Modeling the feedback of social distancing on the dynamics of Covid-19 outbreaks

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classical SIR model

S : susceptible (can be infected)

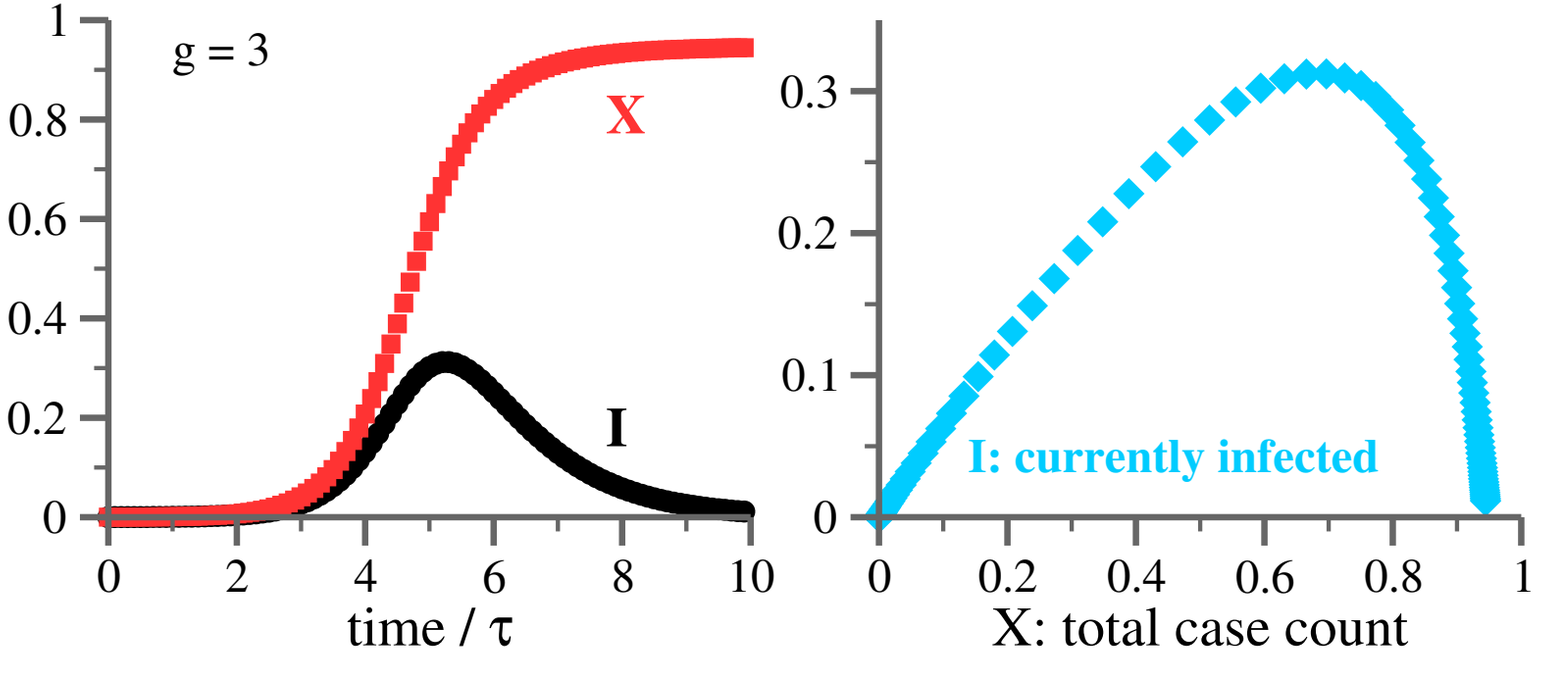
I : infected (infectious)

R : recovered (immune)

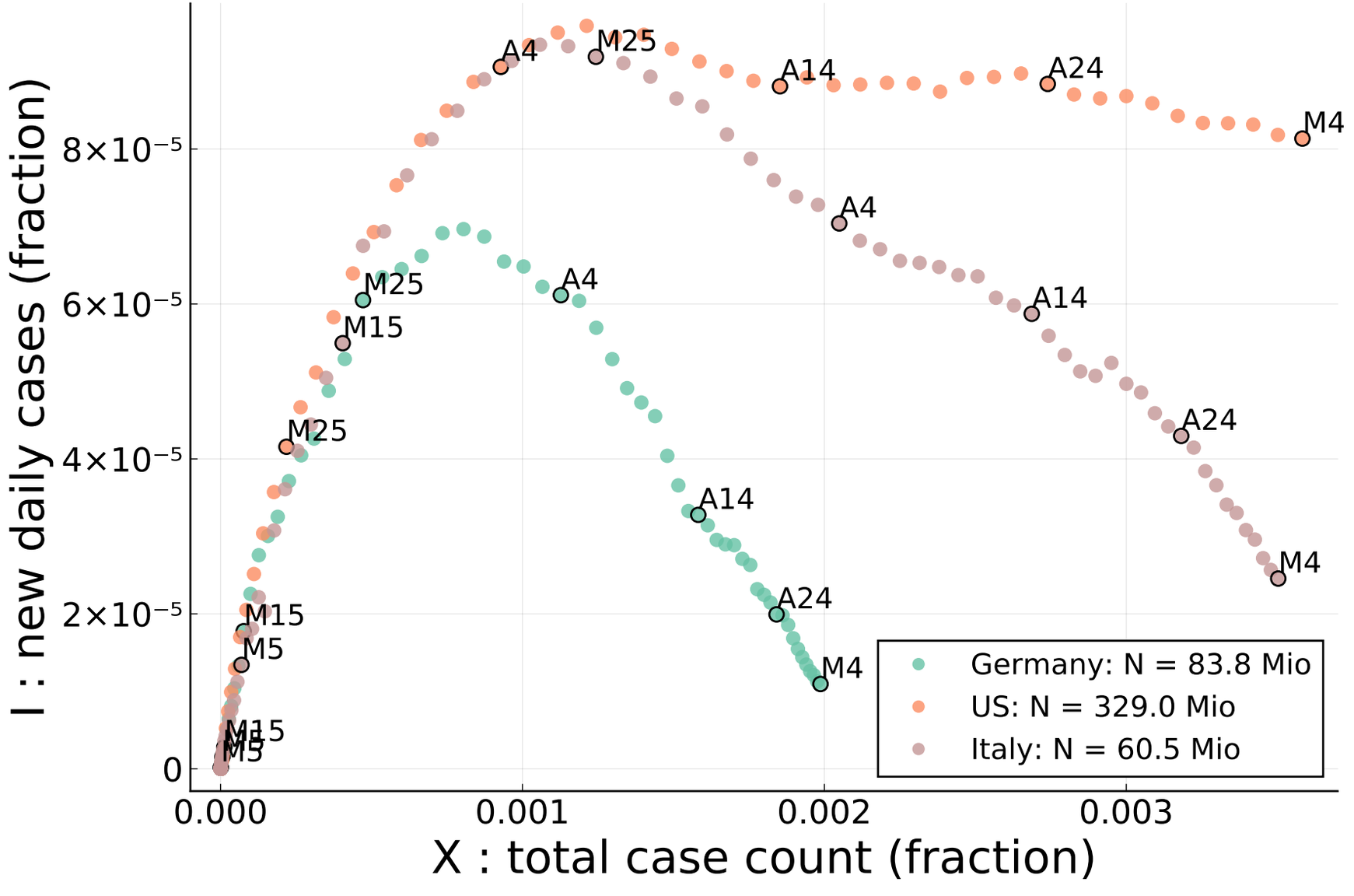
characteristic time scale : τ

dimensionless reproduction rate : g

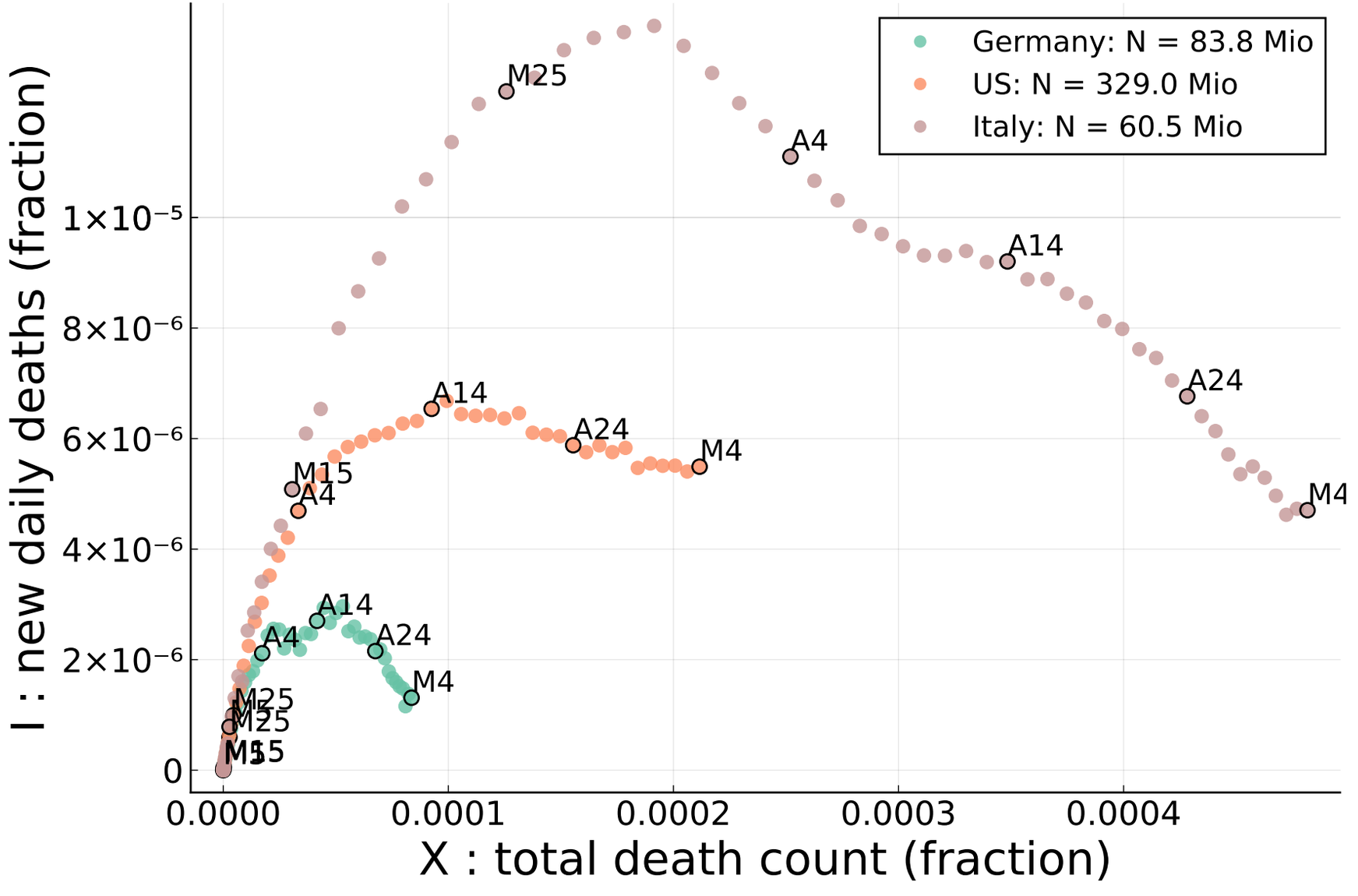
$$\tau\dot{S} = -gSI, \qquad \tau\dot{I} = (gS-1)I, \qquad \tau\dot{R} = I\,,$$



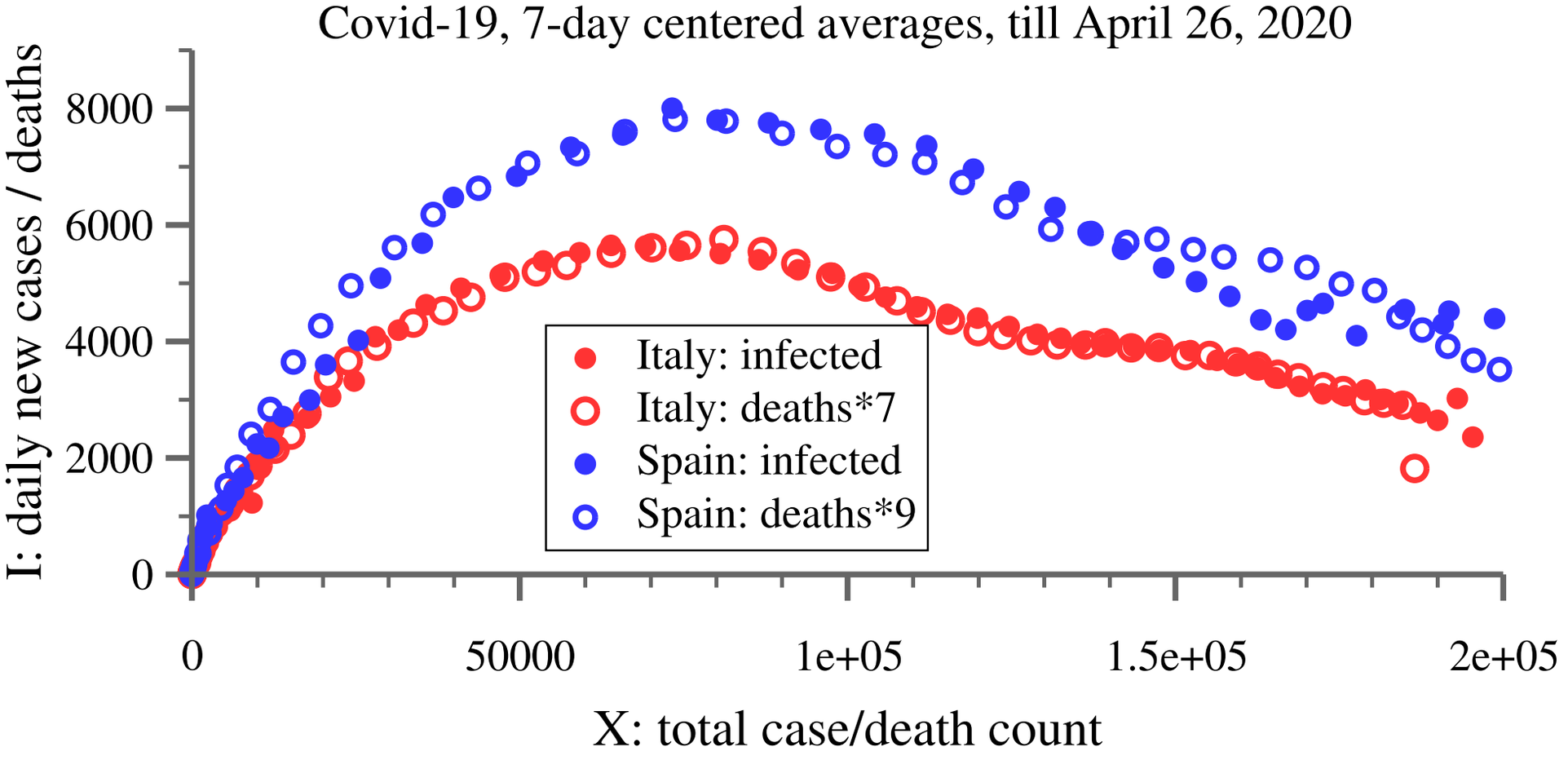
XI representation of case counts



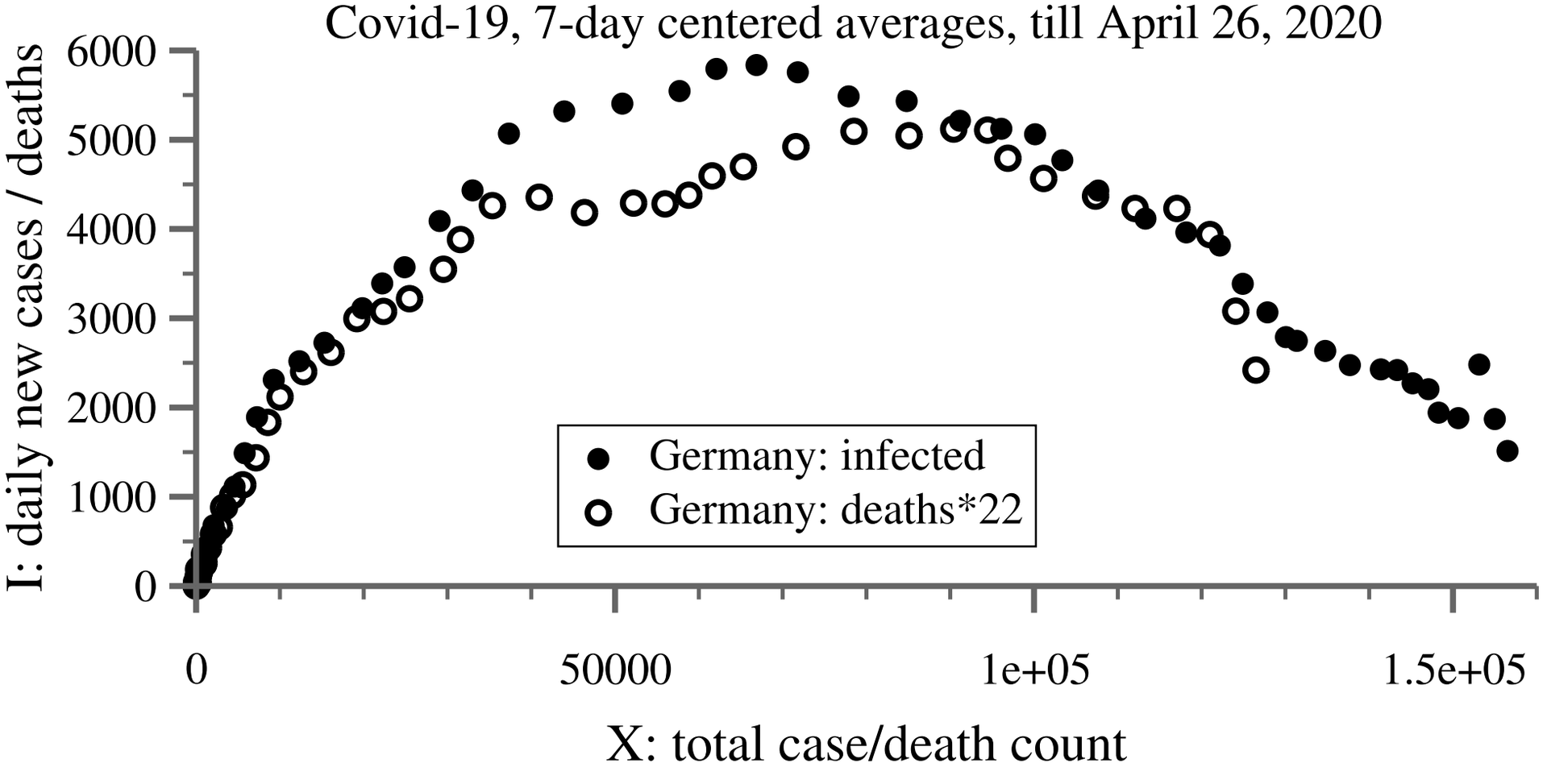
XI representation of death counts



cases/deaths scaling collapse (1)



cases/deaths scaling collapse (2)

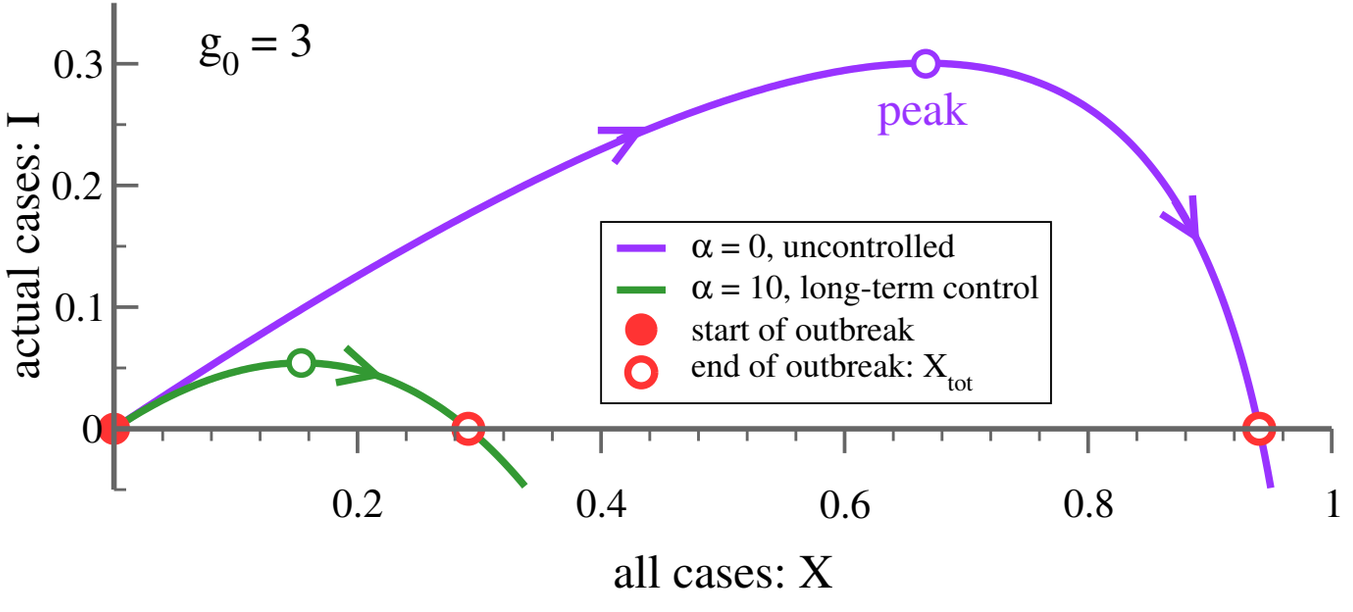


controlled SIR model

$$g = \frac{g_0}{1 + \alpha_X X + \alpha_I I} \qquad \begin{cases} \alpha_X : \text{long-term control} \\ \alpha_I : \text{short-term control} \end{cases}$$

reproduction factor is reduced by

- spontaneous social distancing
- governmental lockdown/containment policies



exact phase-space solution

$$\tau\dot{S} = -gSI, \qquad \tau\dot{I} = (gS-1)I, \qquad \boxed{\frac{dI}{dS} = \frac{1-gS}{gS}}$$

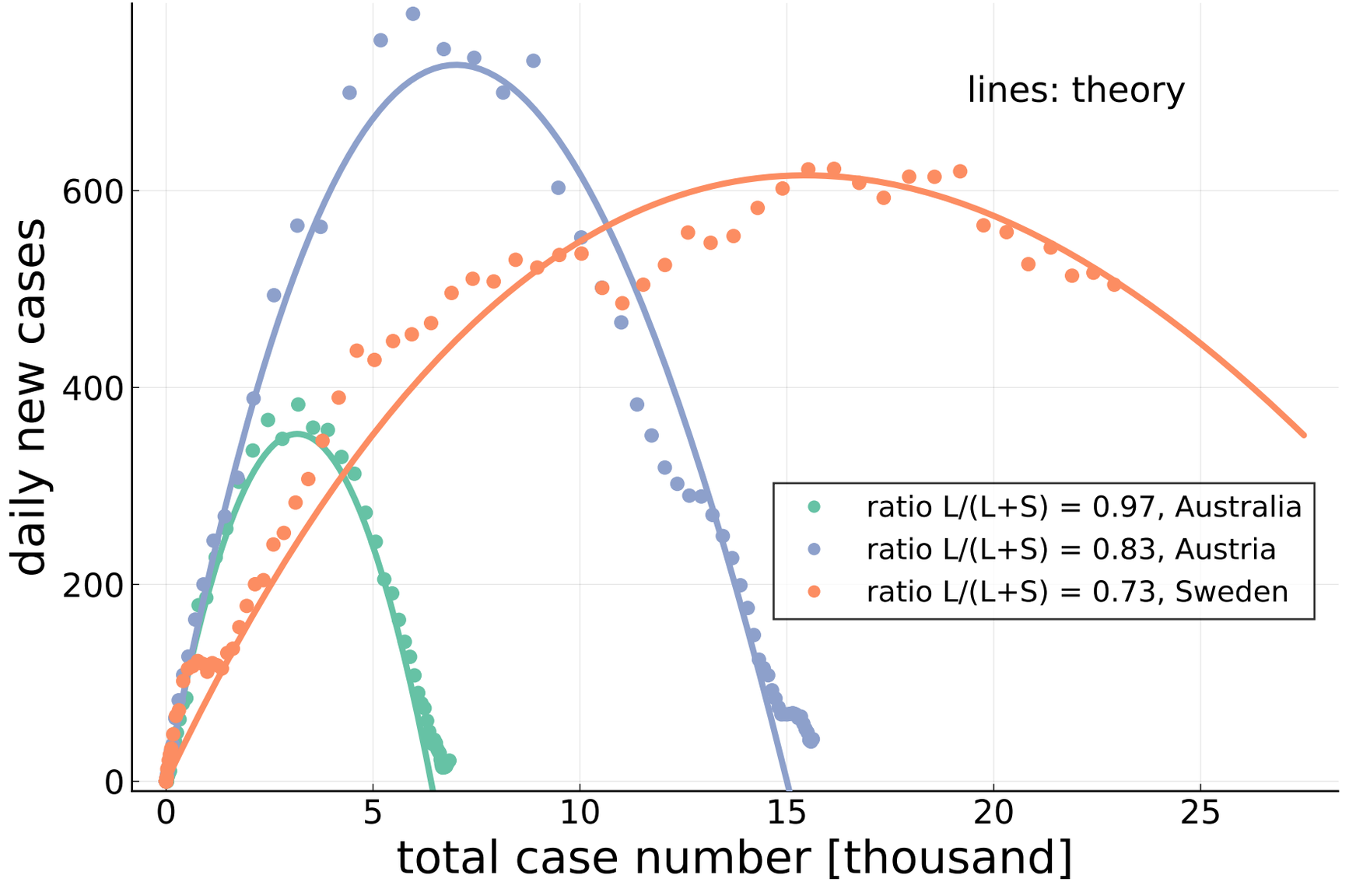
$$dI = -dS + \frac{1+\alpha(1-S)}{g_0 S}\,dS, \qquad S = 1-X$$

XI representation

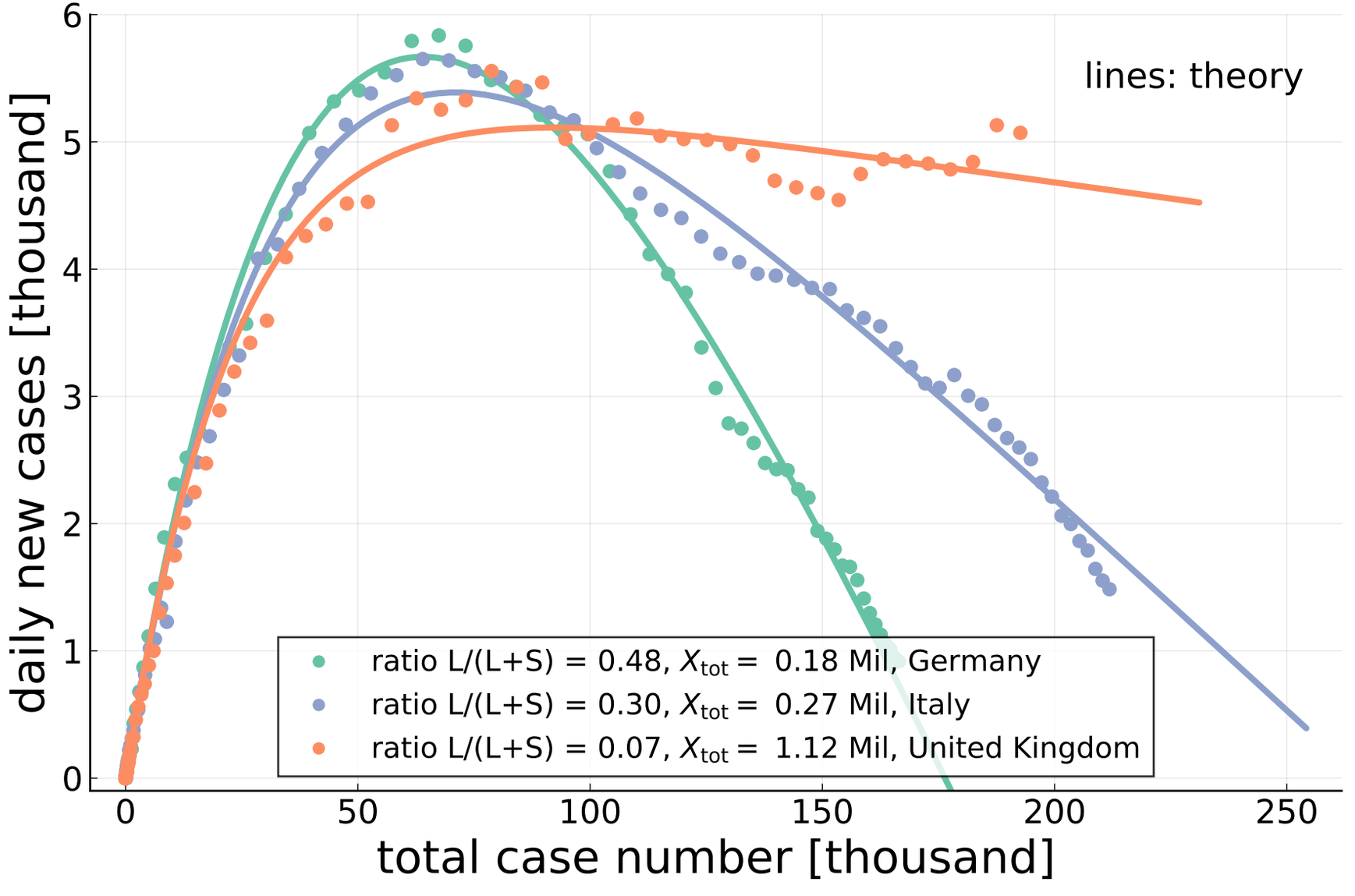
$$\boxed{I = \frac{\alpha+g_0}{g_0}X + \frac{1+\alpha}{g_0}\log(1-X)}$$

- intial condition: $I(X=0)=0$
- equivalently for short term control

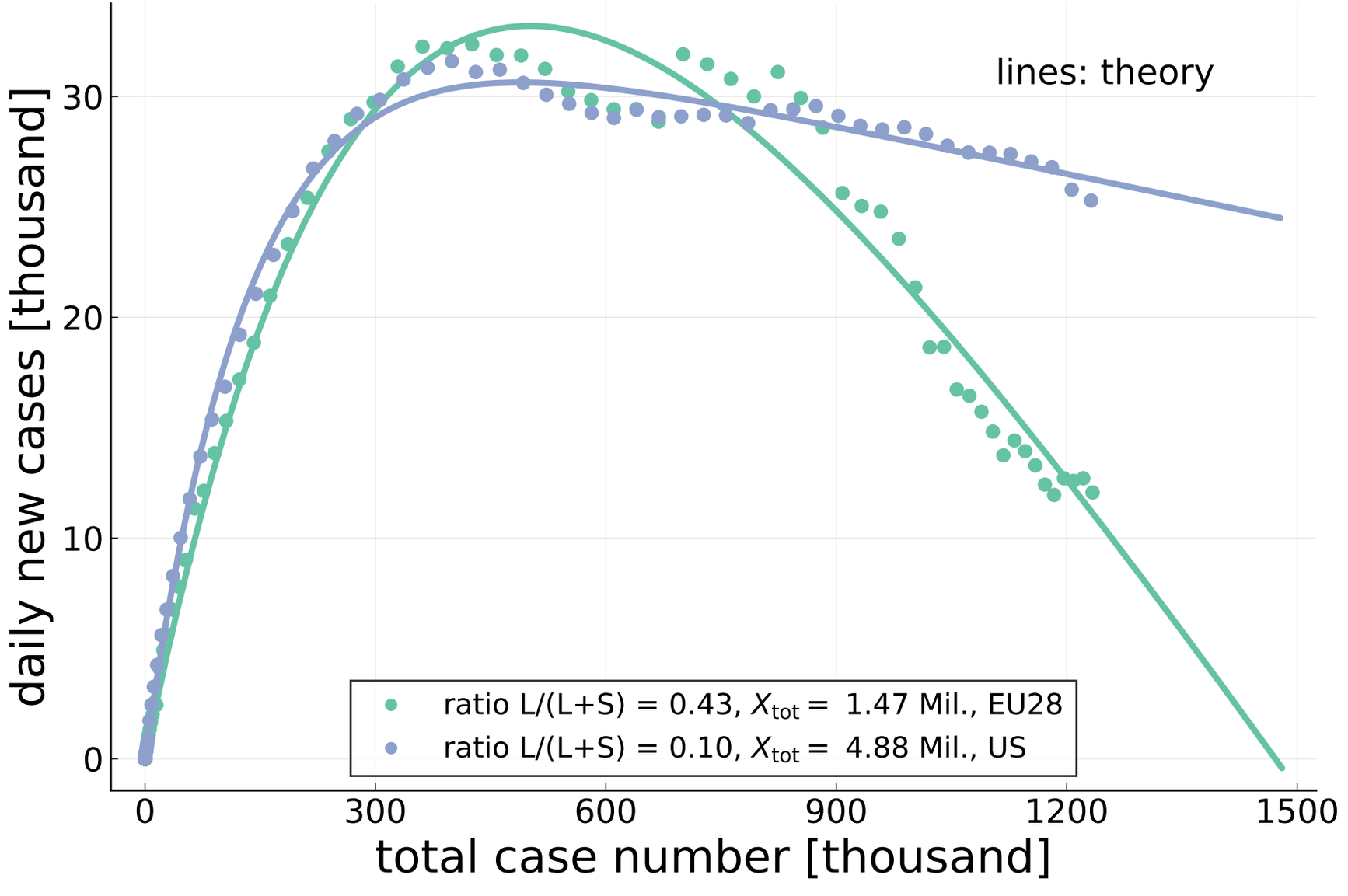
short vs. long term control (1)



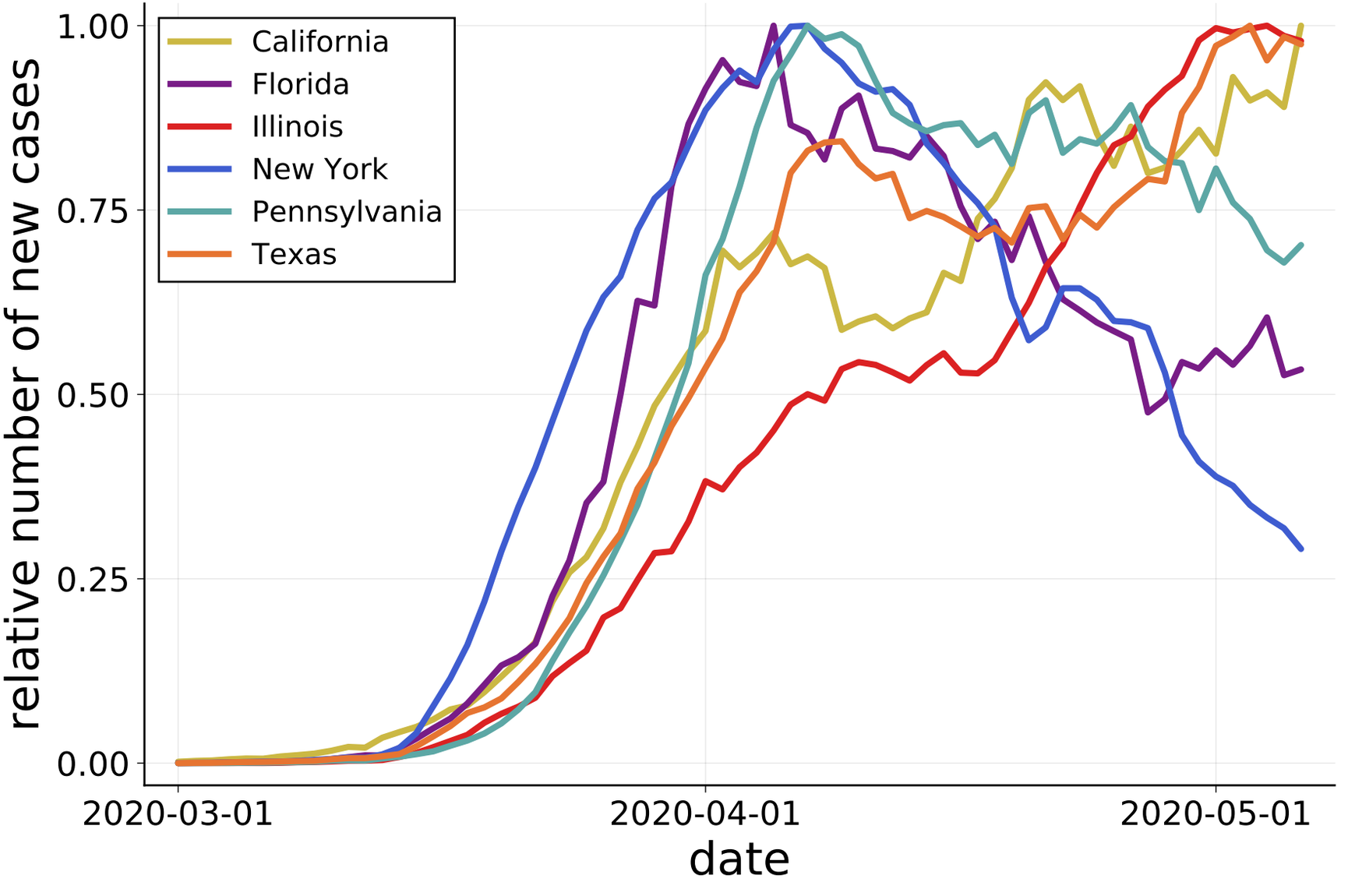
short vs. long term control (2)



US vs. EU; case counts



consecutive infection peaks

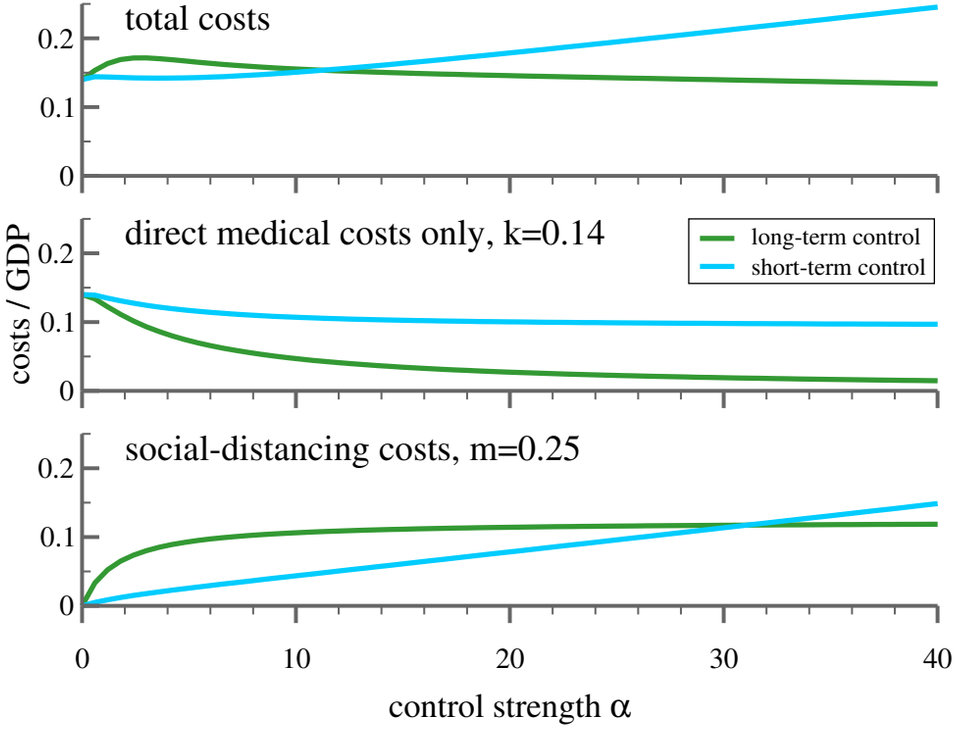


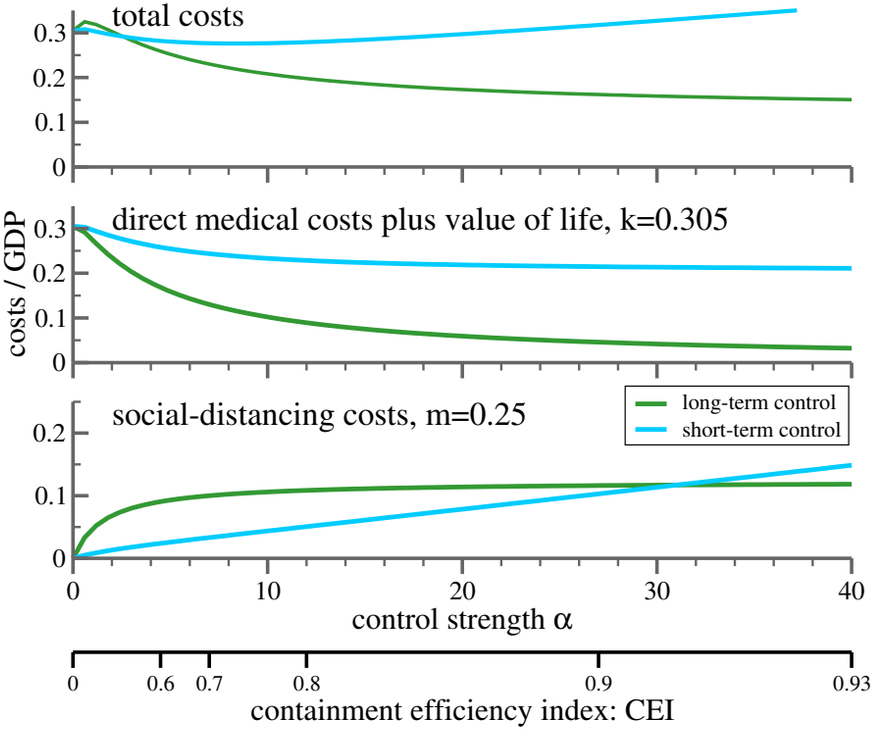
containment ⟷ social-distancing costs

economic costs $\propto$

reduction of reproduction factor

$$m\left[1-\frac{g}{g_0}\right]\frac{2}{52}, \qquad m \approx 0.25$$

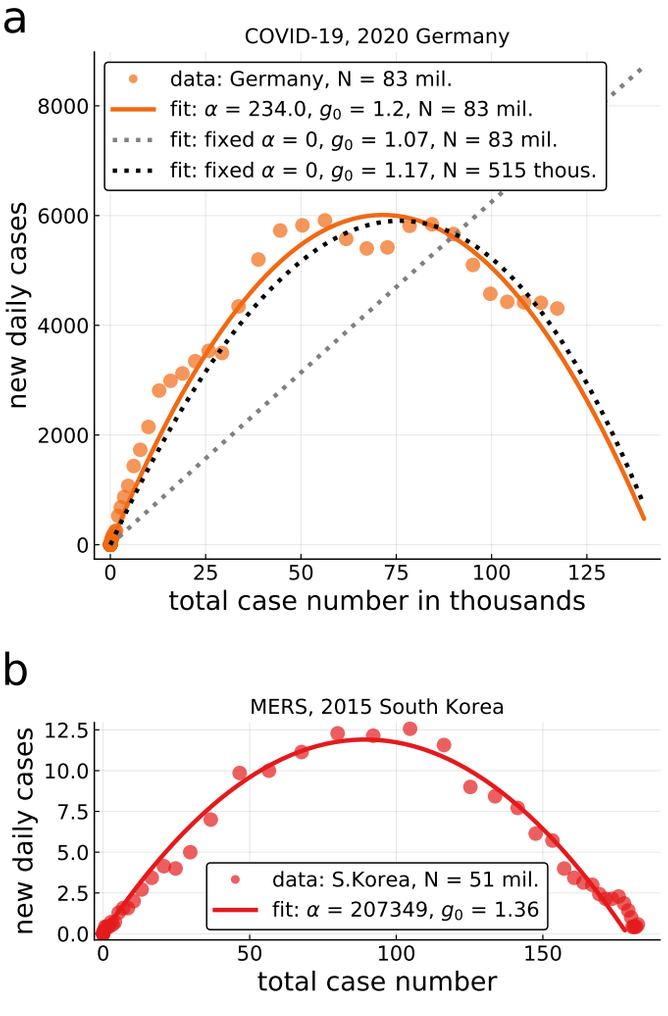


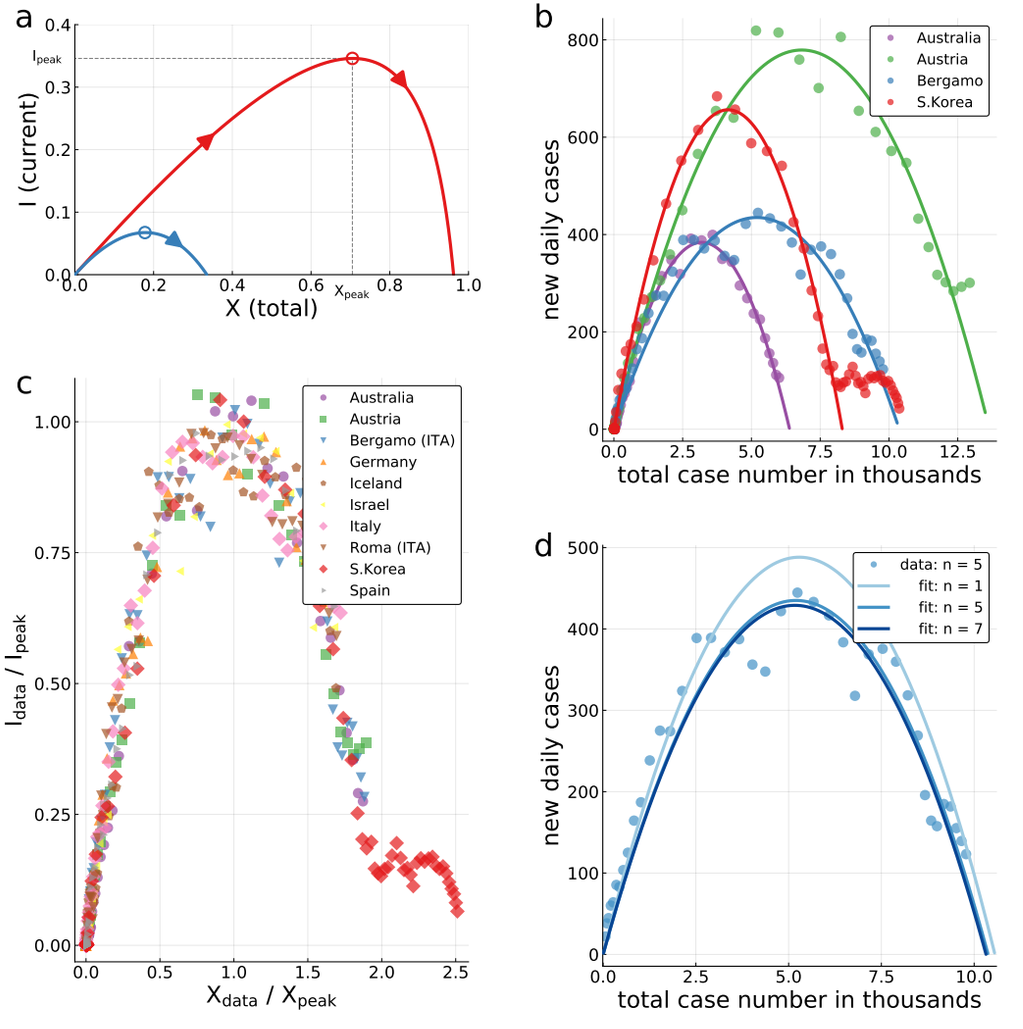


milestones

- fitting entire outbreaks with four parameters
  - g_0: intrinsic reproduction factor
  - α_X: long term control
  - α_I: short term control
  - τ: time scale
- allows to estimates overall, policy-specific costs
- allows to extract country-specific policies
- field data supports phenomenology
  - large number of individual events summed up
  - modulo under-counting

testing / MERS / data collapse





US vs. EU; death counts