CENTRO INTERDIPARTIMENTALE PROSIT
PROMOZIONE DELLA SALUTE E INFORMATION TECHNOLOGY

Evento ProSIT - Epidemiologia: intelligenza artificiale e nuove tecnologie per affrontare le sfide presenti e future

IN SUPREMÆ DIGNITATIS 1343
UNIVERSITÀ DI PISA

Pandemic control by optimal social distancing: the “razor blade” effect between direct impact and societal costs

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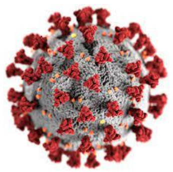
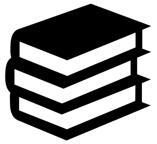
Prelude



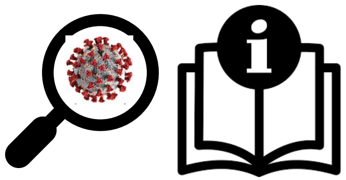
COVID-19

- ✓ Frailty of modern public health system towards pandemic event
- ✓ Worse than other recent pandemics, but not the «perfect storm»
- ✓ Future plans are urgent and should aim to be <u>holistic</u>



Optimal Control

- ✓ COVID-19 epoch has seen revival of studies on Optimal Control applied to epidemics
- ✓ Most studies are reductionist and outdated
- ✓ Optimal Control Theory should have a role to develop preparedness guidelines



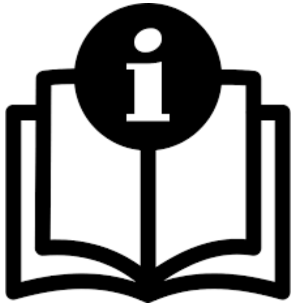
Our work

- ✓ This paper revisits Optimal Control towards preparedness for future pandemics
- ✓ We use the most critical mitigation intervention, namely <u>Social Distancing</u>
- ✓ First step to develop a full preparedness catalogue for policy makers

Pisa young engineers program

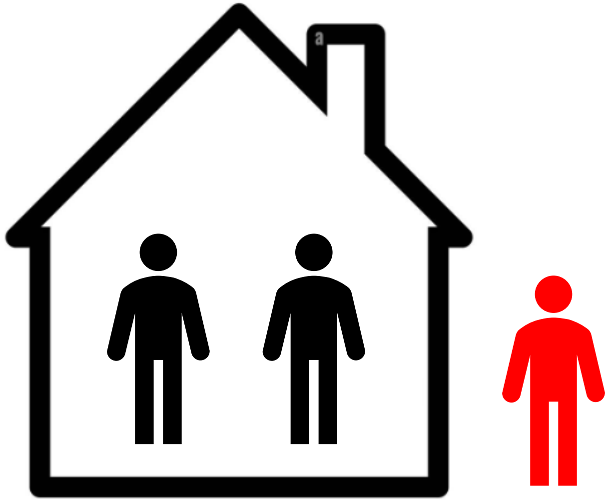
Program for future engineers interested in this field of research to develop preparedness guidelines

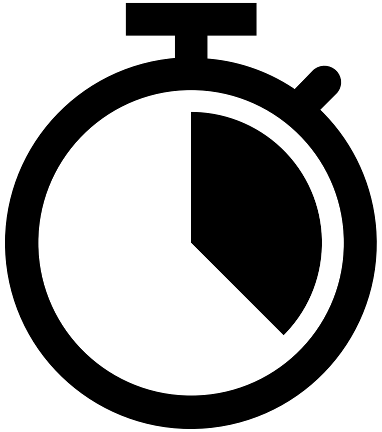
Our work



Preparedness approach. In-depth analysis of optimal control of an epidemic outbreak by social distancing

- ✓ No vaccine available
- ✓ Extensive sensitivity analysis of the three critical policy dimensions.





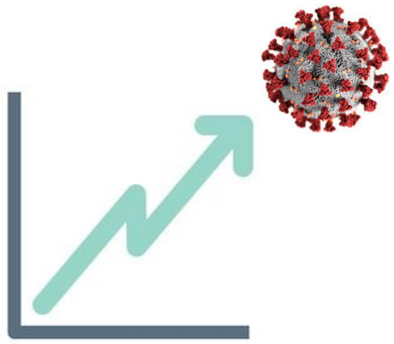
Degree of Prioritization to indirect costs
(economic, societal, relational costs of measures)

Adherence to social distancing
(Lockdown effectiveness)

Timeliness of intervention

Introduction

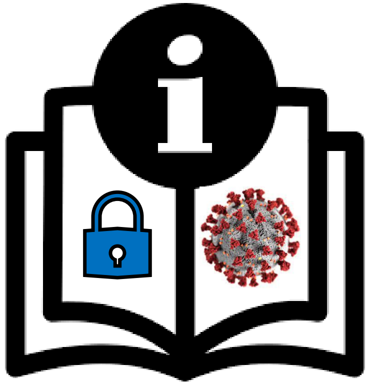
Initial conditions → Epidemic model (System of differential Equations) →



Epidemic model*

Cost functional

Initial conditions → Epidemic model (System of differential Equations) →



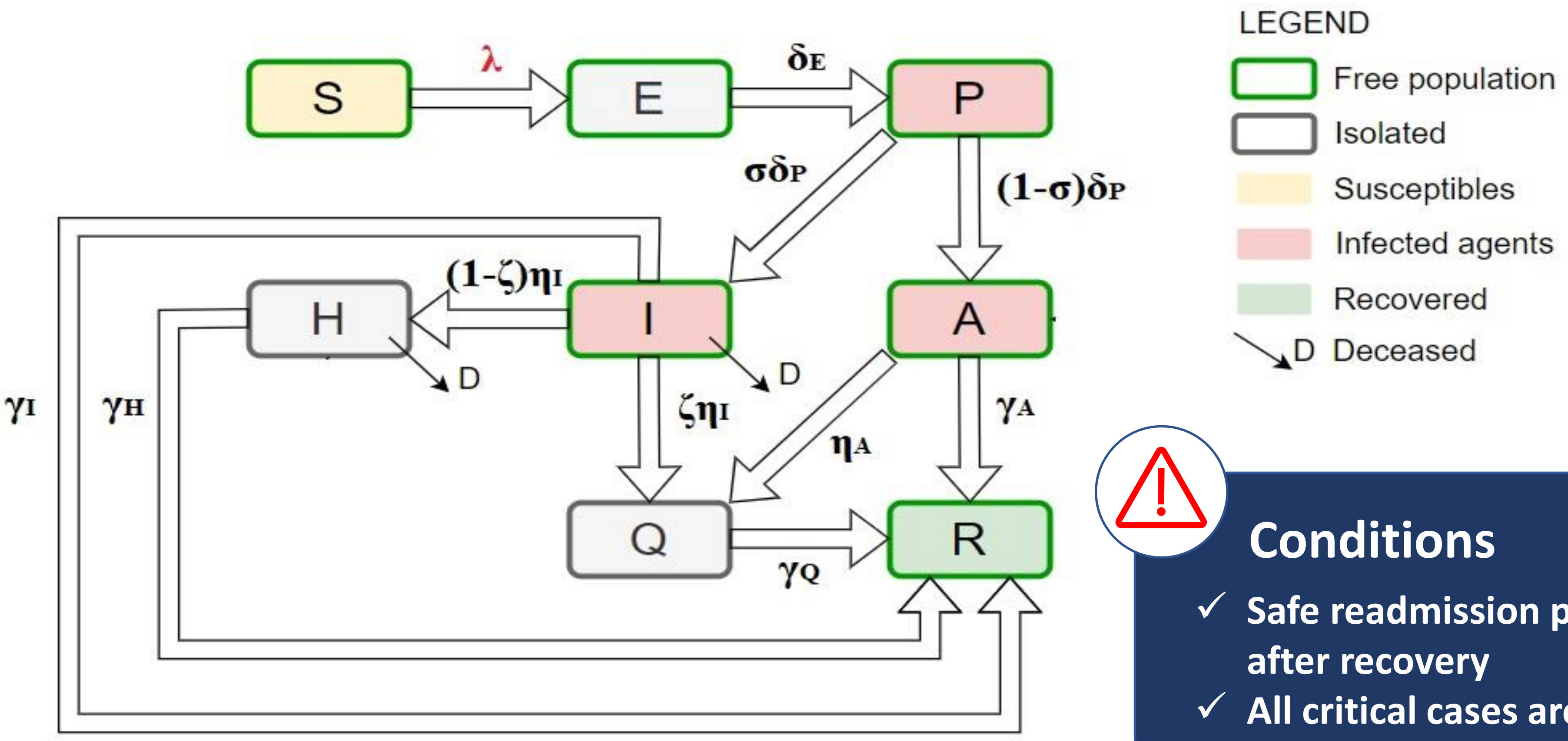
Preparedness Guidelines

Control variable (e.g., social distancing

Optimal control*

*Phase 1: Vaccine not available

Epidemic model*



Conditions

- ✓ Safe readmission procedure after recovery
- ✓ All critical cases are treated

*Gatto, M., et al. (2020). Spread and dynamics of the COVID-19 epidemic in Italy: Effects of emergency containment measures. Proceedings of the National Academy of Sciences, 117(19), 10484-10491.

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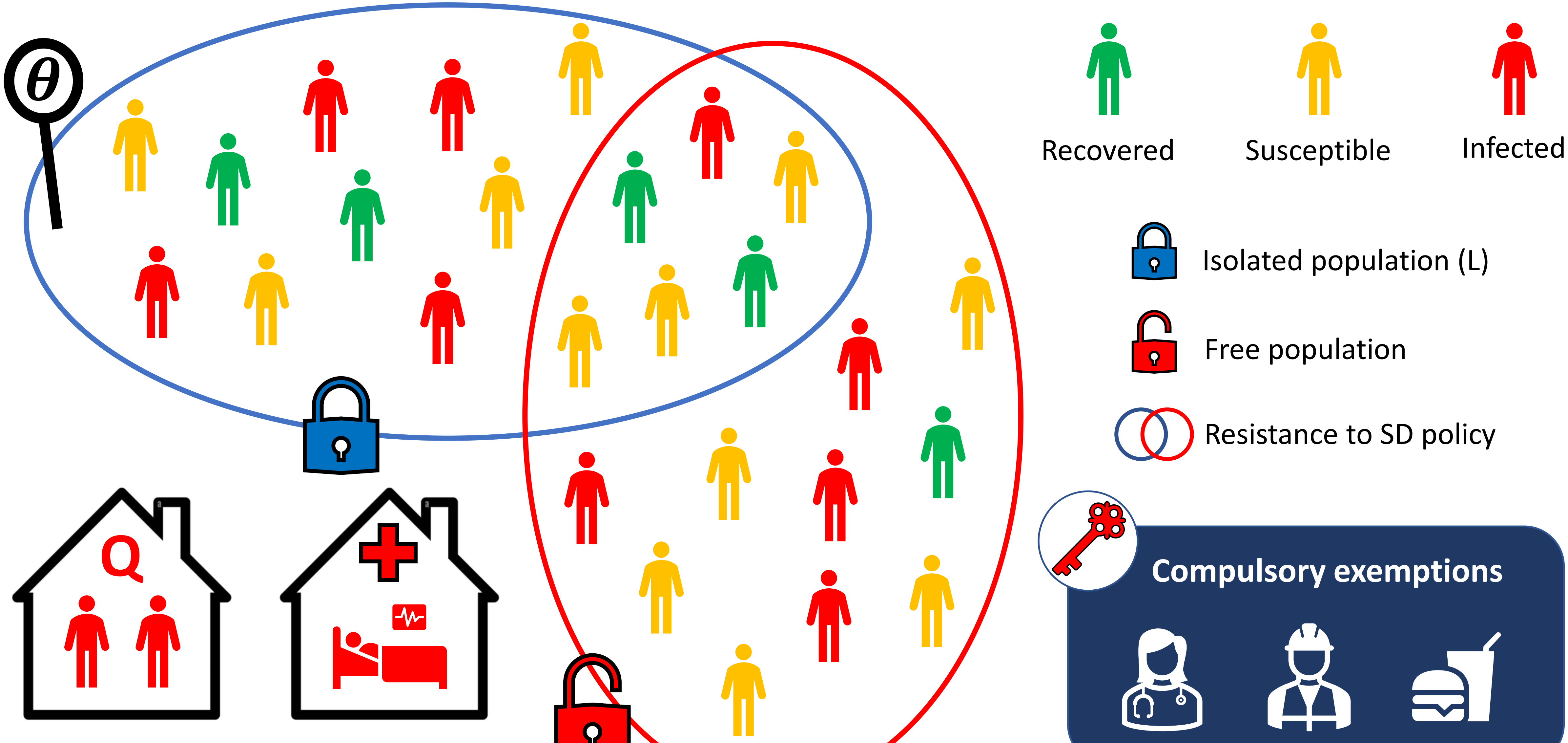
Control variable: social distancing (L)*



*Alvarez, F. E., Argente, D., & Lippi, F. (2020). *A simple planning problem for covid-19 lockdown* (No. w26981). National Bureau of Economic Research.

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Cost functional*

Direct costs

Direct health cost of the epidemic

- Hospitalization of cases of serious infection
- Total infection related deaths**
- **It only accounts for the loss of future income due to death of working individuals

Indirect costs

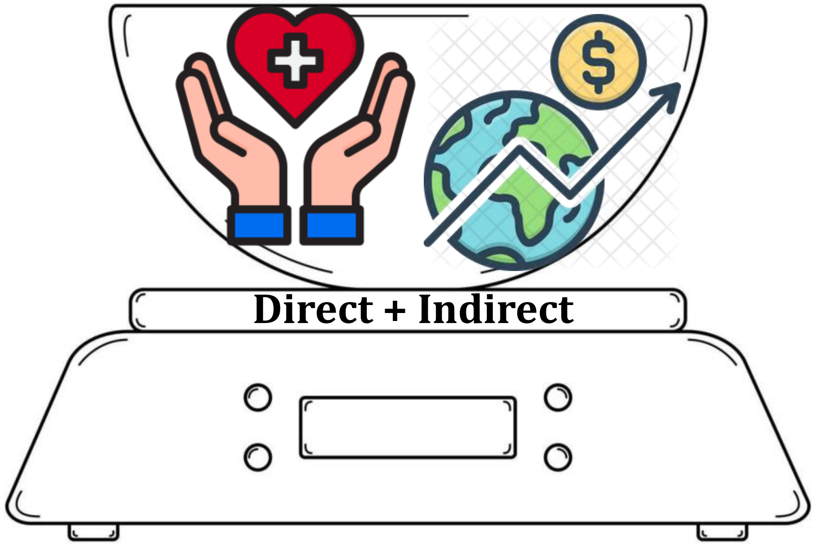
Corrisponding loss of working days

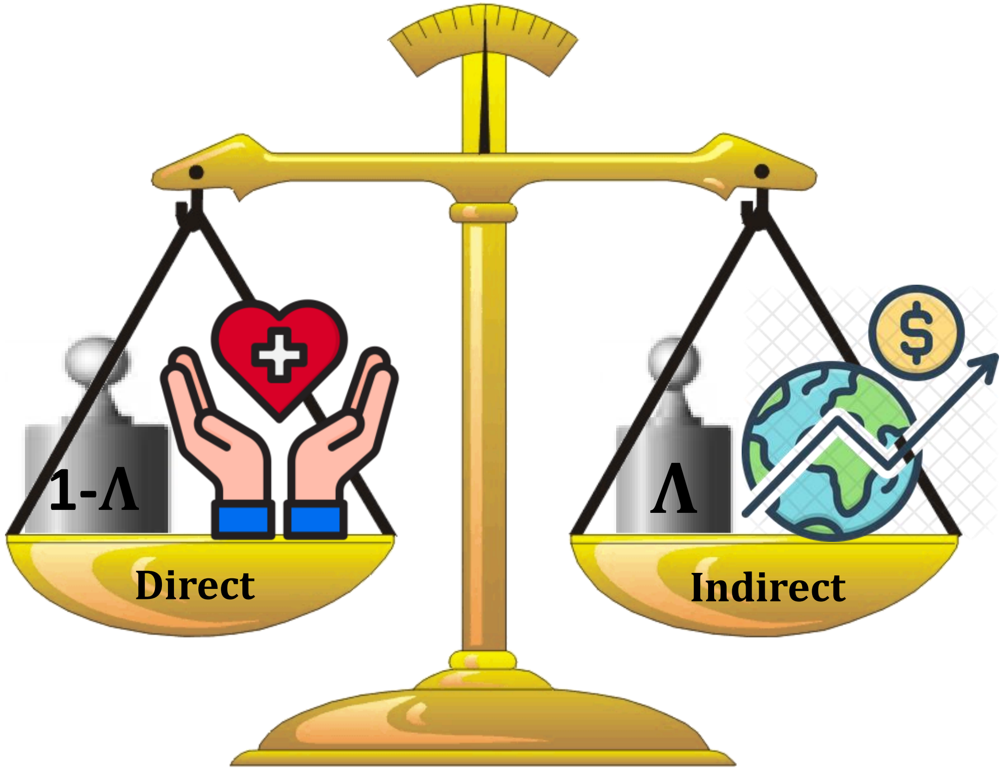
- Work & GDP loss due to confined population (L(t))
- Population unable to work: Quarantined (Q) or seriously ill (H)
- Work re-admission of (previously confirmed cases) fully recovered individuals

*Alvarez, F. E., et al. (2020). *A simple planning problem for covid-19 lockdown* (No. w26981). National Bureau of Economic Research.

*Acemoglu, D., et al. (2021). *Optimal targeted lockdowns in a multigroup SIR model. American Economic Review: Insights, 3(4), 487-502.*

Cost functional: direct vs indirect costs





Objective

Searching the optimal trajectory of social distancing (: «lockdown policy») over time i.e., the one <u>minimising</u> the cost functional for <u>any level of the trade-off</u> between direct and indirect costs.

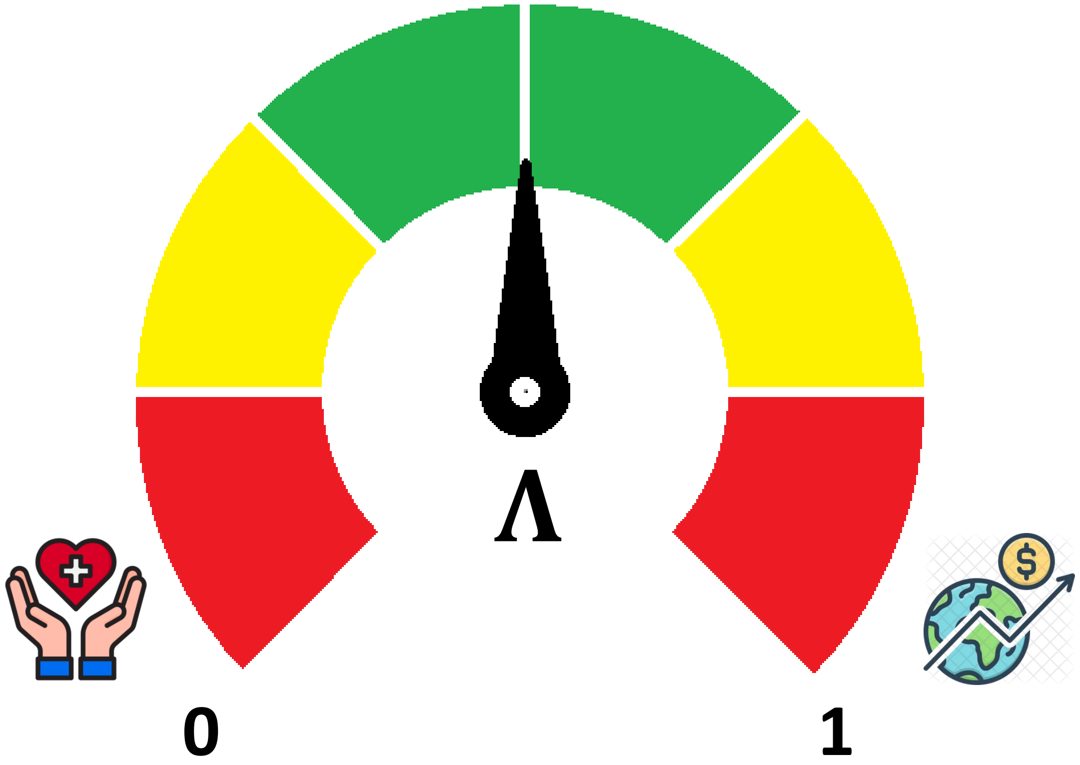
Priority to indirect cost (**Λ**)

Definition - A free parameter ($0 \leq \Lambda \leq 1$), which reflects the policy maker's relative preference for indirect costs.

($\Lambda \rightarrow 0$) : Policy makers pay full priority to **direct costs.**

($\Lambda \rightarrow 1$) : Policy makers pay full priority to **indirect costs.**

We seek optimal social distancing for any combination of (i) prioritization, (ii) adherence, (iii) timeliness



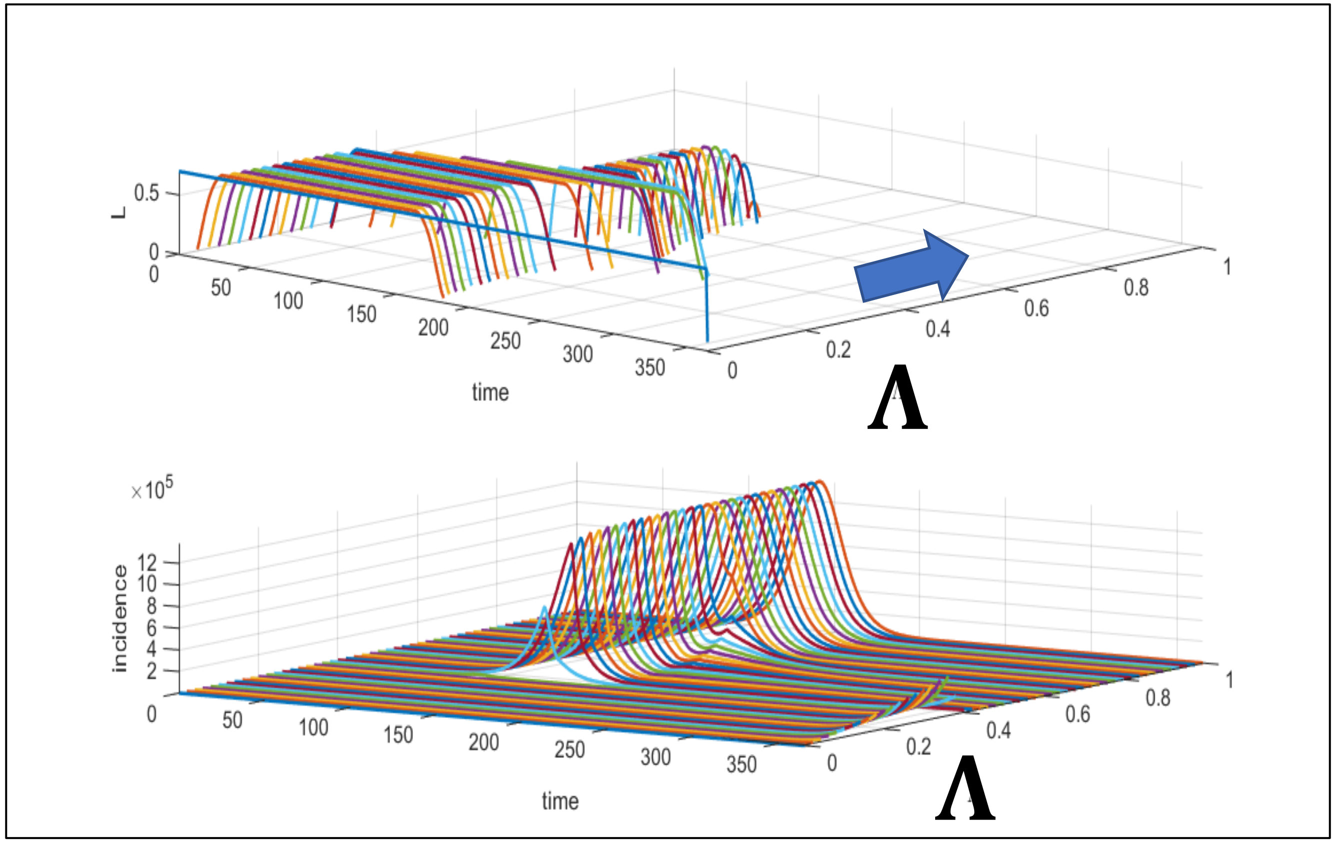
Results

(A) Priority to indirect costs (adherence given)

(B) Adherence to Social Distancing

(C) Timeliness of intervention

Results (A): Priority analysis ($\theta = 0.7$)



“Razor blade” effect

Sudden transition from early effective control (with minor epidemics) to insufficient control (major epidemics)

Optimal controls

Total control policy

Early effective control

Insufficient control

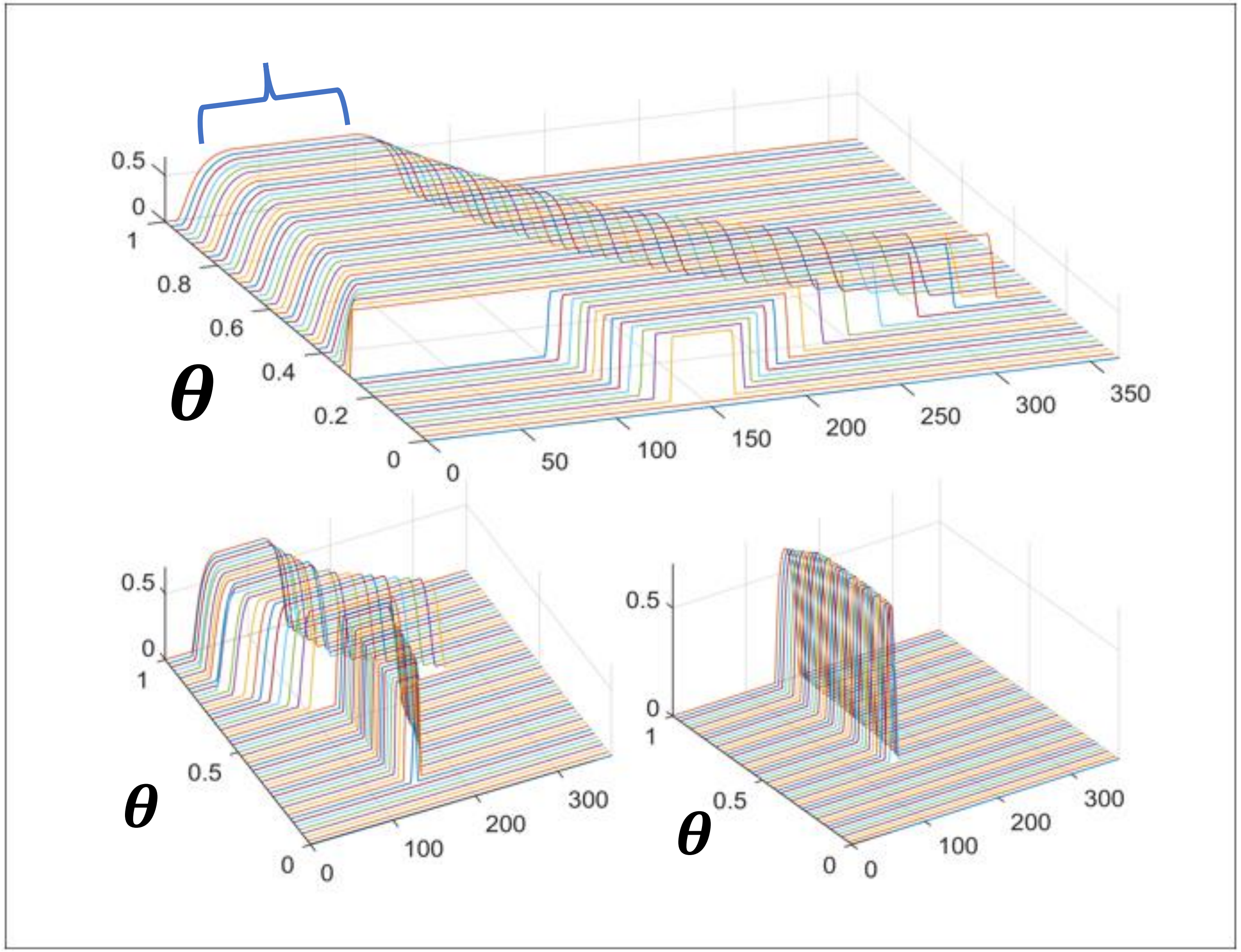
«Do-nothing» policy

Results (B): Sensitivity to Adherence

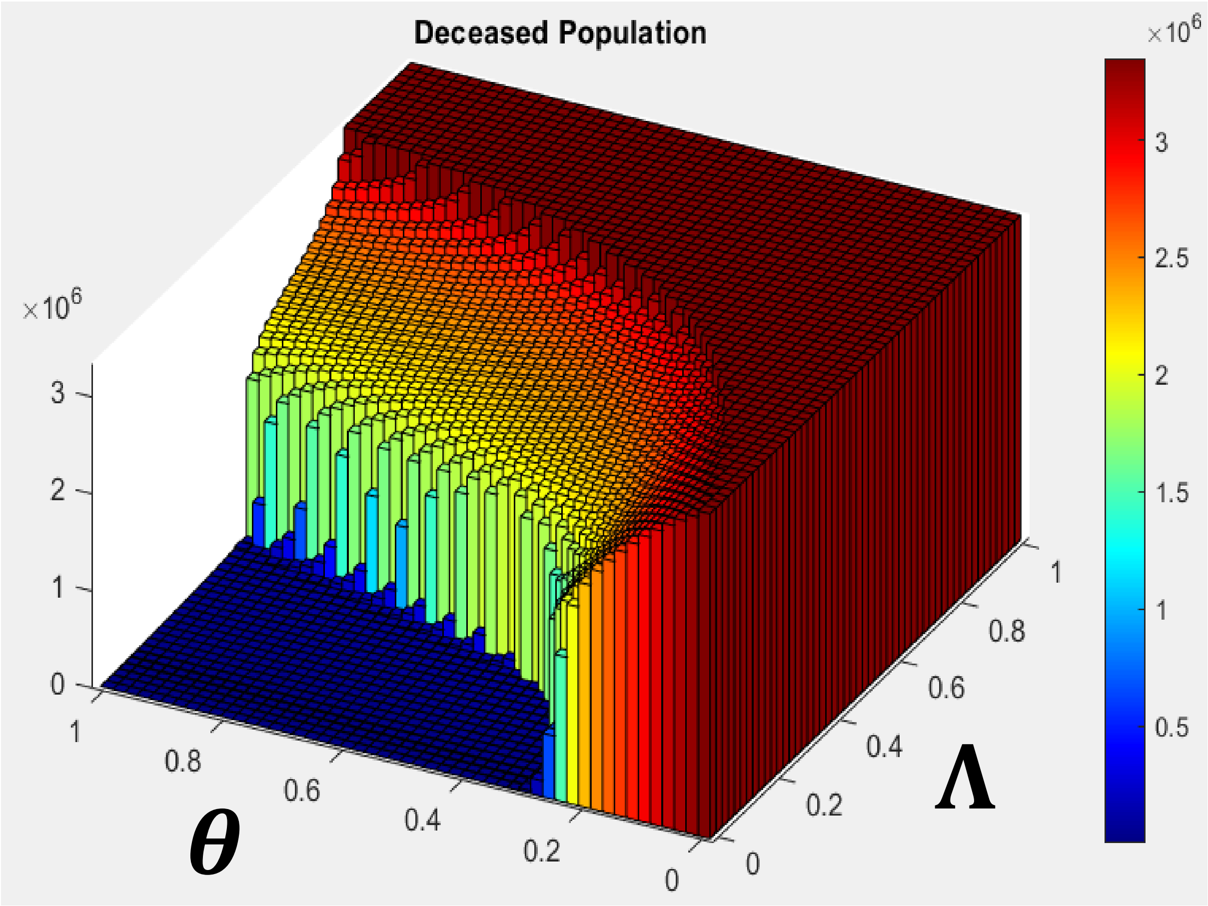
Low values of $\boldsymbol{\Lambda}$ (e.g., $\Lambda = 0.08$, top panel): High adherence helps to contain indirect costs because it minimizes the lockdown duration;

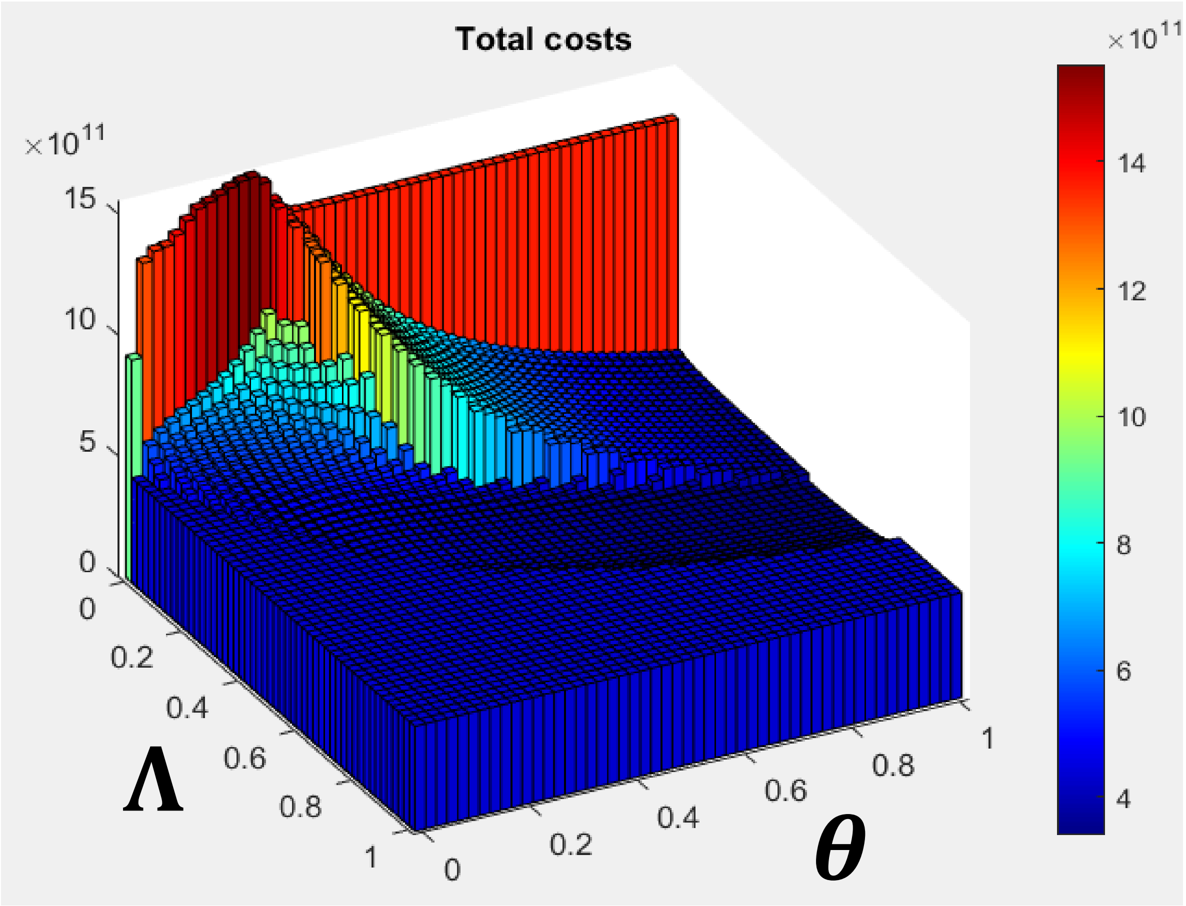
Mid values of $\boldsymbol{\Lambda}$ (e.g., $\Lambda = 0.34$, bottom-left panel): Measures are nearly always delayed and the closures duration is sharply reduced

High values of $\boldsymbol{\Lambda}$ (e.g., $\Lambda = 0.58$, bottom-right panel): “short closures” of constant duration vs the “do nothing” solution.

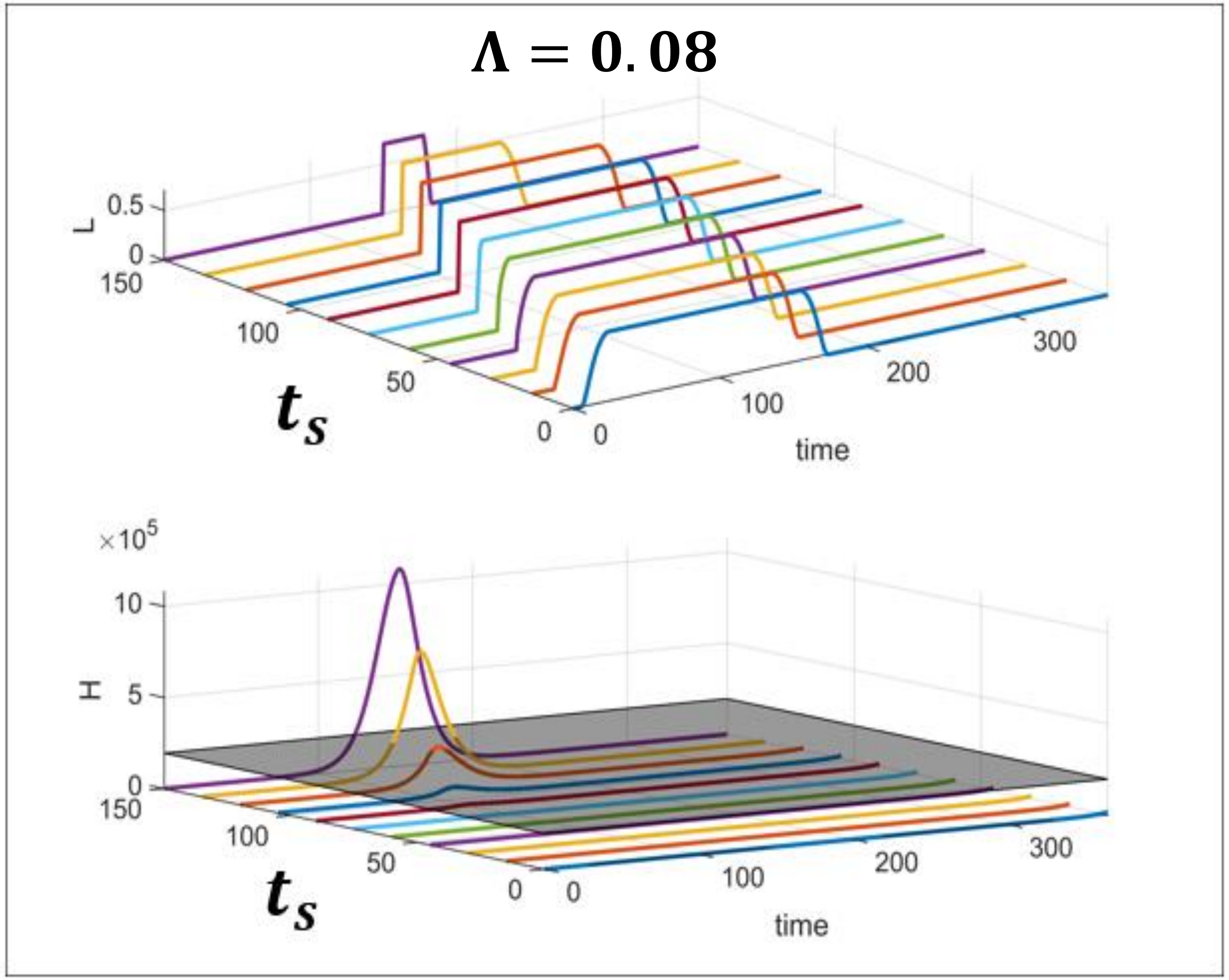


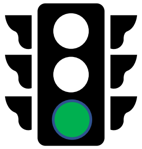
Results (B): joint Sensitivity to Adherence and prioritization



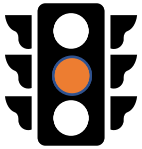


Results (C): Timeliness of intervention

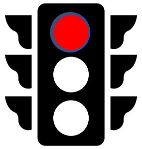




$t_s \leq 60\ days$



$60\ days < t_s \leq 105\ days$



$t_s > 105\ days$

Policy makers have time to act, as long as they do not wait for too many hospitalizations. It is difficult to establish the right time to act. Better be cautious and act as early as possible.

Inspiration from: Morris, D. H., et al. (2021). Optimal, near-optimal, and robust epidemic control. Communications Physics, 4(1), 1-8.

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Conclusions

Preparedness approach. In-depth analysis of optimal control of an epidemic outbreak by social distancing

- ✓ **No vaccine available**
- ✓ **Extensive sensitivity analysis of the three critical policy dimensions.**

Degree of prioritization of the indirect costs

Razor blade effect

High priority

Main focus on direct costs (but $\Lambda \neq 0$)

Adherence to social distancing

Contains indirect costs

Low Adherence

Awareness campaign

Timeliness of intervention

There is time to act

Waiting the optimal time

Early actions may be modified