} = \begin{cases} \frac{M_{ij}}{\sum_j M_{ij}} & \text{if } i \neq j \\ 1 - \kappa \sum_k D_{ik} & \text{if } i = j \end{cases} \quad (3)$$

Response model

How are these perimeter lockdowns implemented in the model?

- 14-day cumulative incidence rate per 10^5 inhabitants as the monitoring variable.
- Set a risk threshold Θ.
- If 14d CIR $> \Theta$ in a subpopulation i, we activate perimeter lockdowns.
- Mobility: $\kappa_{ij} = \kappa_{ji} = 0$ for i and $\forall j$.
- Local transmissibility reduced: $\beta_i = \chi_i \beta$, where $\beta = R_0 T_I$ and χ_i is the transmissibility reduction fraction control parameter.
- Below threshold districts: $\kappa \neq 0$, $\chi = 1$ for any of them.

Parameter and observables outline

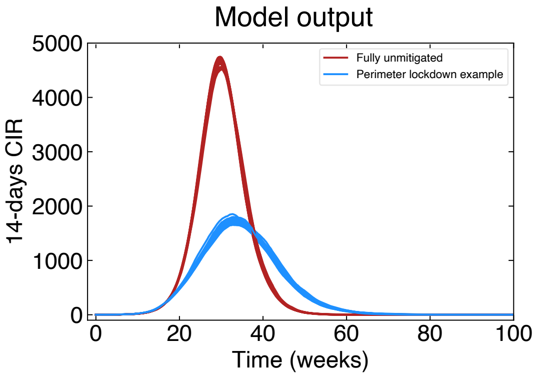
Parameters:

- $V = 21$, number of official Madrid districts.
- $N = 3,312,310$, N_i real population figures in 2020 for every district i.
- $R_0 = 1.25$, $T_I = 4.5$ days. (assume awareness)
- Madrid-based data-driven mobility flows: OD-matrix average flows chosen from a week of regular mobility in February 2020 (baseline).

Observables:

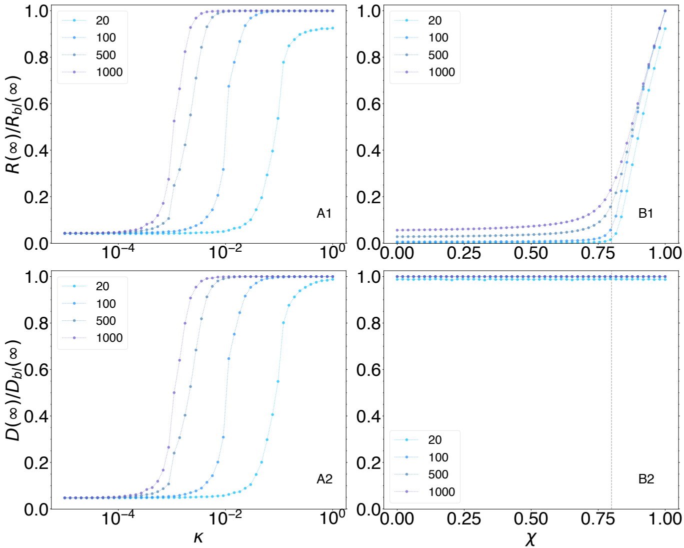
- 14-day cumulative incidence rate per 10^5 inhabitants (14-day CIR).
- Peak incidence.
- Final prevalence.
- Fraction of invaded districts.
  (all results normalized to baseline scenario: no mitigation at all)

Results: example of model time series output

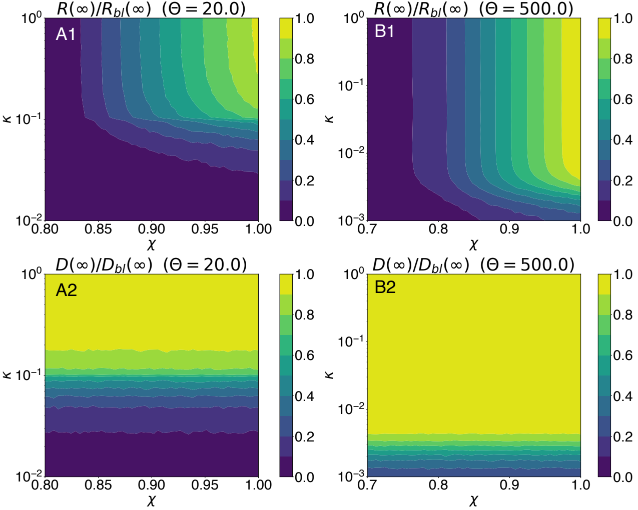


- Not seeking replication of Madrid's particular case.
- Same order of magnitude however.
- Doing something better than nothing (indeed).
- Local outbreaks highly synchronized.

Results: Phase diagrams



Left: fixed $\chi = 1$. Right: fixed $\kappa = 1$.


$R(\infty)/R_{bl}(\infty)$ $(\Theta = 20.0)$
A1
$R(\infty)/R_{bl}(\infty)$ $(\Theta = 500.0)$
B1
$D(\infty)/D_{bl}(\infty)$ $(\Theta = 20.0)$
A2
$D(\infty)/D_{bl}(\infty)$ $(\Theta = 500.0)$
B2
κ
χ
10^{0}
10^{-1}
10^{-2}
10^{-3}
0.80 0.85 0.90 0.95 1.00
0.7 0.8 0.9 1.0
0.0 0.2 0.4 0.6 0.8 1.0

Conclusions

Take-home lessons:

- Urban scale $\rightarrow$ Small and well-interconnected systems $\rightarrow$ outbreaks highly synchronized.
- If aim is to protect some parts of the system...
- Lockdowns have to be activated unrealistically soon and tight.
- Restricting mobility by itself does nothing.

Limitations (good and bad):

- We only resolve the district level, had not data for BHZs.
- Homogeneous-mixing at patch level overestimates.
- Latency and asymptomatics are not accounted for.
- Measures are activated smoothly and with no imperfections.

THANK YOU!