

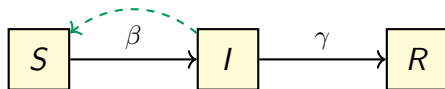
COVID-19 pandemic control: balancing detection policy and lockdown intervention under ICU sustainability

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<https://www.medrxiv.org/content/10.1101/2020.05.13.20100842v2>

June 2020

The *SIR* model

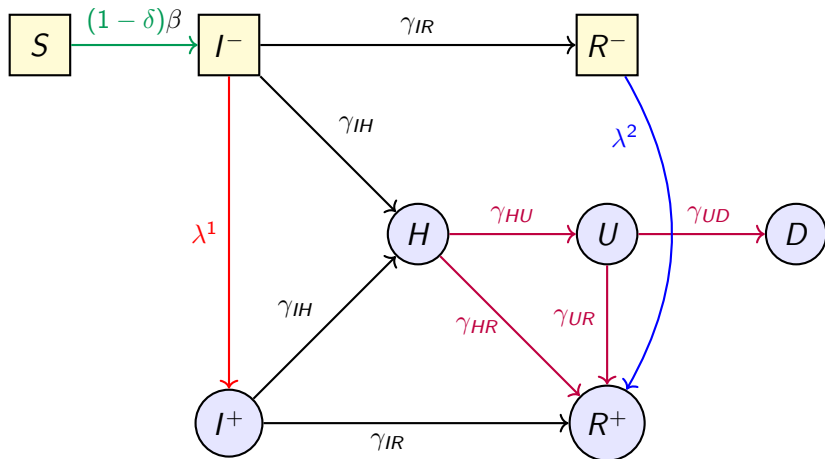


$$\frac{dS_t}{dt} = -\beta S_t I_t, \quad \frac{dI_t}{dt} = \beta S_t I_t - \gamma I_t, \quad \text{and} \quad \frac{dR_t}{dt} = \gamma I_t.$$

Important quantity: $\mathfrak{R}_0 = \frac{\beta}{\gamma}$ (reproductive ratio).

- ▶ lockdown: $S \rightarrow (1 - \delta)S$
- ▶ asymptotic: $I \rightarrow (I^+, I^-)$ and $R \rightarrow (R^+, R^-)$
- ▶ more categories: H , ICU and D
- ▶ testing/detection: $I^- \rightarrow I^+$ and $R^- \rightarrow R^+$

The $SIDUHR^{+/-}$ model



The *SIDUHR*^{+/-} model

$$\left\{ \begin{array}{l} dS_t = -(1 - \delta_t)\beta I^- S_t dt, \\ dI_t^- = (1 - \delta_t)\beta I_t^- S_t dt - \lambda_t^1 I_t^- dt - (\gamma_{IR} + \gamma_{IH}) I_t^- dt, \\ dI_t^+ = \lambda_t^1 I_t^- dt - (\gamma_{IR} + \gamma_{IH}) I_t^+ dt, \\ dR_t^- = \gamma_{IR} I_t^- dt - \lambda_t^2 R_t^- dt, \\ dR_t^+ = \gamma_{IR} I_t^+ dt + \lambda_t^2 R_t^- dt + \gamma_{HR} H_t dt + \gamma_{UR}(U_t) U_t dt, \\ dH_t = \gamma_{IH}(I_t^- + I_t^+) dt - (\gamma_{HR} + \gamma_{HU}) H_t dt, \\ dU_t = \gamma_{HU} H_t dt - (\gamma_{UR}(U_t) + \gamma_{UD}(U_t)) U_t dt, \\ dD_t = \gamma_{UD}(U_t) U_t dt, \end{array} \right. \begin{array}{l} \text{Susceptible} \\ \text{Infected -} \\ \text{Infected +} \\ \text{Recovered -} \\ \text{Recovered +} \\ \text{Hospitalized} \\ \text{ICU} \\ \text{Dead} \end{array}$$

$$\mathfrak{R}_0 = \frac{(1 - \delta_0)\beta}{\lambda_0^1 + \gamma_{IR} + \gamma_{IH}} \text{ and } \mathfrak{R}_t = \frac{(1 - \delta_t)\beta S_t}{\lambda_t^1 + (\gamma_{IR} + \gamma_{IH})}.$$

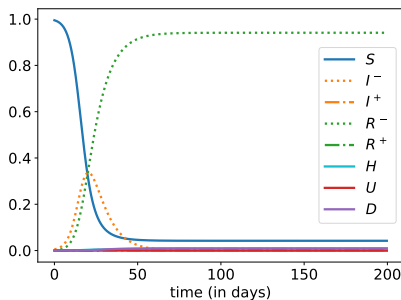
Parameters (Tab. 1)

Parameters	Value	Reference
\mathfrak{R}_0	3.3	Salje <i>et al.</i> (2020)
β	0.436	Salje <i>et al.</i> (2020)
γ_{IR}	0.130	Domenico <i>et al.</i> (2020)
γ_{IH}	0.00232	Domenico <i>et al.</i> (2020)
γ_{HR}	0.048	Salje <i>et al.</i> (2020)
γ_{HU}	0.091	Salje <i>et al.</i> (2020)
$\gamma_{UR}(U) \times U$	$0.078U \wedge 1.564 \cdot 10^{-5}$	Salje <i>et al.</i> (2020)
$\gamma_{UD}(U) \times U$	$0.02 \cdot U \wedge U_{\max} + 2(U - 0.0002)^+$	Salje <i>et al.</i> (2020)
U_{\max}	0.0002	estimated
I_0^-	0.005	estimated

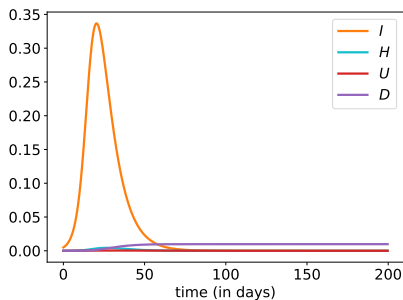
Domenico *et al.* (2020) medrxiv: 2020.04.13.20063933.

Salje *et al.* (2020) Hal Pasteur: 02548181

Dynamics of the $SIDUHR^{+/-}$ model (Fig. 2)



(a) All states



(b) States $I = I^- + I^+$, H , U , D only

Note: $\max\{I_t\} \sim 33.7\%$ and $D_T \sim 9.8\%$.

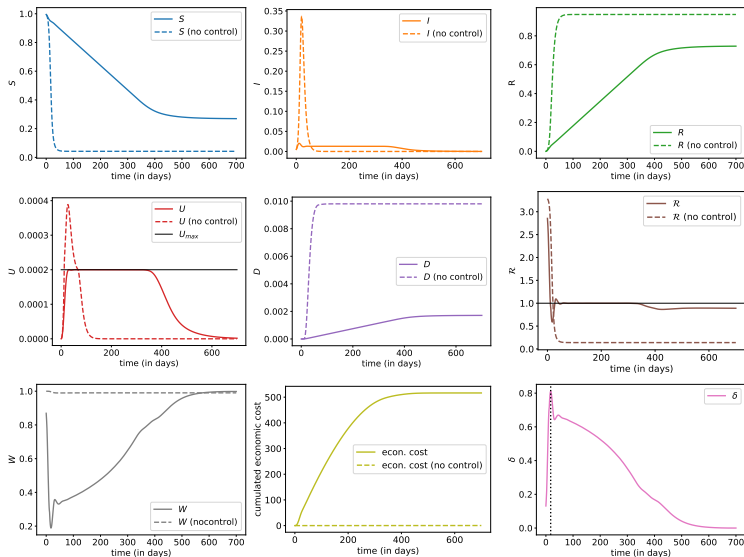
The objective functions

$$\left\{ \begin{array}{ll} Q_t = R_t^- + I_t^- + S_t & \text{(suceptible to be) quarantined/lockdowned} \\ W_t = (1 - \delta_t)Q_t + R_t^+ & \text{work force} \\ N_t^1 = \lambda_t^1 Q_t + \gamma_{IH} I_t^- & \text{virologic tests, type-1 (short term)} \\ N_t^2 = \lambda_t^2 Q_t & \text{antibody tests, type-2 (long term)} \end{array} \right.$$

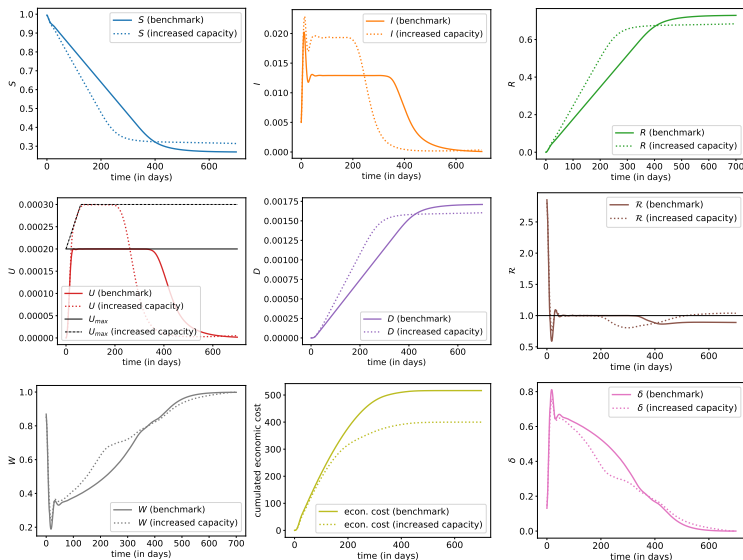
$$\left\{ \begin{array}{ll} C_{\text{sanitary}} & = \mathbb{E}(D_\tau) = \int_0^\infty e^{-\alpha t} dD_t \\ C_{\text{econ}} & = \mathbb{E} \left[\int_0^\tau (1 - W_t)^2 dt \right] = \int_0^\infty e^{-\alpha t} (1 - W_t)^2 dt \\ C_{\text{prevalence}} & = \mathbb{E} \left[\int_0^\tau |N_t^1|^2 dt \right] = \int_0^\infty e^{-\alpha t} |N_t^1|^2 dt \\ C_{\text{immunity}} & = \mathbb{E} \left[\int_0^\tau |N_t^2|^2 dt \right] = \int_0^\infty e^{-\alpha t} |N_t^2|^2 dt \end{array} \right.$$

Computational issue: $\infty = 700$ days

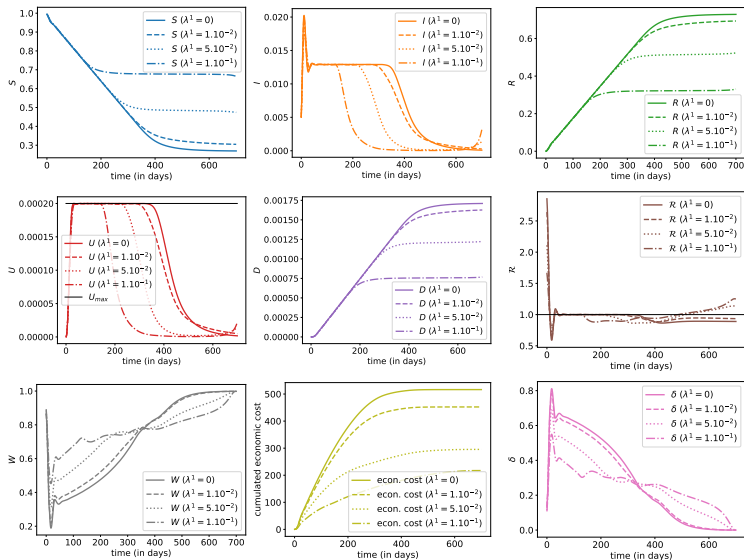
With optimal (δ_t^*) (Fig. 3)



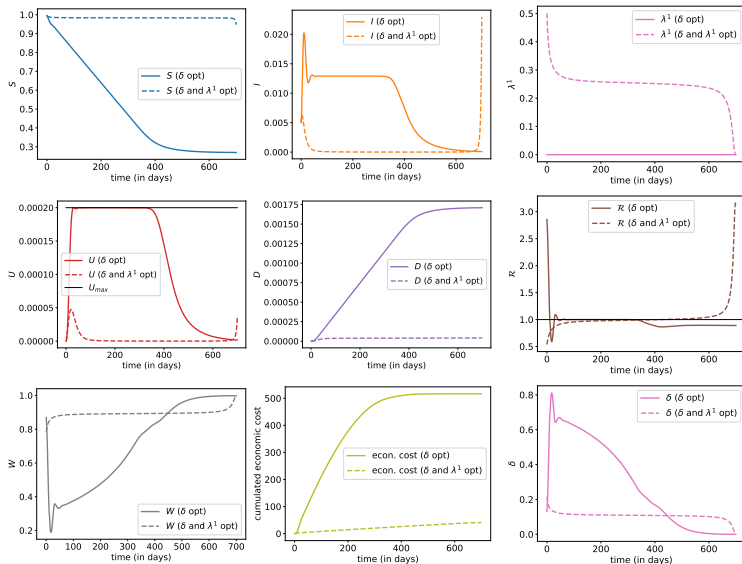
Optimal (δ_t^*) with increase of ICU (Fig. 4)



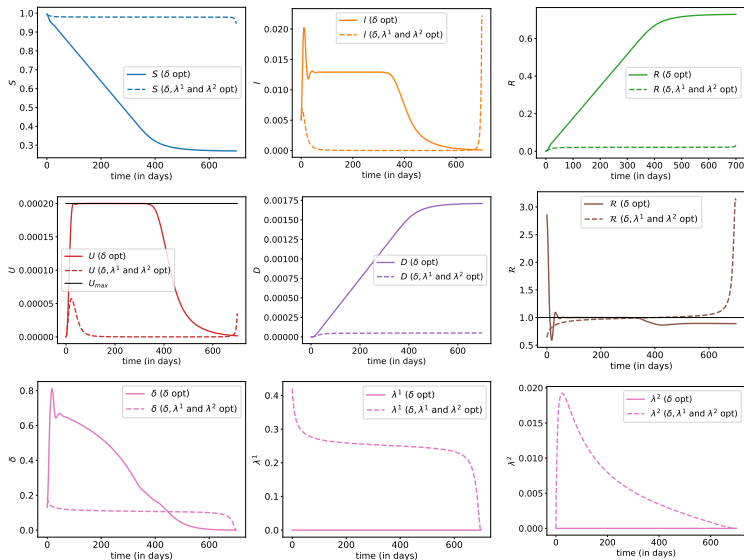
Impact of (λ_t^1) (constant, Fig. 10, B5)



Impact of (λ_t^{1*}) (Fig. 12, B7)



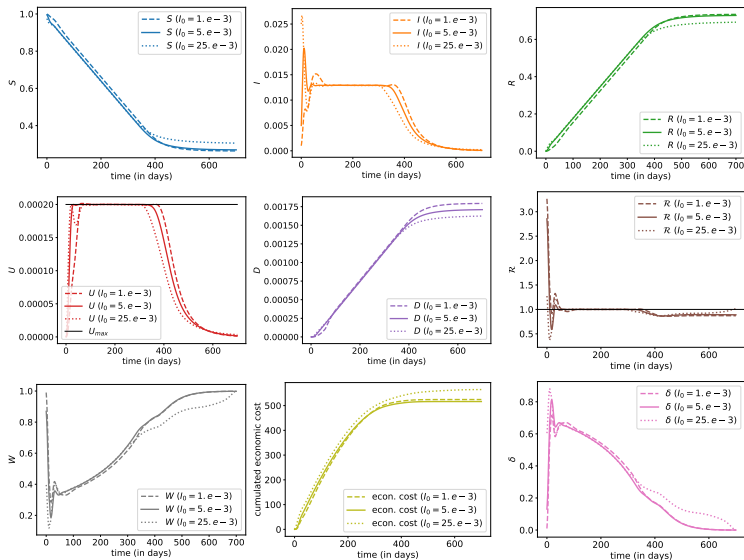
Impact of (λ_t^{2*}) (Fig. 16, B11)



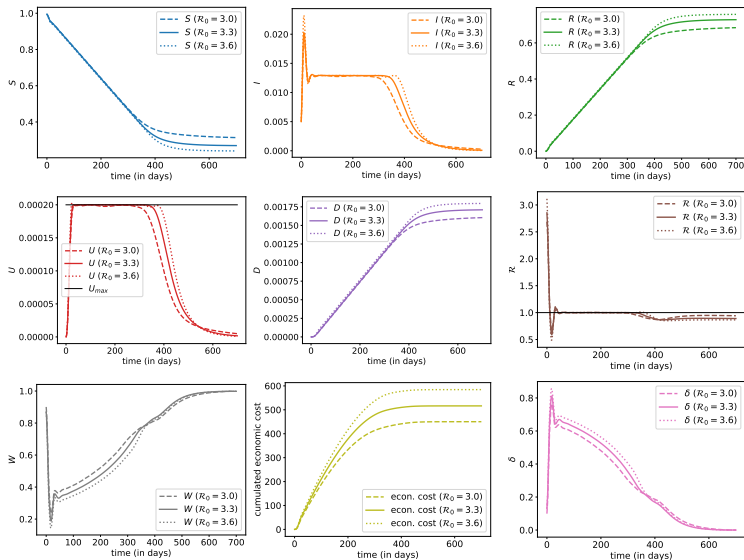
Wrap-Up

- ▶ initial objective : realistic model for the COVID-19 pandemic
- ▶ "*flatten the curve*" : ICU sustainability
- ▶ virologic tests, type-1 (short term) : identify I^- ($\rightarrow I^+$)
- ▶ antibody tests, type-2 (long term) : identify R^- ($\rightarrow R^+$)
- ▶ need to get accurate cost function (trade-off sanitary / economic & welfare)
- ▶ never relax the control before reaching herd immunity
- ▶ quite robust on various parameters
- ▶ more on <https://doi.org/10.1101/2020.05.13.20100842>
- ▶ can go further...
 - ▶ take into account age structure (contact matrices)
 - ▶ impact of lockdown duration
 - ▶ trace, test and isolate

Sensitivity in I_0 (Fig. 6, B1)



Sensitivity in \mathfrak{R}_0 (Fig. 7, B2)



Sensitivity in α (Fig. 9, B4)

