Coordinated effects of fear-induced behaviour changes and lockdown measures on pandemic severity

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Outline

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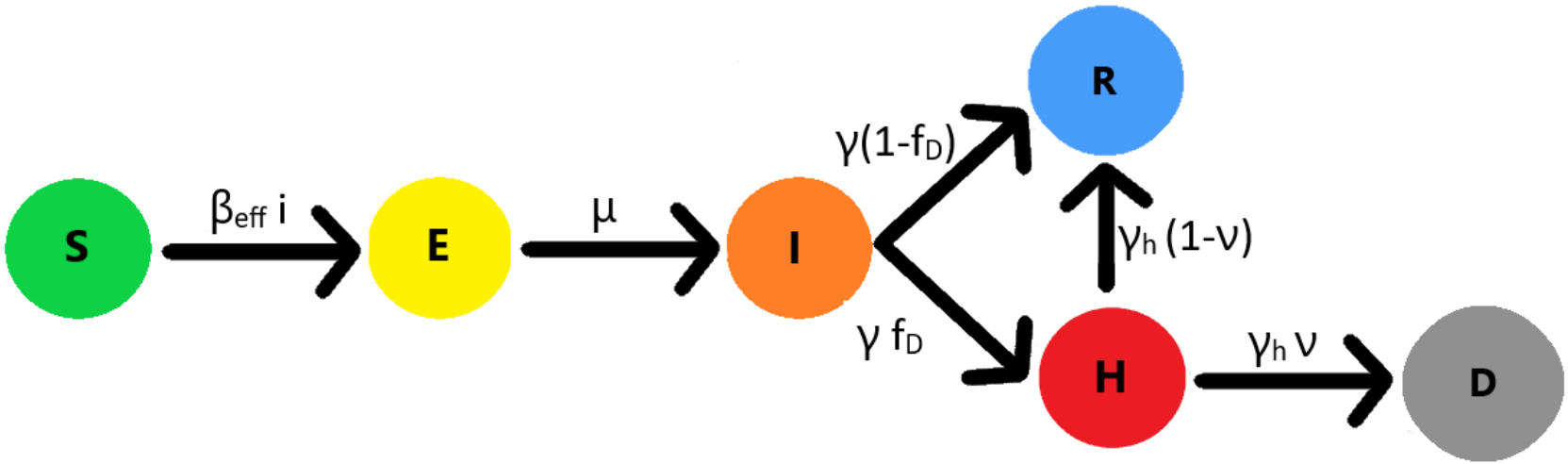
Introduction

- **Aim**: studying the interplay of fear-induced behaviour changes and imposed lockdown measures on pandemic severity
- **Model**: SEIHRD model
- **Lockdown**: modelled via imposed β reduction
- **Fear**: including both short and long term awareness, depending on the Deaths (D) compartment
- **Indicators**: position, height and number of the peaks, dynamics behaviour and cumulative deaths

Outline

Compartmental model



Differential equations:

$$\dot{s} = -\beta_{eff}\, is$$
$$\dot{e} = \beta_{eff}\, is - \mu e$$
$$\dot{i} = \mu e - \gamma i$$
$$\dot{r} = (1 - f_D)\gamma i + (1 - \nu)\gamma_H h$$
$$\dot{h} = f_D \gamma i - \gamma_H h$$
$$\dot{d} = \nu \gamma_H h$$

Parameters [1],[2],[3]:

R_0	3.49
μ	$1/2\ d^{-1}$
γ	$1/6\ d^{-1}$
f_D	0.08
γ_H	$1/10\ d^{-1}$
ν	0.47

Modelling fear

Fatality-induced behaviour changes are modelled via a reduction of the transmission rate β [2], both for the short and long term individual protective measures.

- the **short term** fear depends on the death rate $\delta = \dot{d}$:

$$\beta \to \frac{\beta}{1 + (\frac{\delta}{\delta_c})^k},$$

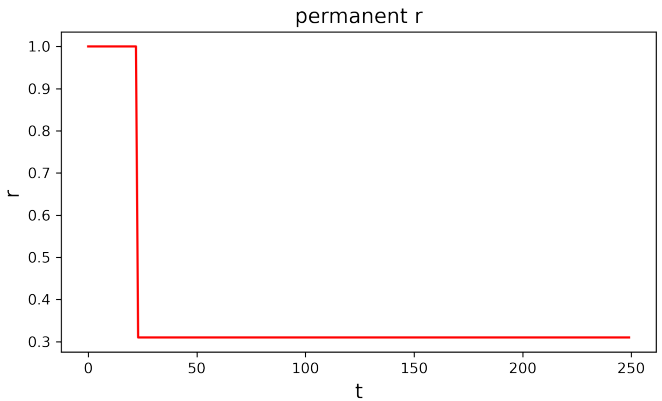
  the half-saturation constant δ_c regulates the death rate repercussion on behaviour and k regulates the sharpness of effect

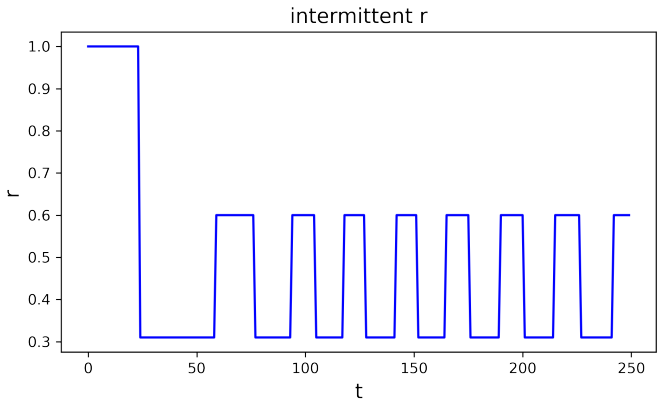
- the **long term** fear depends on the cumulative deaths d having D_c as half-saturation constant and the **cooperation** of both long and short terms reads:

$$\beta \to \frac{\beta}{1 + (\frac{\delta}{\delta_c})^k + (\frac{d}{D_c})^k}$$

Modelling lockdown

The lockdown effect is encoded in a multiplicative factor $\mathbf{r \leq 1}$, which reduces the transmission rate $\beta \rightarrow r\beta$ [1]
The lockdown starts when a certain **threshold** in the hospitalized H/N it's reached:





Then, the **combined effect** of fear and lockdown, on the baseline transmission rate β, leads to an effective parameter $\beta_{\mathbf{eff}}$

$$\beta_{eff} = \frac{r\beta}{1 + (\frac{\delta}{\delta_c})^k + (\frac{d}{D_c})^k}$$

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Permanent lockdown - short term fear

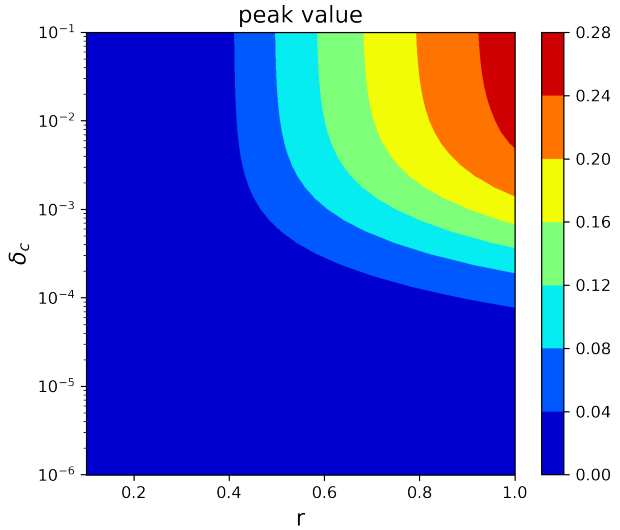
Model:

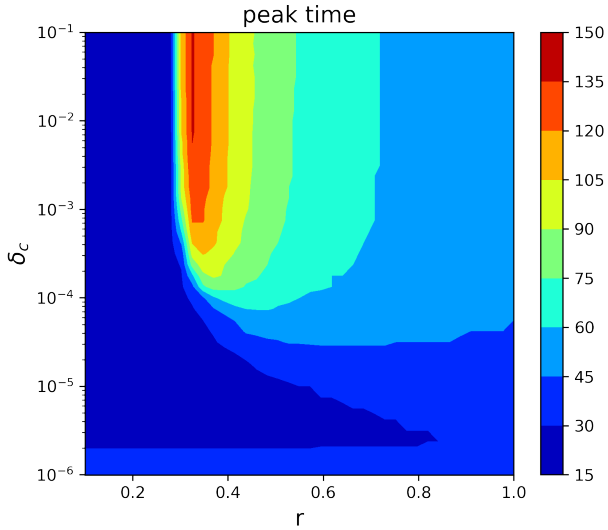
- permanent lockdown ($threshold = 10^{-4}$, $r_{perm} = 0.31$)
- short term awareness
- $k = 1$

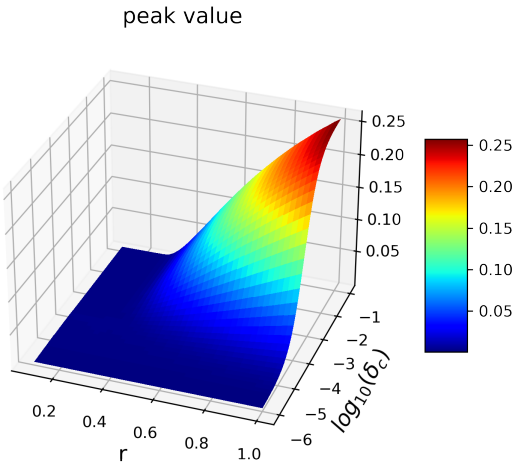
$$\beta_{eff} = \frac{\beta r_{perm}}{1 + (\frac{\delta}{\delta_c})^k}$$

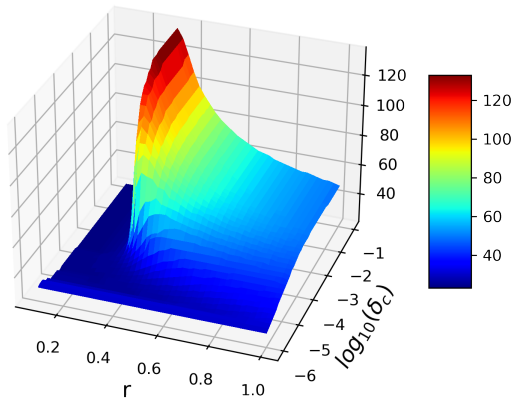
Permanent lockdown - short term fear

Parameters' space



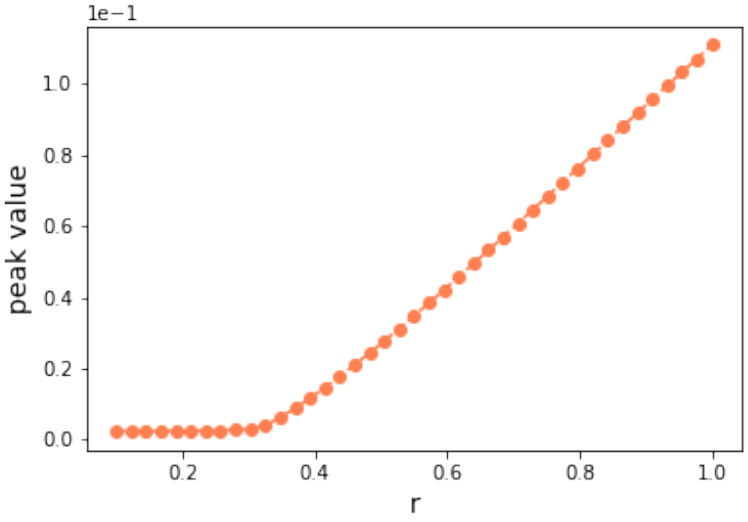


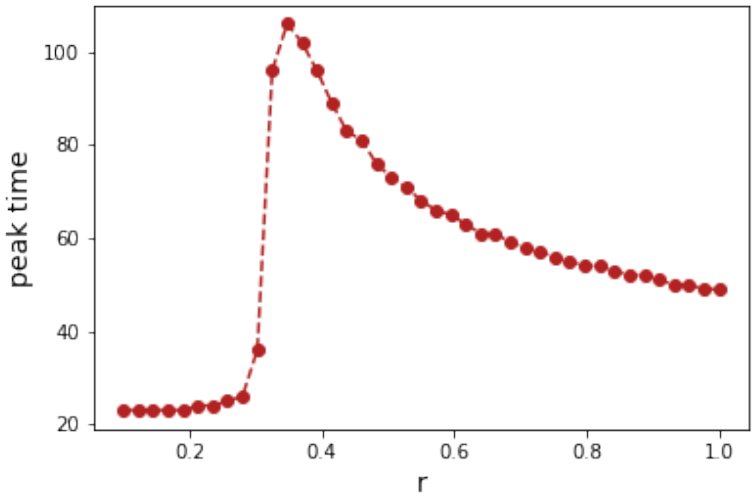


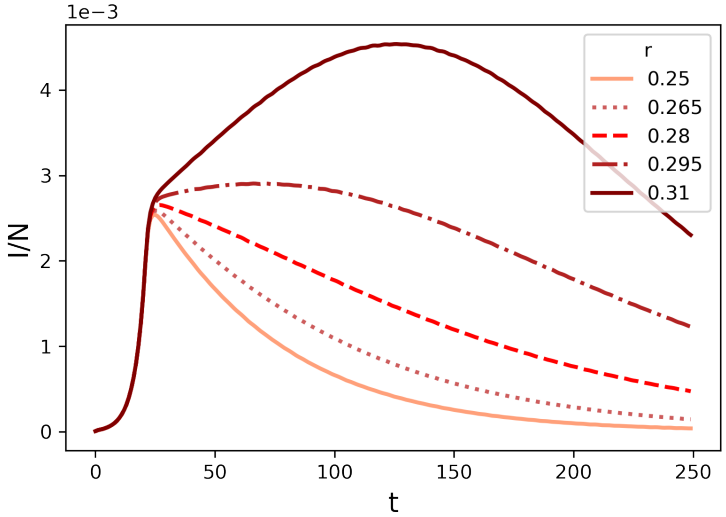


Permanent lockdown - short term fear

Peak value, peak time and incidence. Varying r, fixed $\delta_c = 0.01$



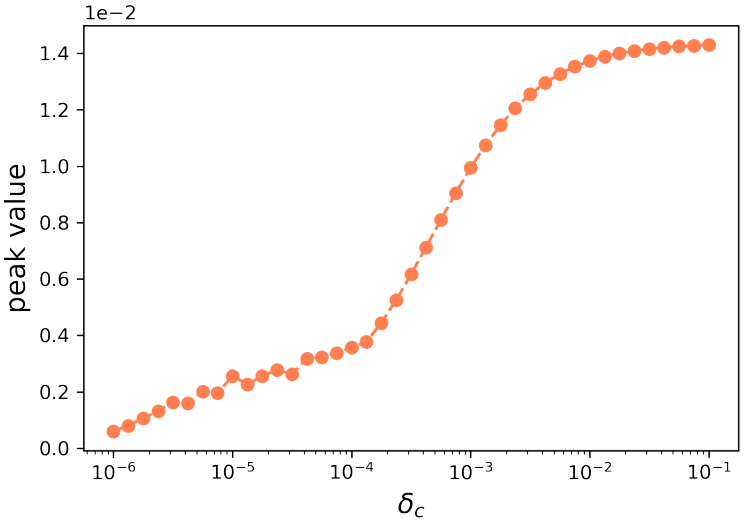


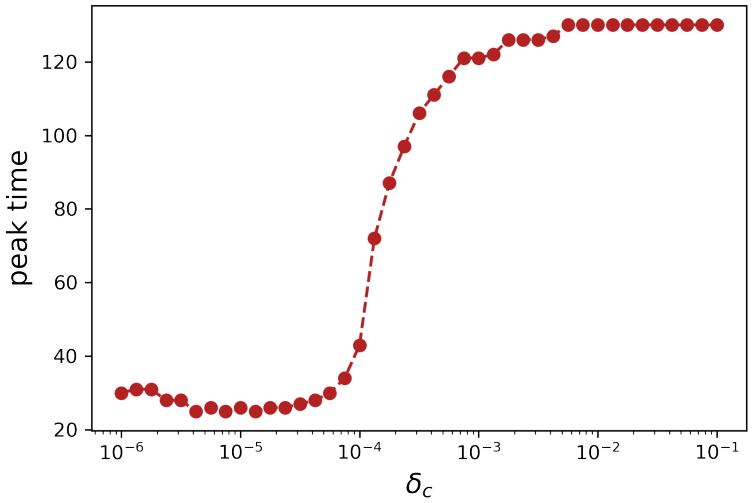


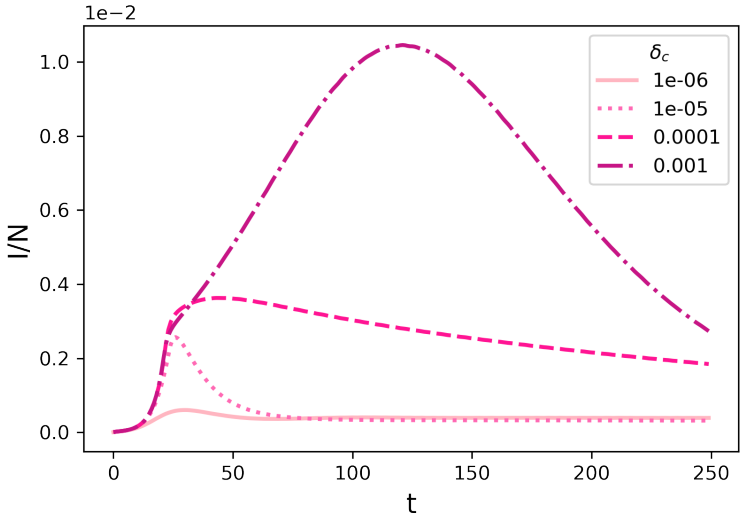
- existence of $r_c \sim 0.3$
- for $r < r_c$ early peak and epidemic extinction
- for $r > r_c$ late peak and higher incidence

Permanent lockdown - short term fear

Peak value, peak time and incidence. Varying δ_c, fixed $r = 0.35$



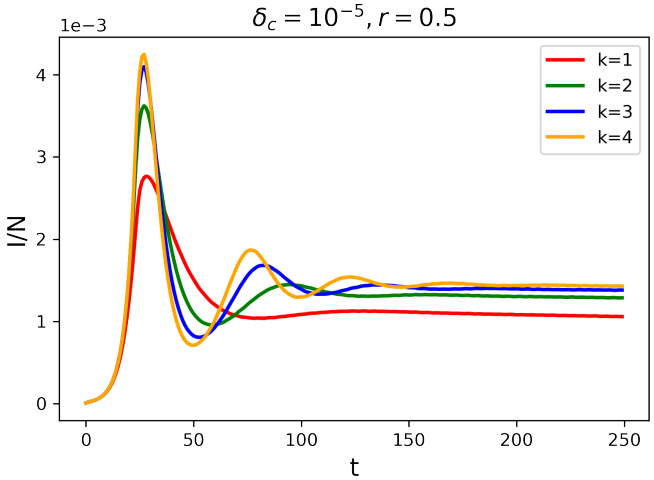




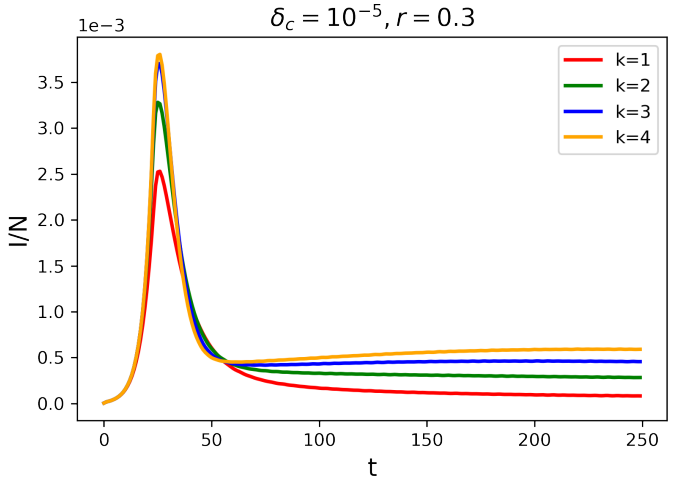
- distinct phases are not displayed
- increasing δ_c (low risk perception), higher incidence
- lower values of δ_c, exhibition of plateau

Permanent lockdown - short term fear

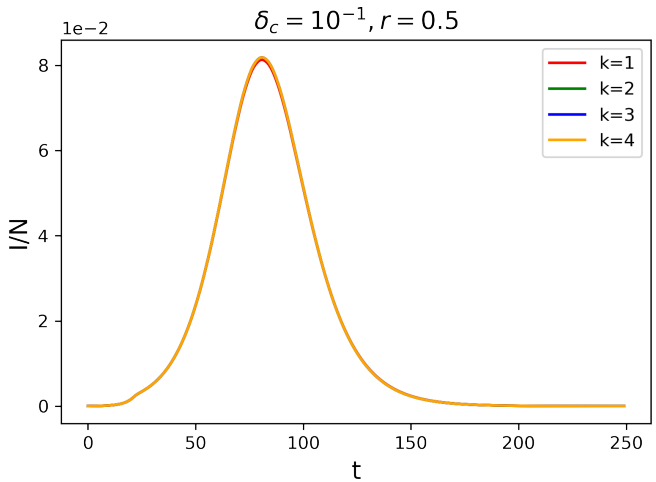
Incidence varying k



if δ_c is sufficiently high and $r > r_c$ oscillatory behavior appears



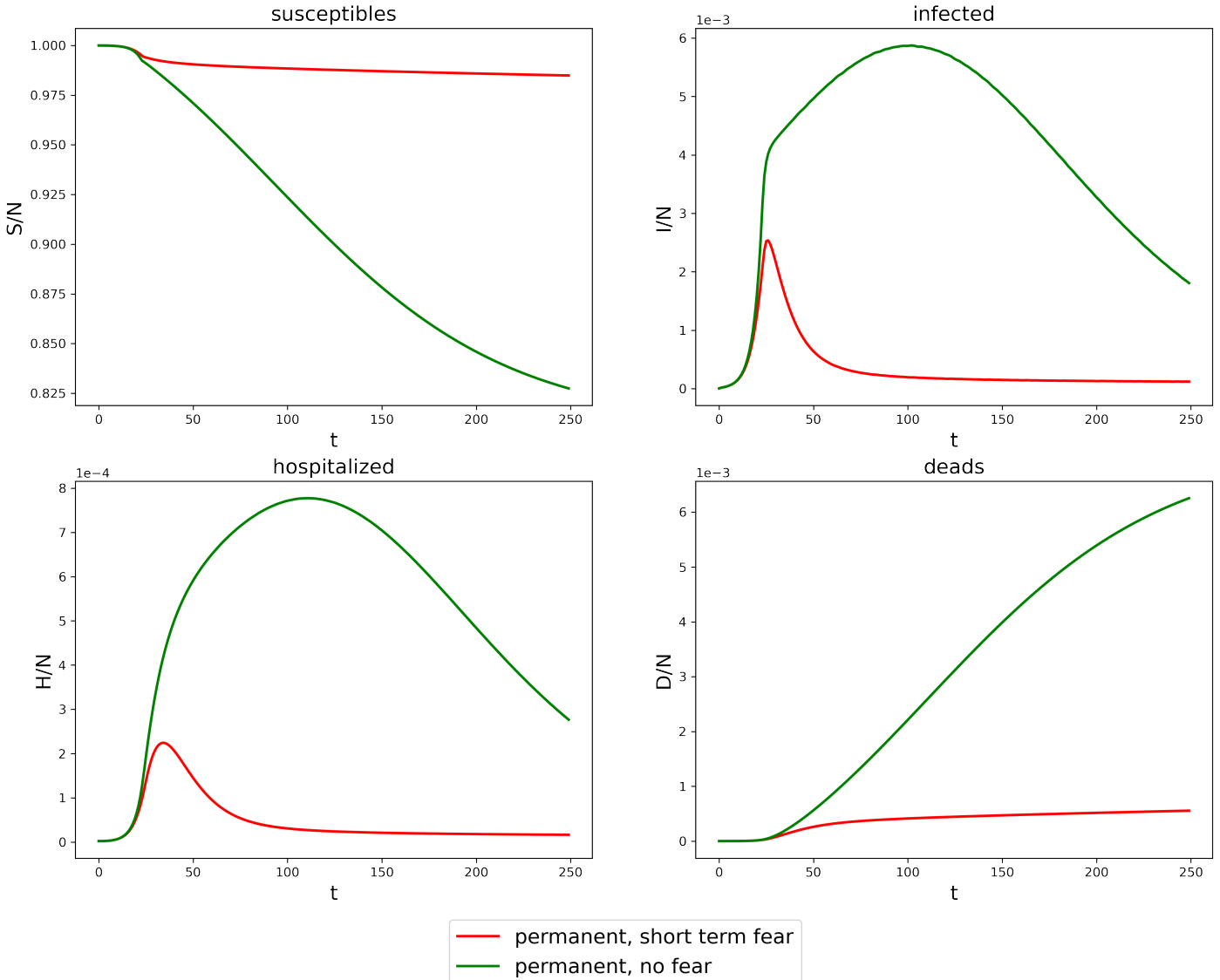
if δ_c is sufficiently high and $r \sim r_c$ the oscillations disappear, different k leads to different dynamics



k has not any influence for high value of δ_c (low fear)

Permanent lockdown - fear/no fear

r=0.31



Outline

Permanent lockdown - long term fear

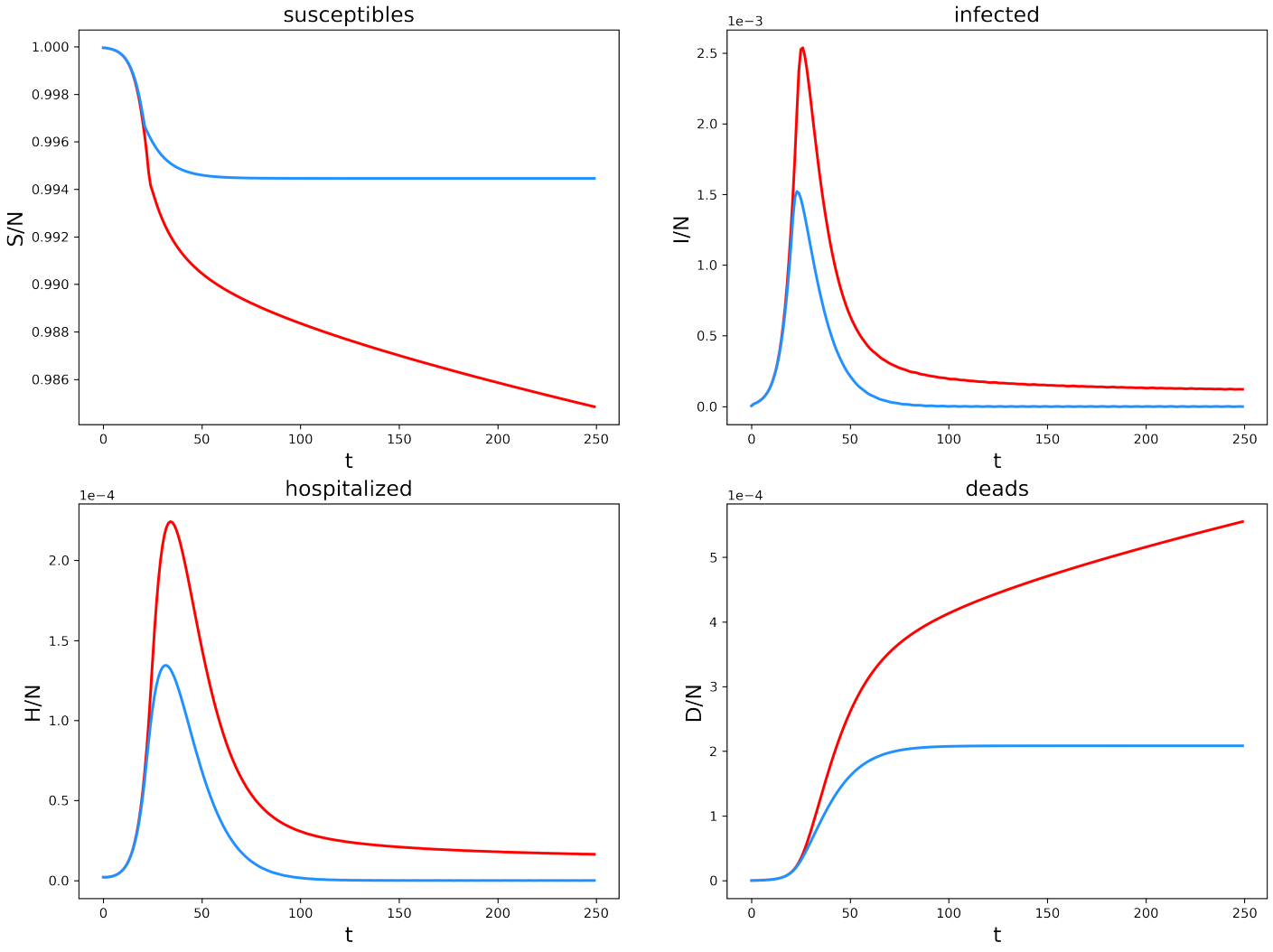
Model:

- permanent lockdown ($threshold = 10^{-4}$)
- short-term awareness
- long-term awareness
- $k = 1$

$$\beta_{eff} = \frac{\beta r_{perm}}{1 + (\frac{\delta}{\delta_c})^k + (\frac{d}{D_c})^k}$$

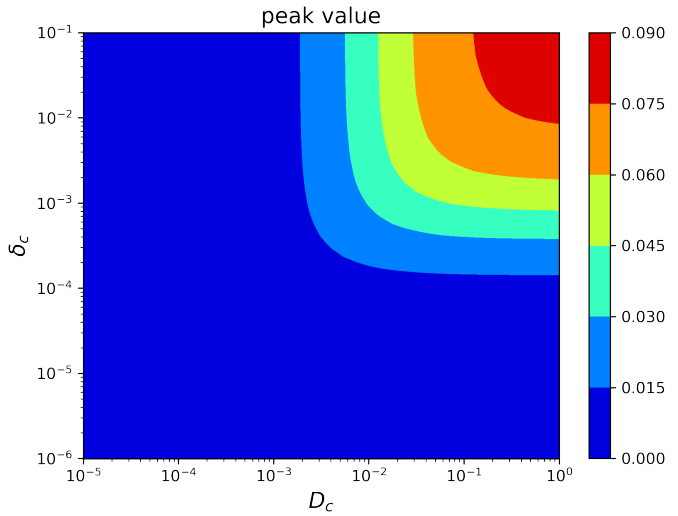
Permanent lockdown - long term fear

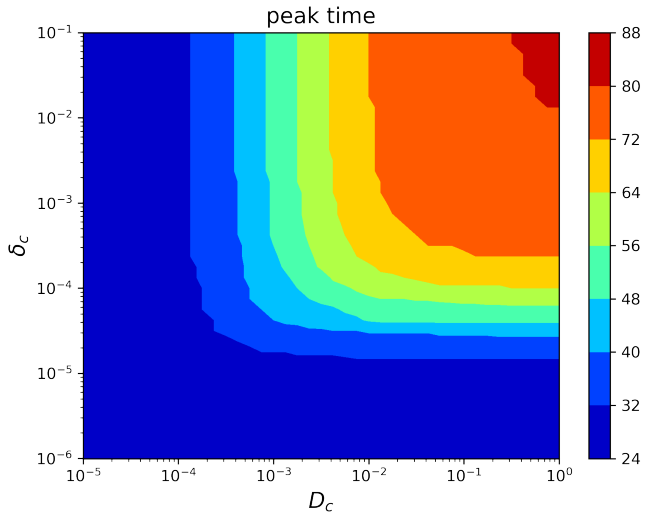
r=0.31

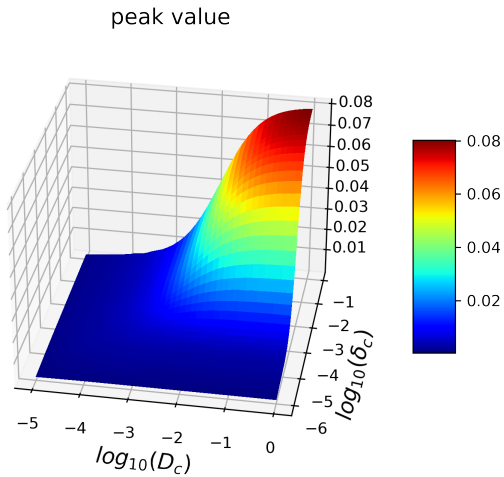


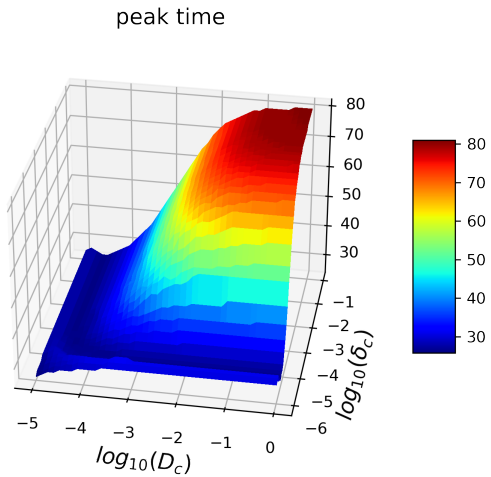
Permanent lockdown - long term fear

Parameters' space - $r = 0.5$



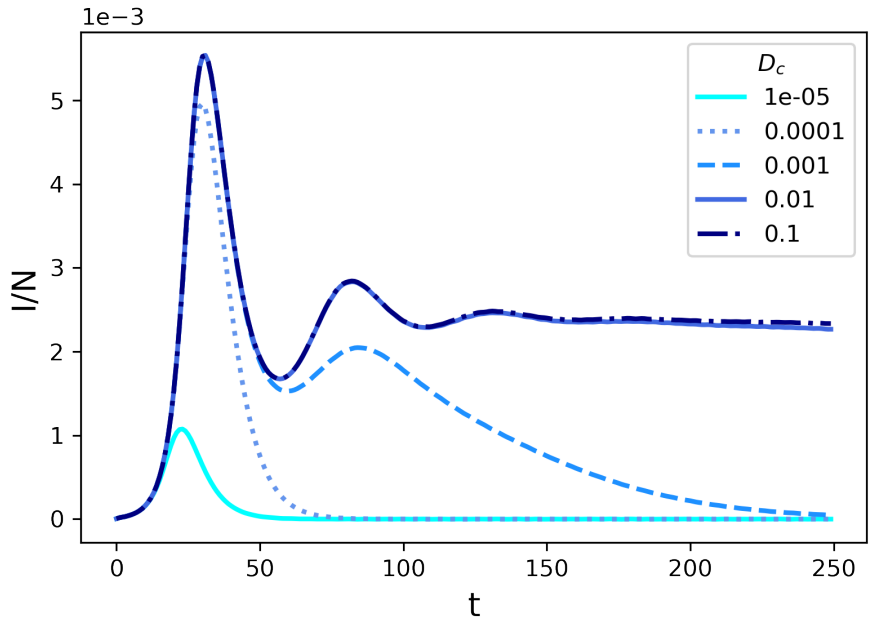






Permanent lockdown - long term fear

Incidence. Varying D_c, fixed $\delta_c = 10^{-5}$, $r = 0.5$
In high short-term-awareness situation, which is the effect of the long-term-awareness?



- high long term awareness (low D_c): low incidence with a peak at the beginning and then the epidemic gets extincted
- low long term awareness (high D_c): higher incidence, oscillatory dynamics after the peak and then it stabilizes in a plateau

Outline

Intermittent lockdown

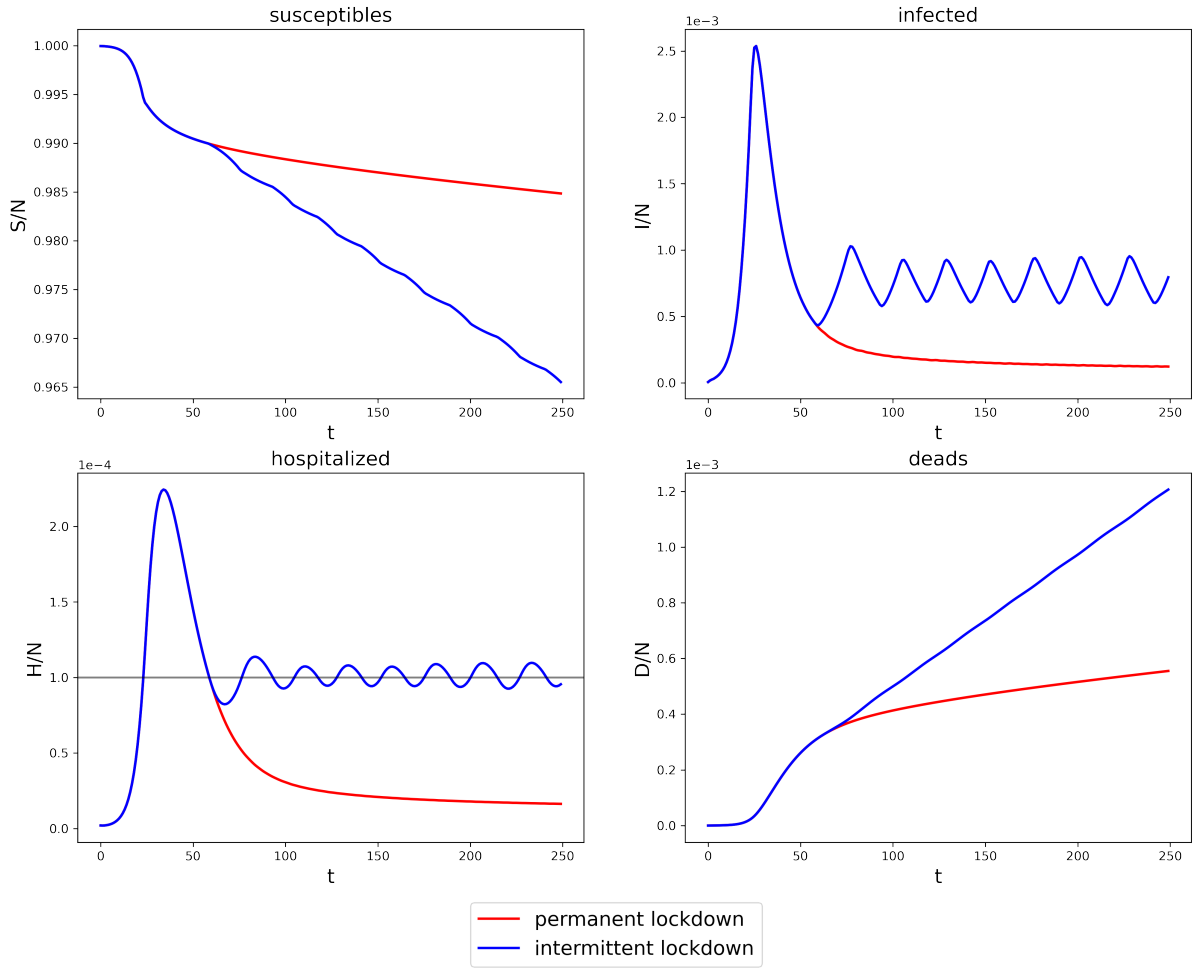
Model:

- intermittent lockdown ($threshold = 10^{-4}$, $r_{inter} = 0.31, 0.6$)
- short term awareness
- $k = 1$

$$\beta_{eff} = \frac{\beta r_{inter}}{1 + (\frac{\delta}{\delta_c})^k}$$

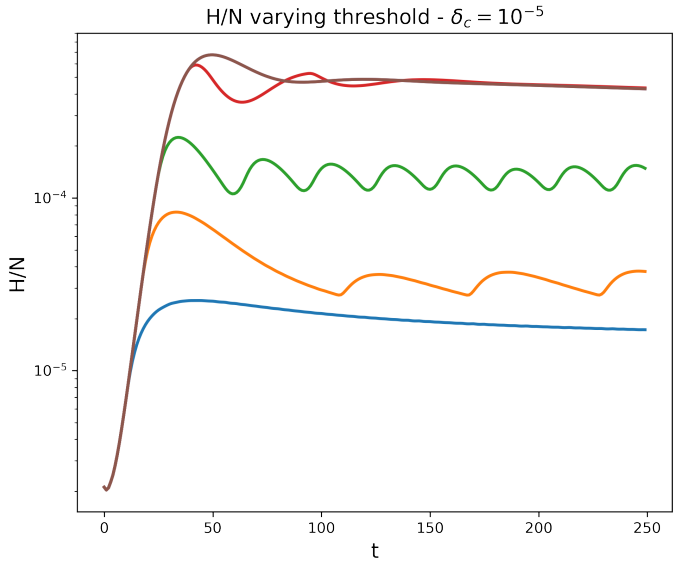
Intermittent lockdown

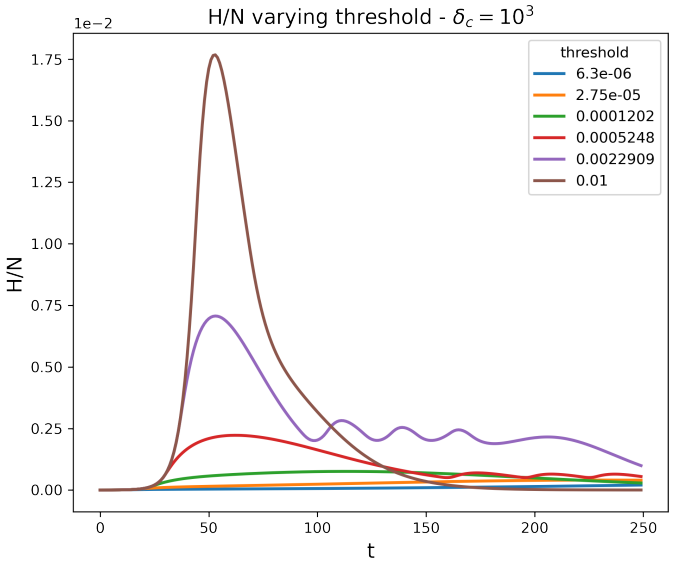
r=0.31



Intermittent lockdown

Hospitalized dynamics varying threshold





On the left, $\delta_c = 10^{-5}$ = high risk perception:

- with intermediate thresholds,the dynamics oscillate around the threshold (due to intermittent lockdown)
- with thresholds $> 10^{-5}$, the threshold is never reached due to fear-induced behaviour changing

On the right, $\delta_c = 10^{3}$ = low risk perception: dynamics are no more limited by fear, thresholds are reached and lockdown effects are visible.

Outline

Conclusion

Studying the coordinated effect of lockdown restrictions and fear-driven behaviour is not an easy task, due to the interplay of several parameters, varying by several orders of magnitude.

- **Lockdown** measures are clearly impacting the stronger response in the pandemic containment, in particular if strict enough, to the point of making fear-induced behaviour changes inconsistent. Lighter restrictions allow fear-induced behaviour changes to role the dynamics:
- **Short-term** attention, besides lowering the peak, give rise to plateaus in the incidence.
- **Long-term** attention can have a much stronger effect, to the point of leading to pandemic suppression.
- Clearly, a **permanent** lockdown, triggered when a certain hospitalized ratio is reached, allows to contain in a stricter way the epidemic spread. Anyway, it is not sustainable. Then, when imposing **intermittent** lockdown, an oscillatory behaviour around the threshold is obtained.

Thanks for the attention!

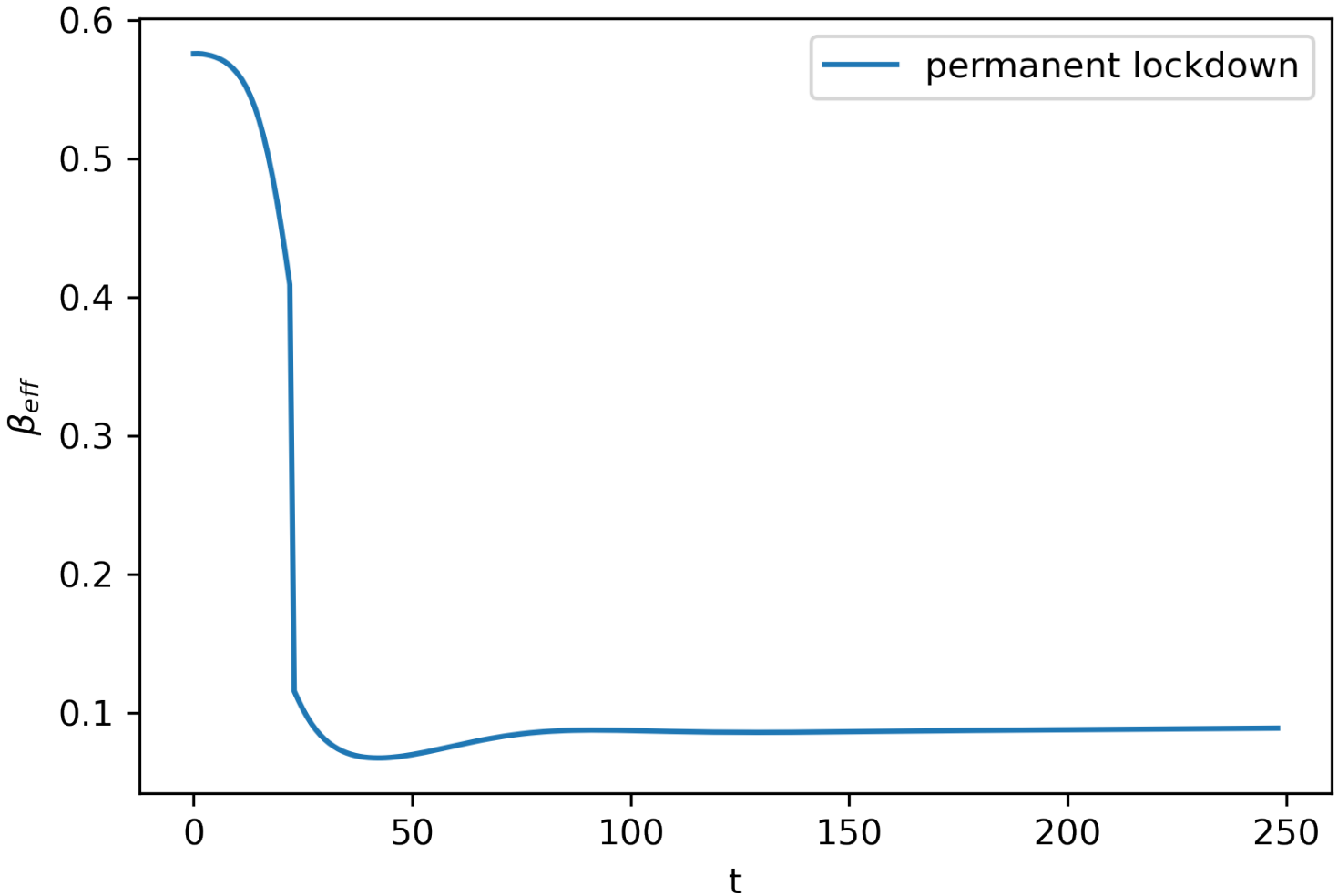
Outline

Initial data for the simulation [1]:

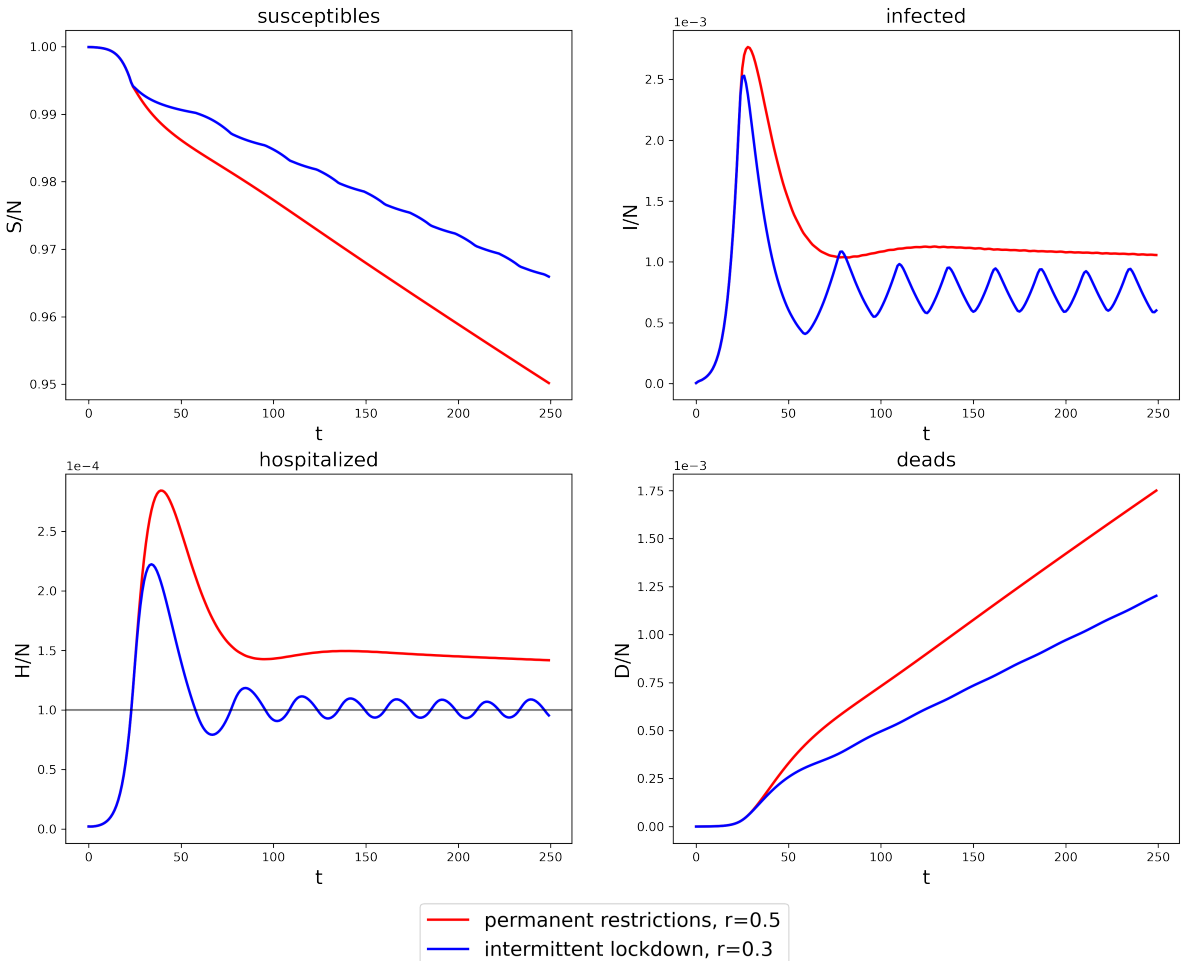
S_0	$60.352 \cdot 10^6$
E_0	1695
I_0	308.8
R_0	311.1
H_0	127.4
D_0	0
N_0	$S_0 + E_0 + I_0 + R_0 + H_0$

Appendix

β_{eff}



Example of situation in which having intermittent lockdown is better than having permanent lockdown:



References

[1] Bruno Buonomo and Rossella Della Marca. "Effects of information-induced behavioural changes during the COVID-19 lockdowns: the case of Italy". In: *Royal Society Open Science* (Oct. 2020). DOI: 10.1098/rsos.201635.

[2] Joshua S. Weitz et al. "Awareness-driven behavior changes can shift the shape of epidemics away from peaks and toward plateaus, shoulders, and oscillations". In: *Proceedings of the National Academy of Sciences* (2020). DOI: 10.1073/pnas.2009911117.

[3] Agnese Zardini et al. "A quantitative assessment of epidemiological parameters required to investigate COVID-19 burden". In: *Epidemics* 37 (2021), p. 100530. ISSN: 1755-4365. DOI: https://doi.org/10.1016/j.epidem.2021.100530. URL: https://www.sciencedirect.com/science/article/pii/S1755436521000748.