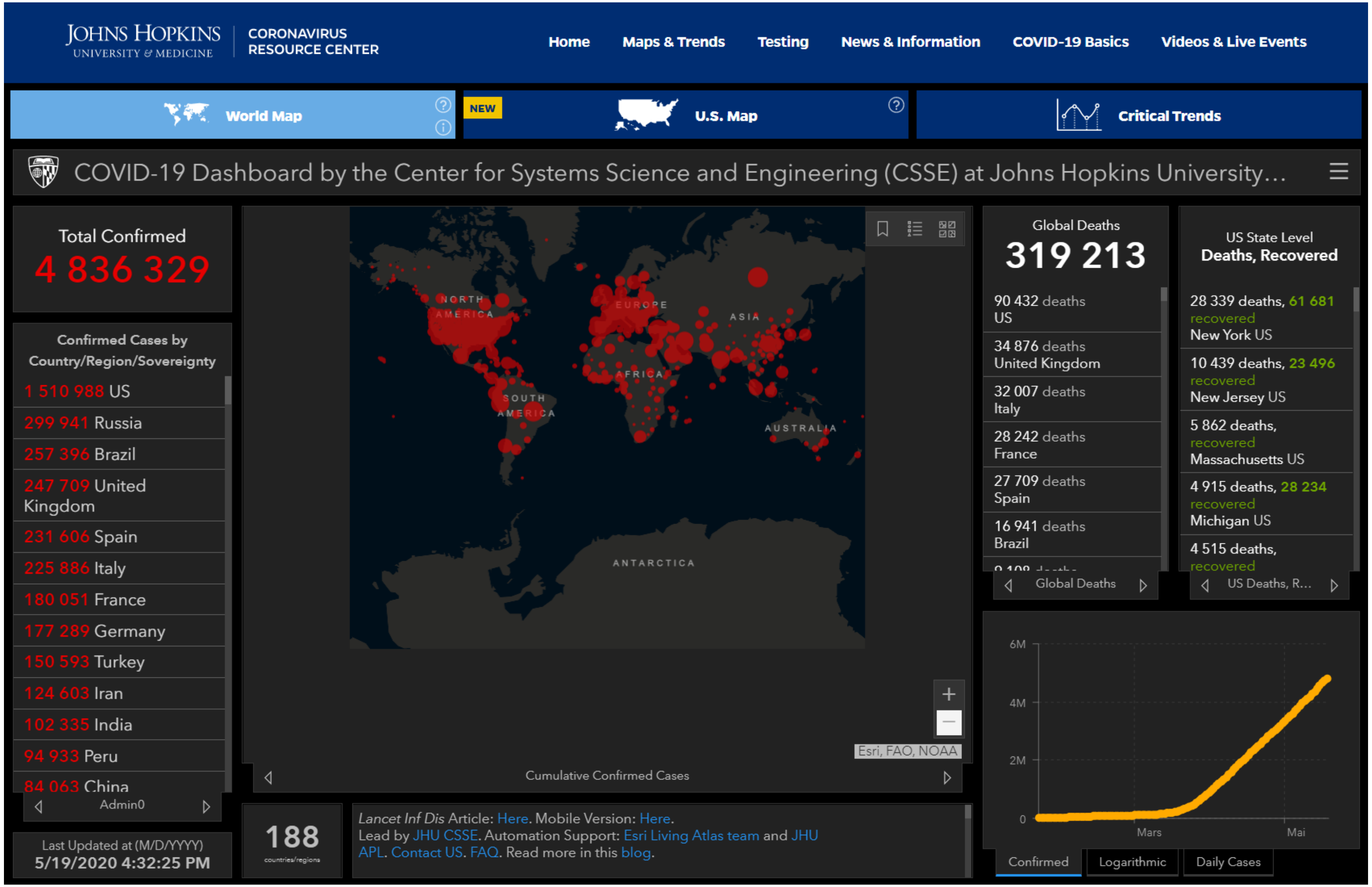
MODELLING THE COVID-19 PANDEMIC REQUIRES A MODEL… BUT ALSO DATA!

Marc Lavielle
Inria Saclay & Ecole Polytechnique

https://coronavirus.jhu.edu/map.html



CSSEGISandData / COVID-19

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time_series_covid19_recovered_global.csv	automated update	13 hours ago

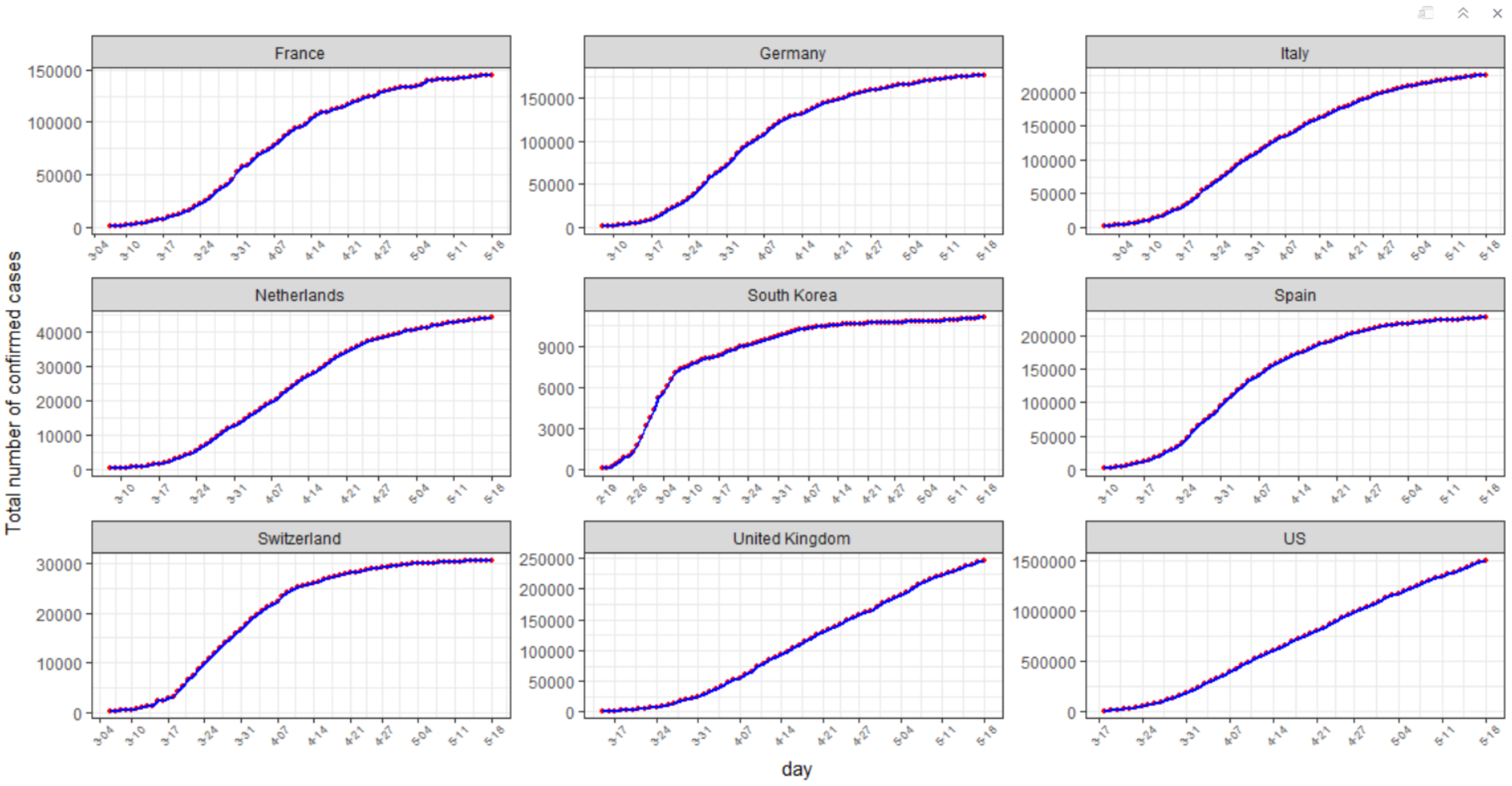
README.md

Time series summary (csse_covid_19_time_series)

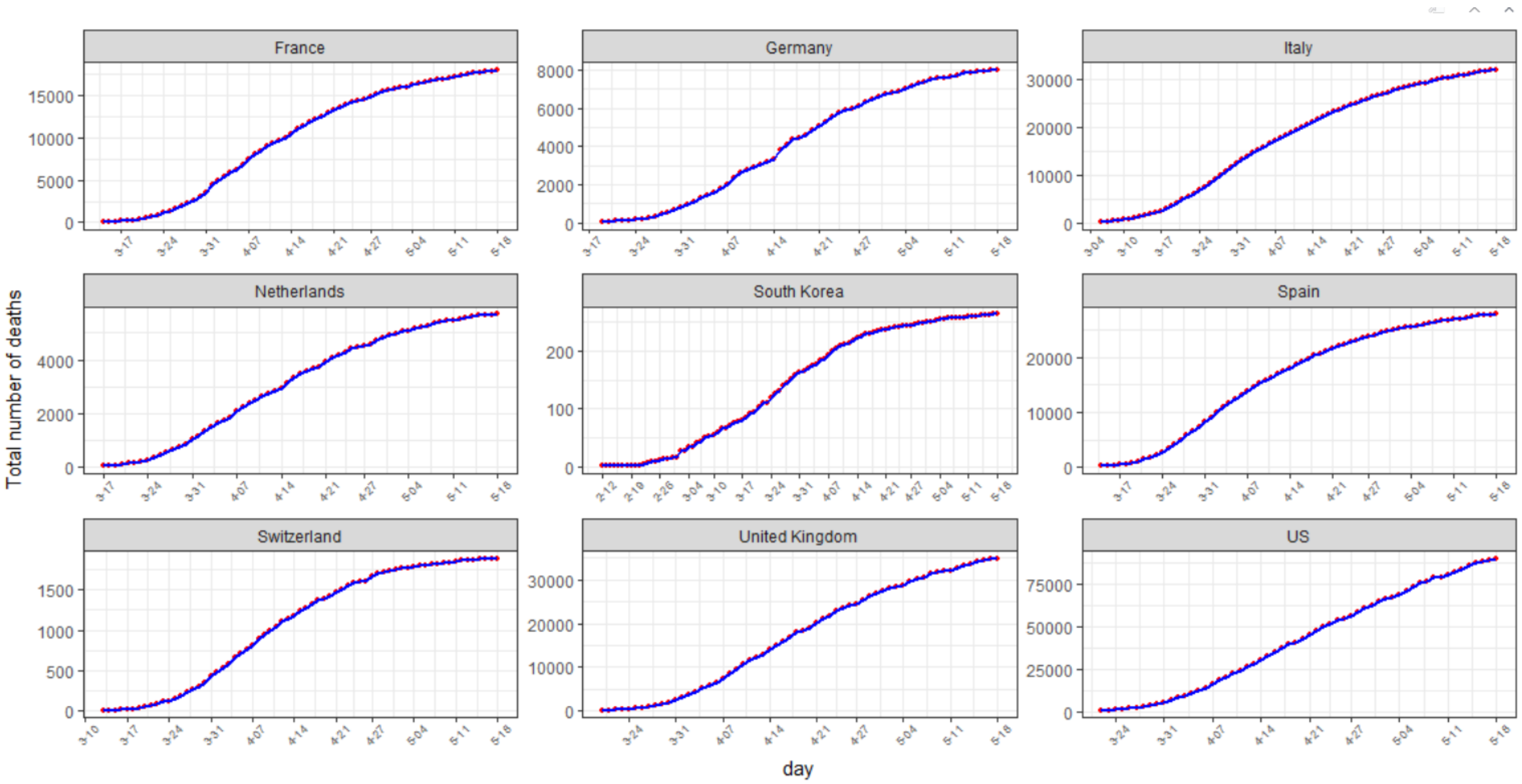
This folder contains daily time series summary tables, including confirmed, deaths and recovered. All data is read in from the daily case report. The time series tables are subject to be updated if inaccuracies are identified in our historical data. The daily reports will not be adjusted in these instances to maintain a record of raw data.

Two time series tables are for the US confirmed cases and deaths, reported at the county level. They are named `time_series_covid19_confirmed_US.csv`, `time_series_covid19_deaths_US.csv`, respectively.

Cumulated number of confirmed cases



Cumulated number of deaths



- The objective **is not** to build a model… and try to “calibrate” it in order to fit the data as well as possible

- The objective **is not** to build a model… and try to "calibrate" it in order to fit the data as well as possible

- The objective is to develop a model

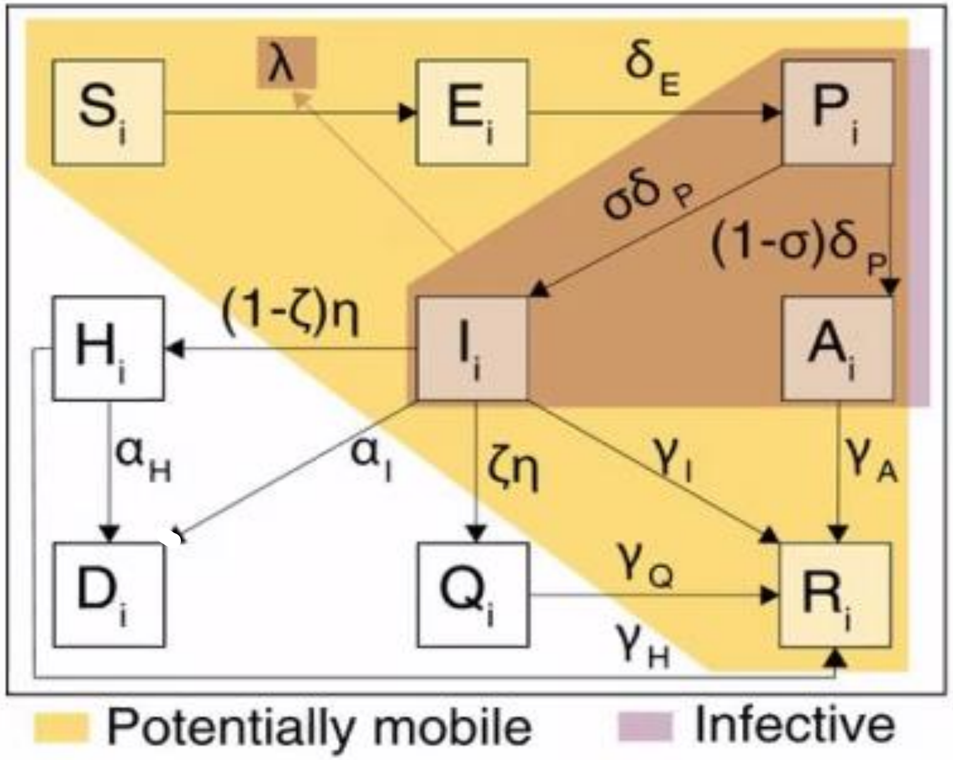
  - **for the observed data**, and validated by the data,

  - that provides good short-term predictions,

  - that is mechanistic **and** parsimonious,

  - that is implemented as an open-access interactive tool.

The epidemiological compartments



S_i: susceptibles in site *i*

E_i: exposed in *i*

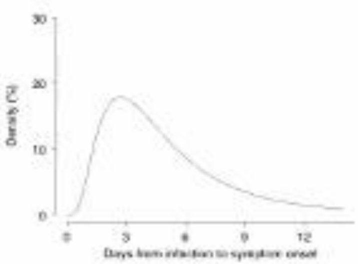
P_i: pre-symptomatic infectious in *i*

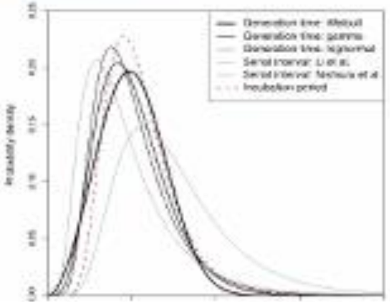
I_i: symptomatic infectious in *i*

A_i: asymptomatic/mildly symptomatic infectious in *i*

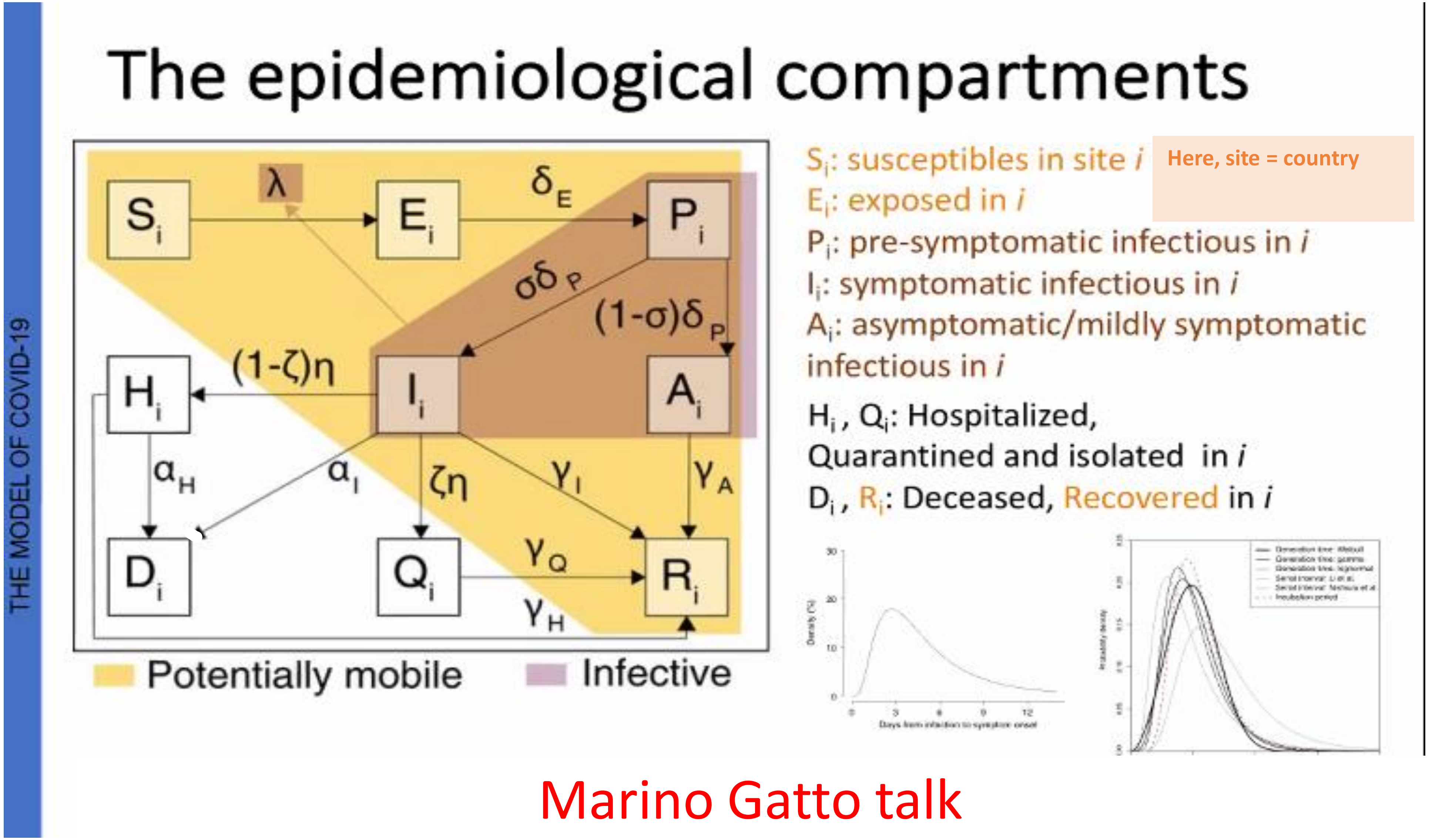
H_i, Q_i: Hospitalized, Quarantined and isolated in *i*

D_i, R_i: Deceased, Recovered in *i*





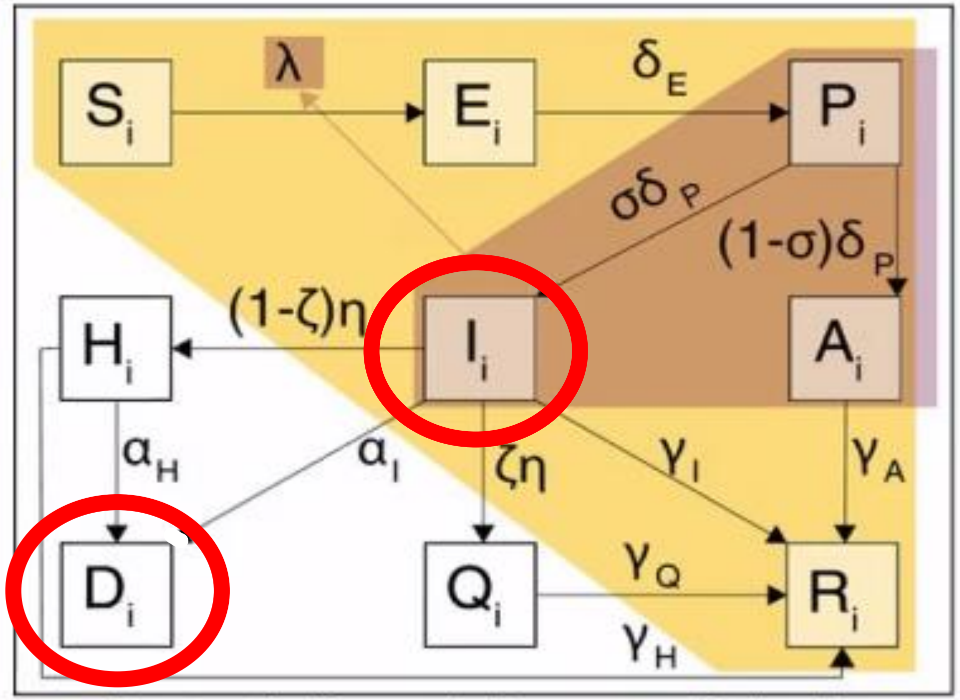
Marino Gatto talk



Marino Gatto talk

THE MODEL OF COVID-19

The epidemiological compartments



Potentially mobile   Infective

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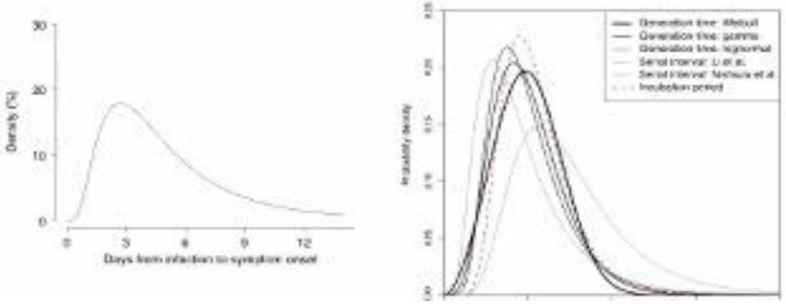

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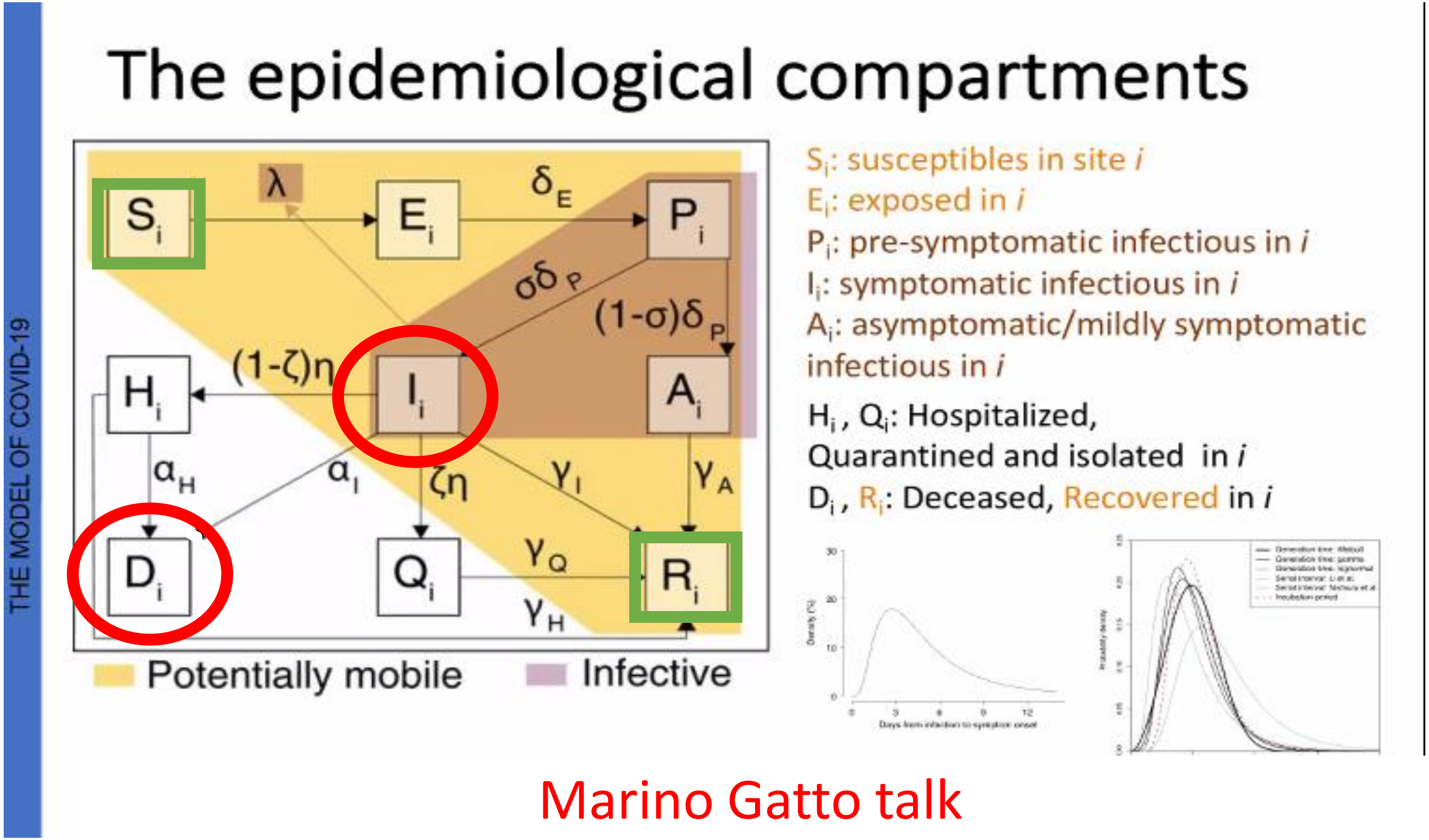

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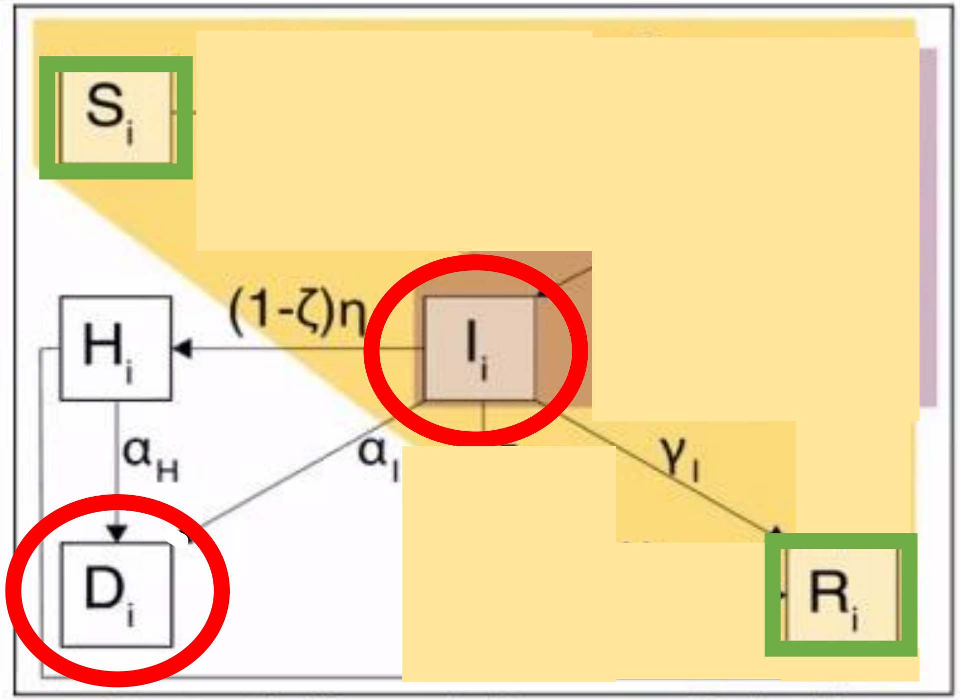
The epidemiological compartments



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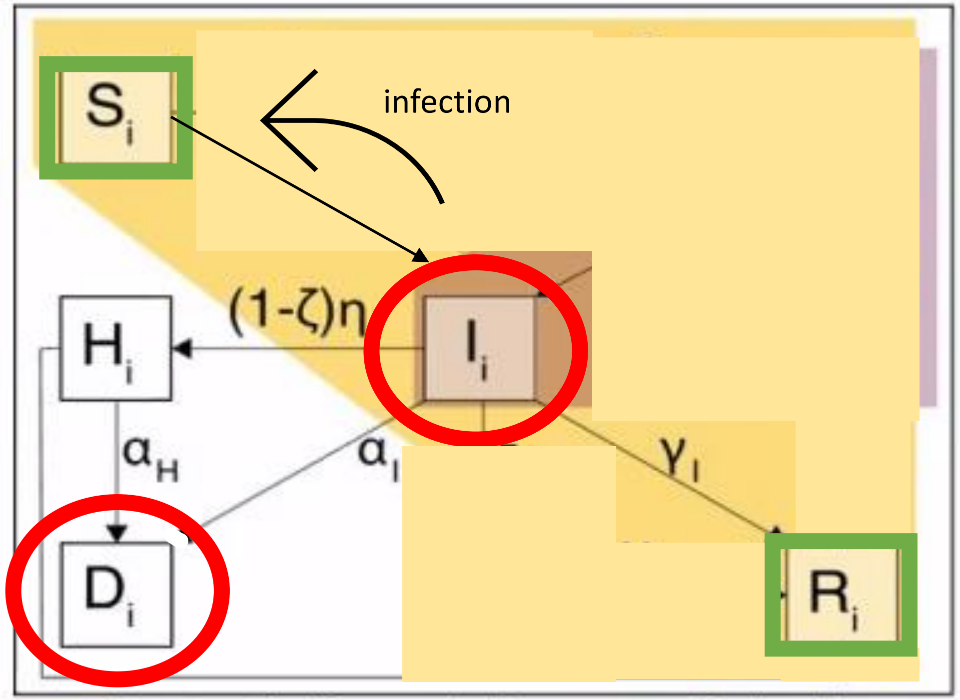

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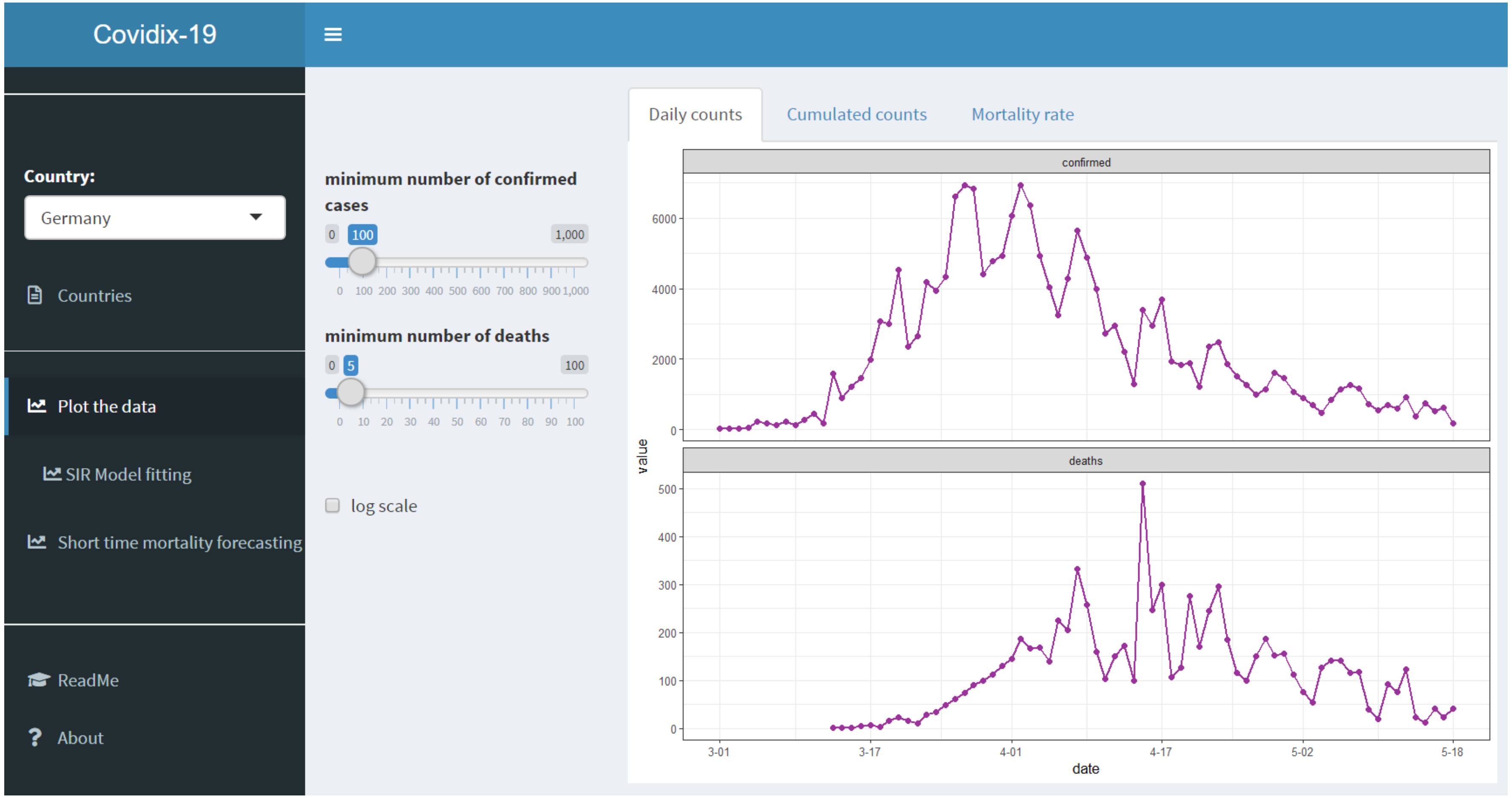
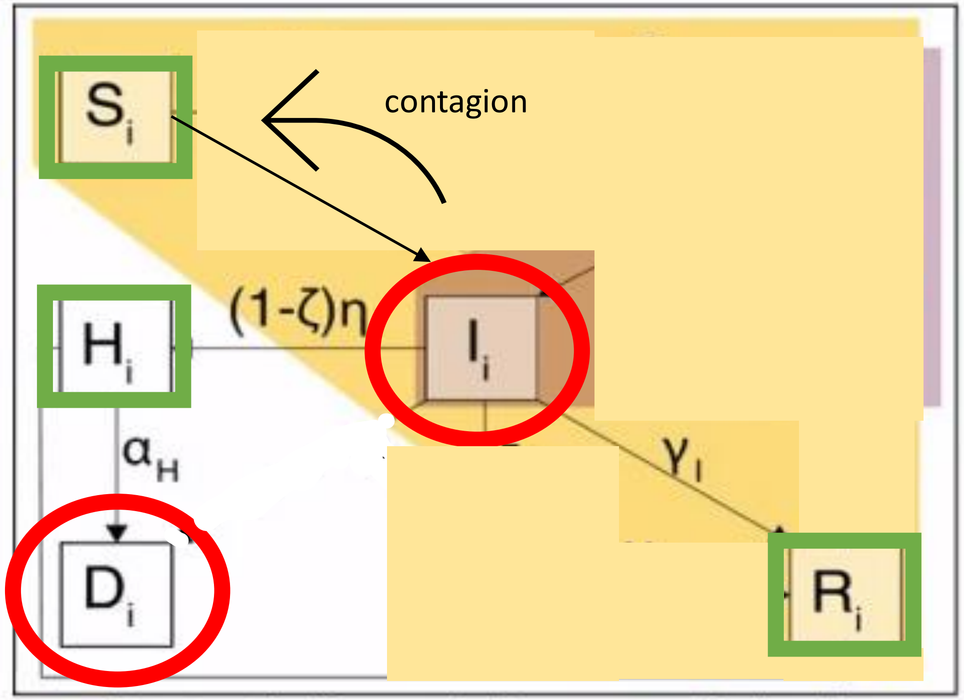


http://shiny.webpopix.org/covidix/app2/

The epidemiological compartments



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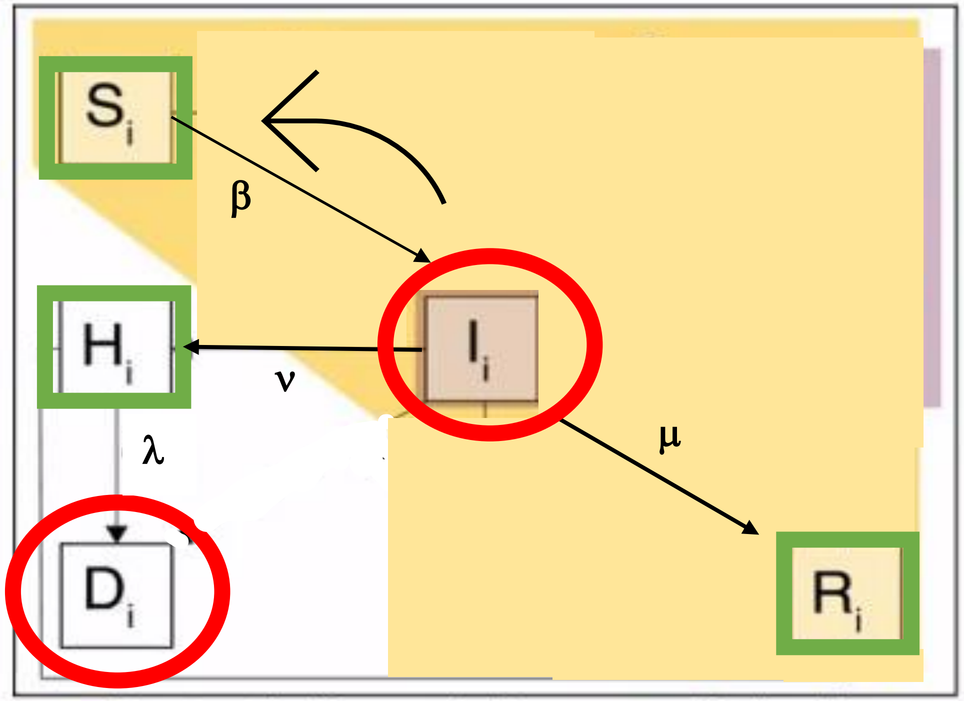

THE MODEL OF COVID-19

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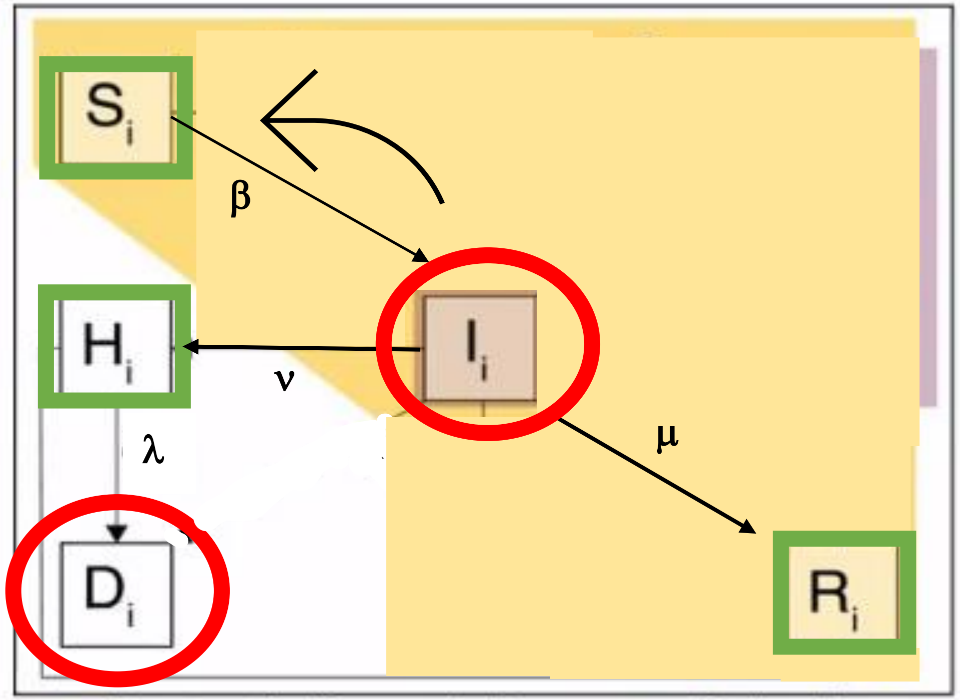

$$\dot{S}(t) = -\beta \frac{S(t)}{N} I(t)$$

$$\dot{I}(t) = \beta \frac{S(t)}{N} I(t) - \mu I(t) - \nu I(t)$$

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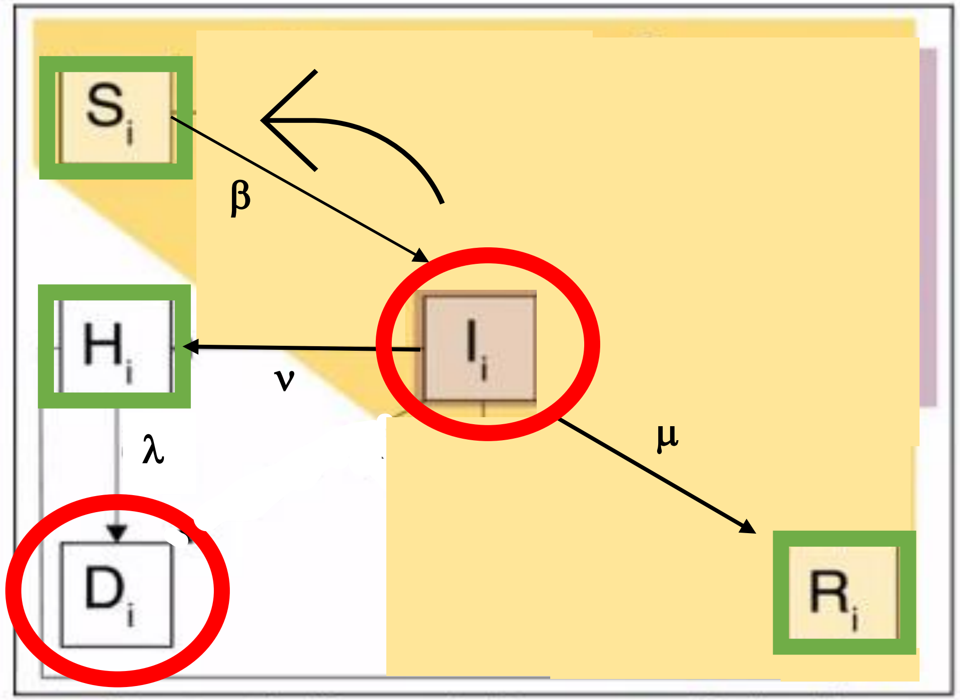

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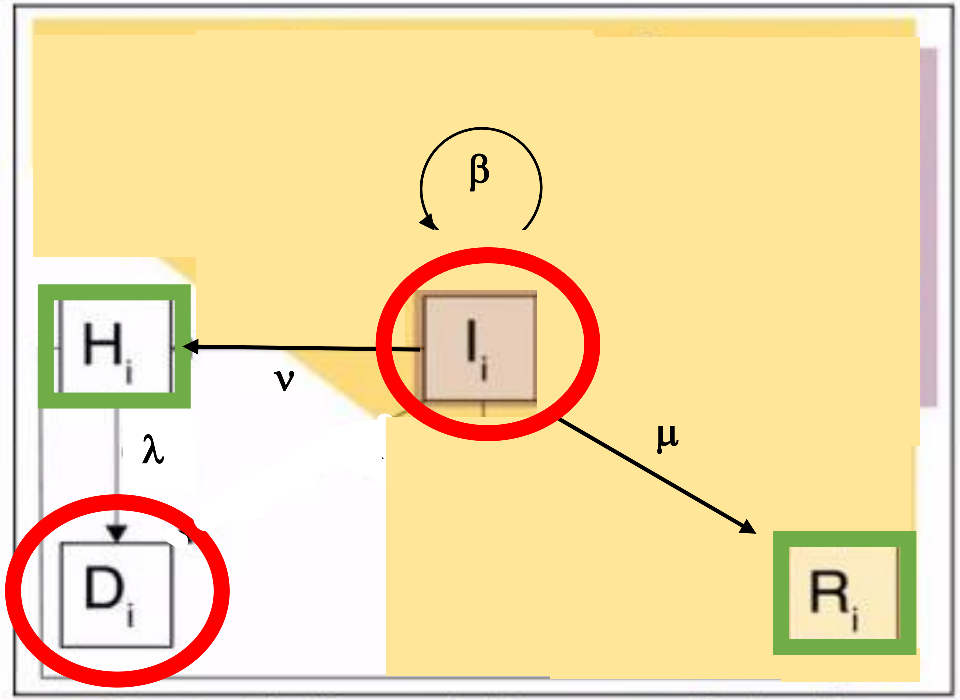
Approximation : *S(t)* = *N*

THE MODEL OF COVID-19

The epidemiological compartments



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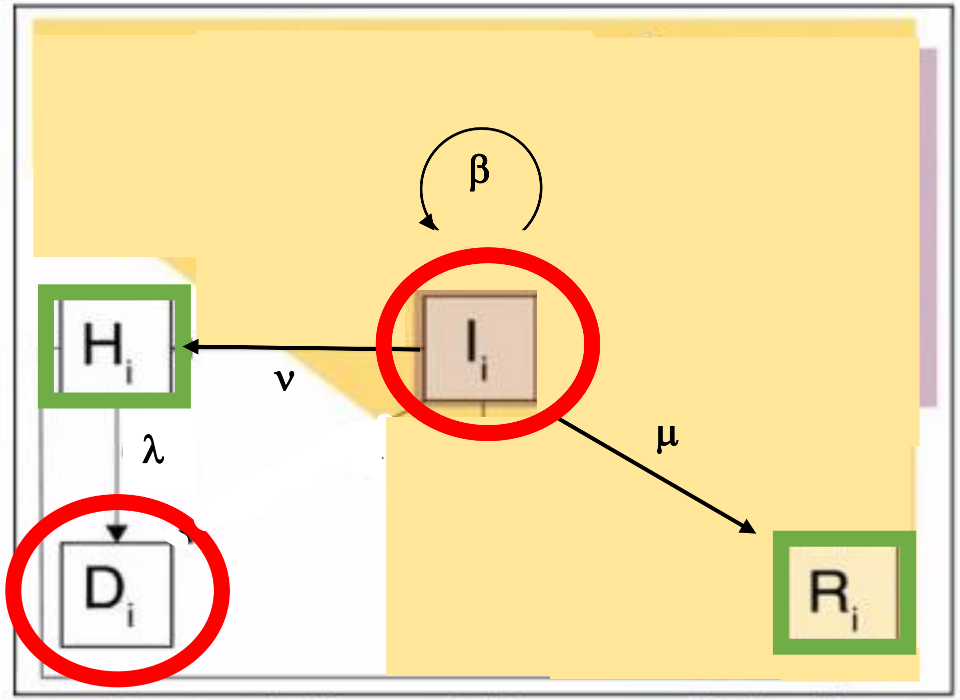

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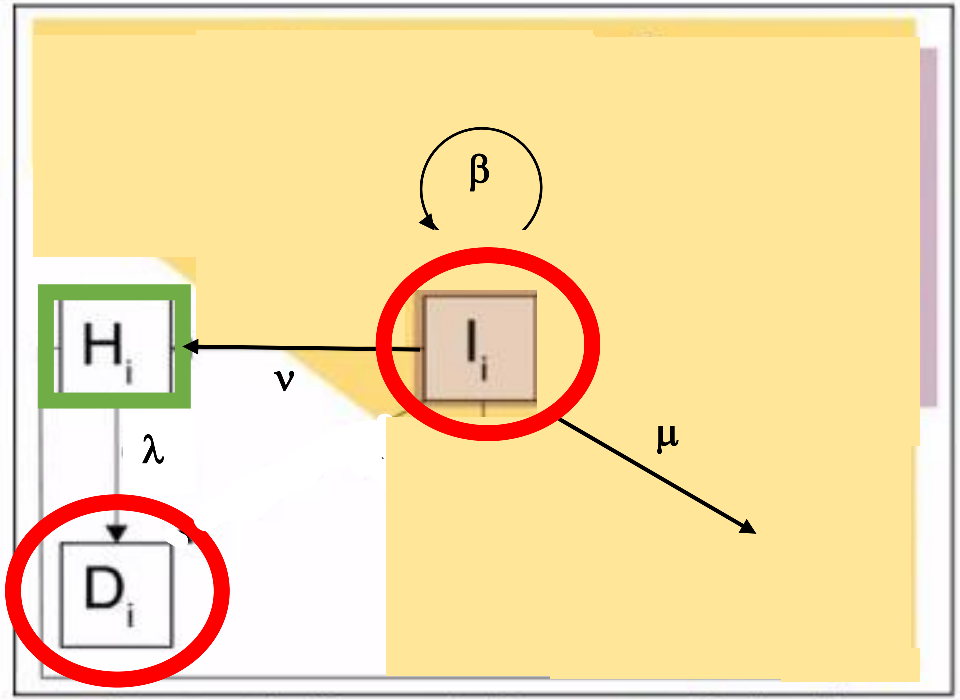
R not needed for fitting the data

The epidemiological compartments



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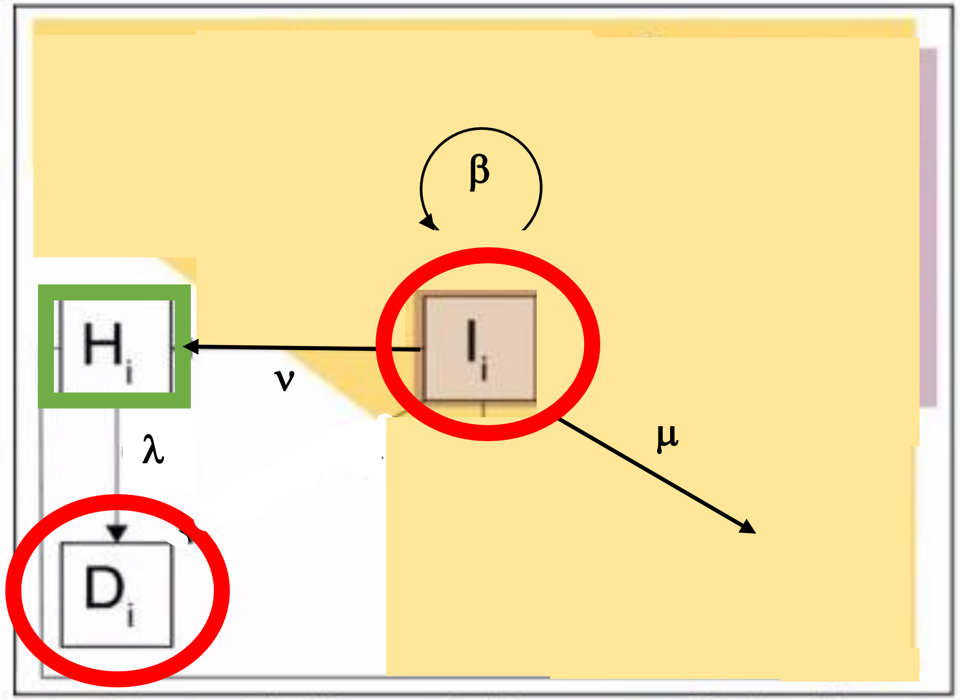

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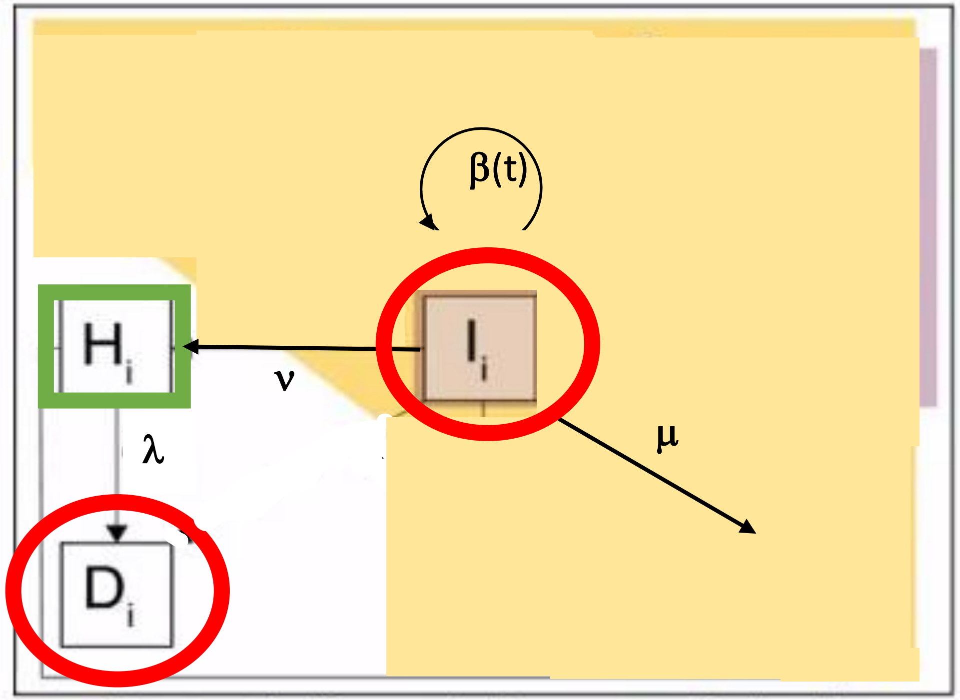
The transmission rate β changes over time

The epidemiological compartments



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THE MODEL OF COVID-19

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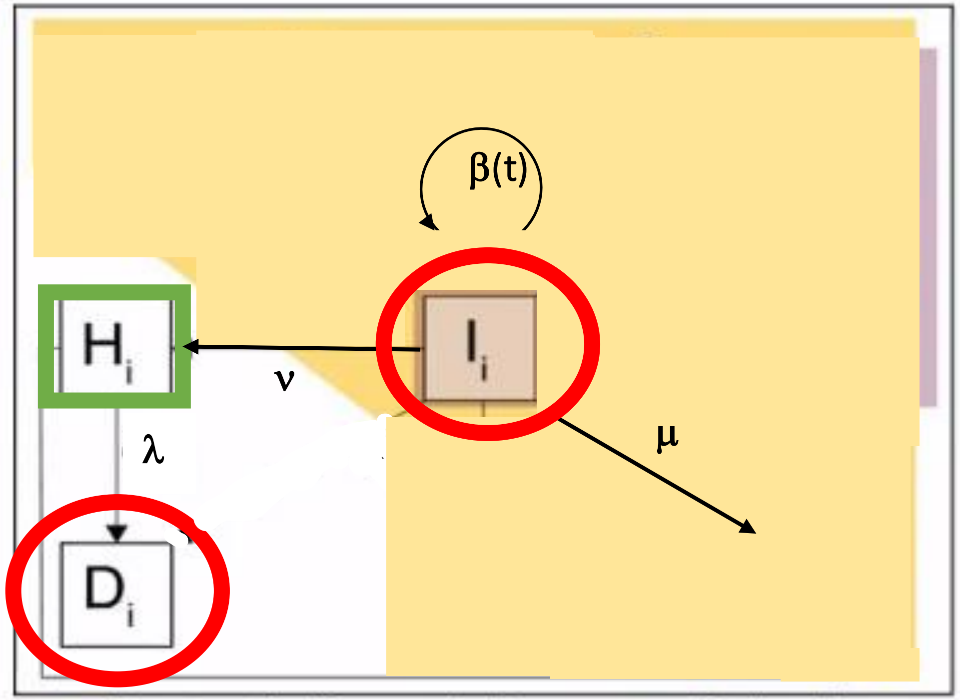

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$$\beta(t) = \beta_0 + a\,t + \sum_{k=1}^{K} h_k\,t \times \mathbb{1}\{t \geq \tau_k\}$$

We will use a piecewise linear function for β

The observation model

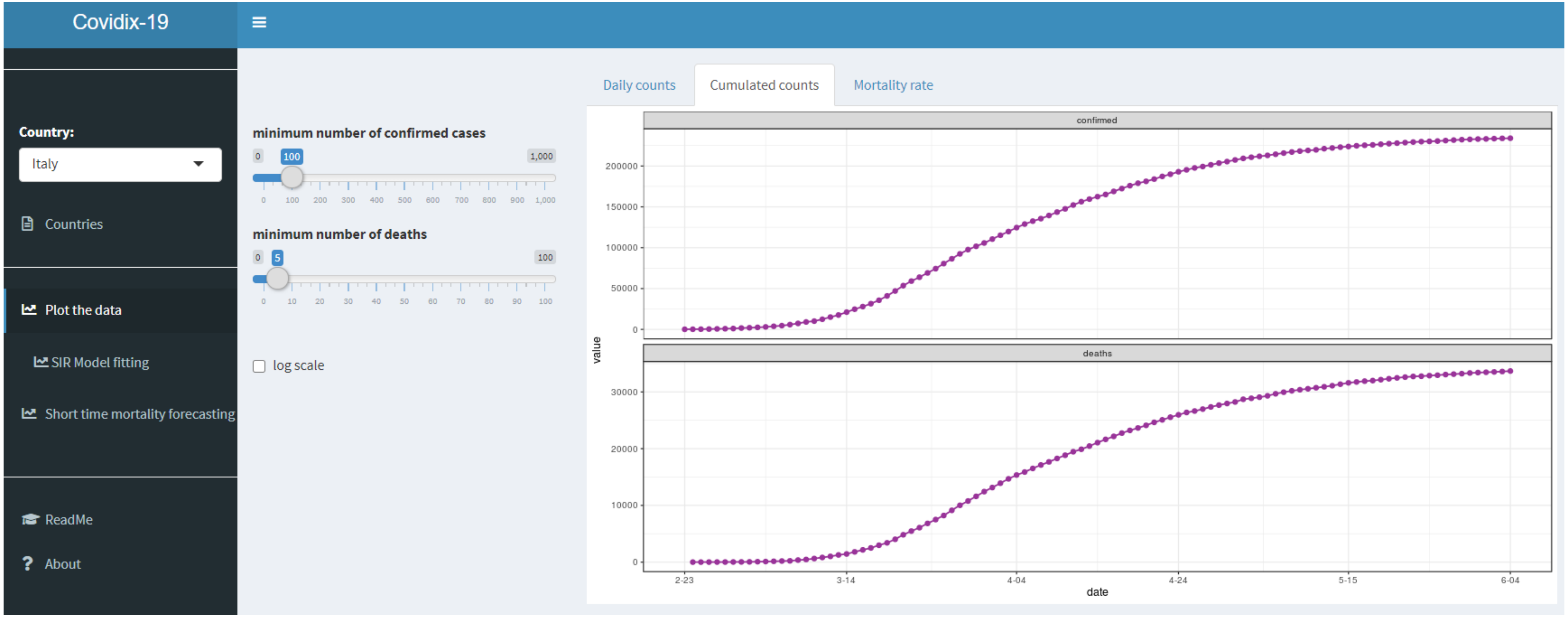
Available data:

- $w = (w_j\ , j = 1, 2, \ldots)$ where w_j is the cumulated number of confirmed cases

  Then, $w_j - w_{j-1}$ is the number of new confirmed cases on day j

- $d = (d_j\ , j = 1, 2, \ldots)$ where d_j is the cumulated number of deaths

  Then, $d_j - d_{j-1}$ is the number of new deaths on day j



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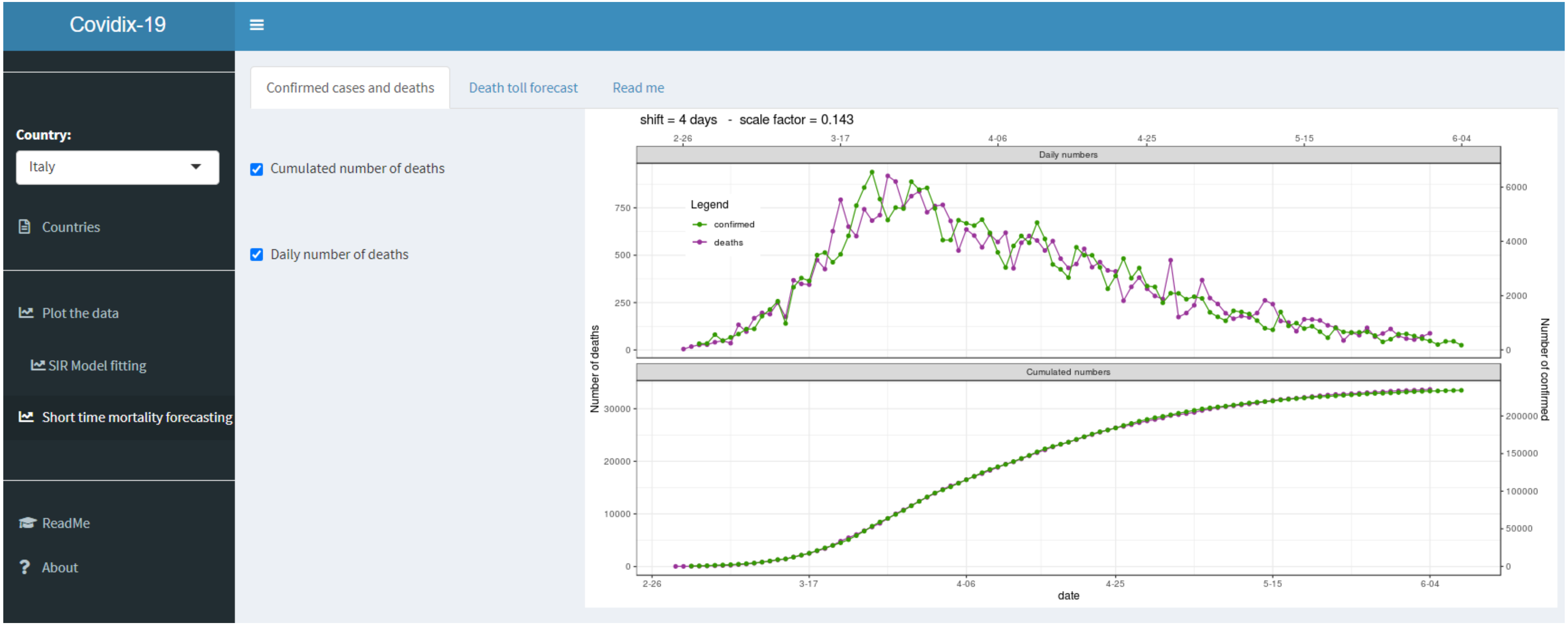

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The observation model

The data:

- cumulated number of *confirmed* cases (w_j)
- cumulated number of deaths (d_j)

The epidemiological model:

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The observation model

The data:

- cumulated number of *confirmed* cases (w_j)
  w_j predicted by $W_c(t_j)$
- cumulated number of deaths (d_j)
  d_j predicted by $D(t_j)$

The epidemiological model:

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The observation model

A first statistical model for the daily counts:

$$w_j - w_{j-1} = W(t_j) - W(t_{j-1}) + e_j \quad ; \quad e_j \sim \mathcal{N}(0, \sigma_e^2)$$

$$d_j - d_{j-1} = D(t_j) - D(t_{j-1}) + u_j \quad ; \quad u_j \sim \mathcal{N}(0, \sigma_u^2)$$

Parameters of the model:

$$\theta = (\alpha, \beta_0, a, h_1, \ldots, h_K, \tau_1, \ldots, \tau_K, \mu, \nu, \lambda, I_0, H_0, D_0, \sigma_e^2, \sigma_u^2)$$

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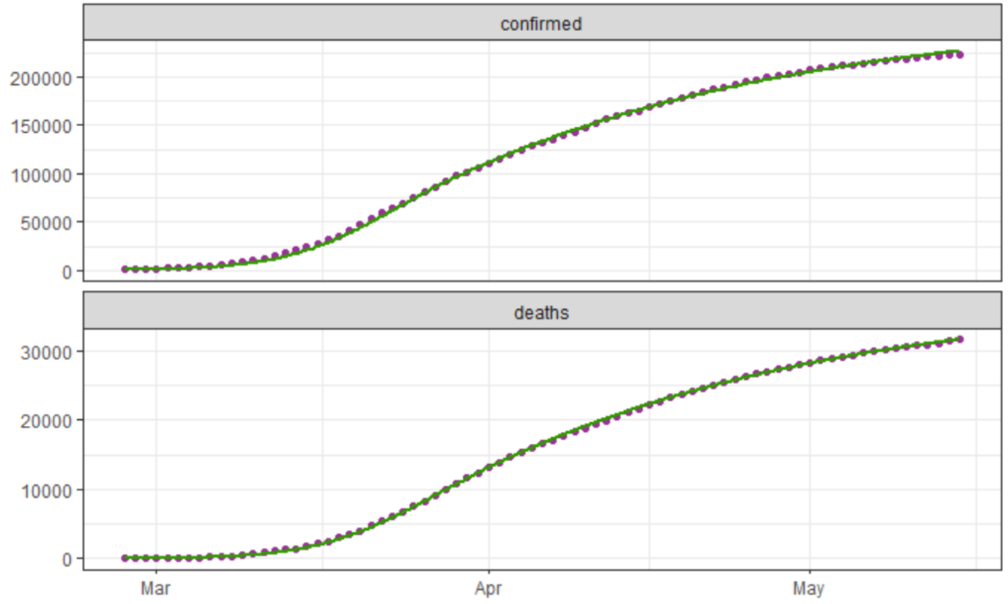
θ obtained by Maximum Likelihood (ML) Estimation

K obtained by minimizing the Bayesian Information Criteria (BIC)

Fitting the Italian data

Cumulated numbers



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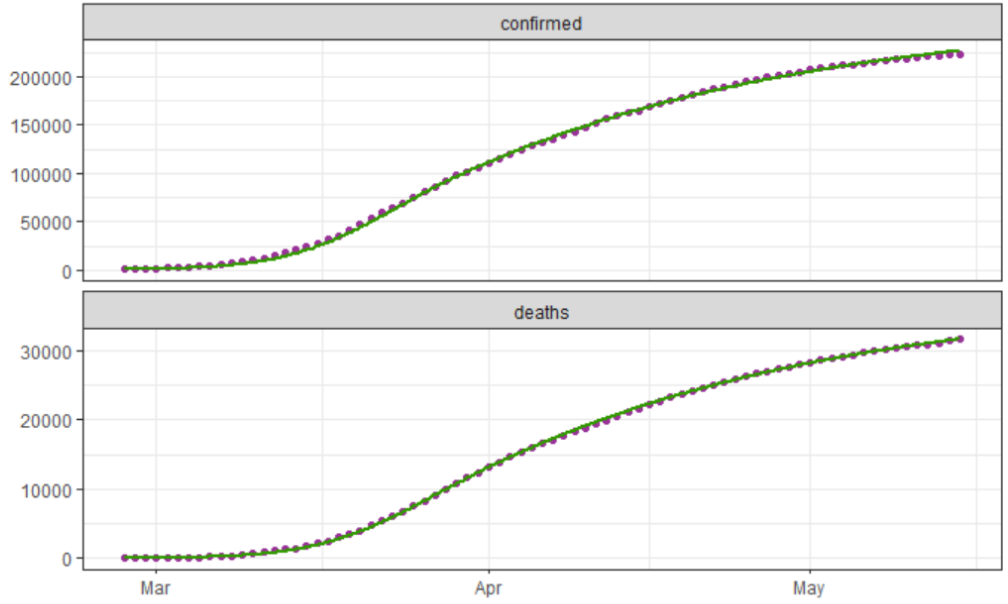
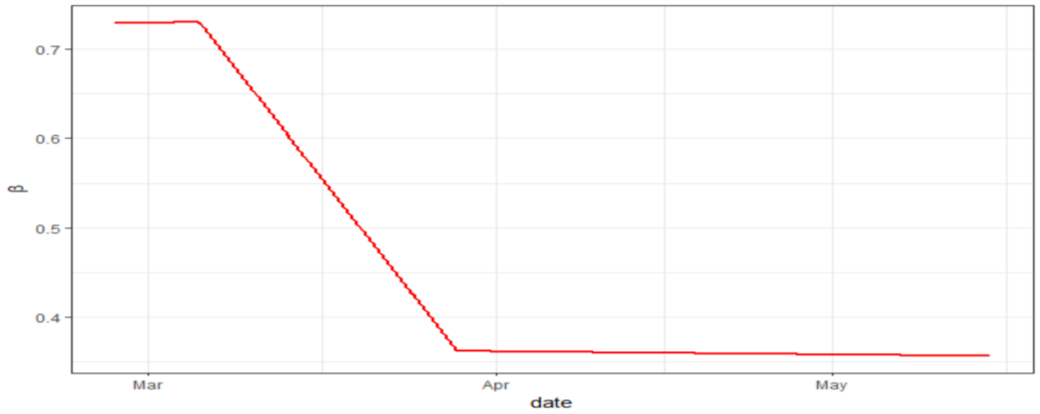


Transmission rate



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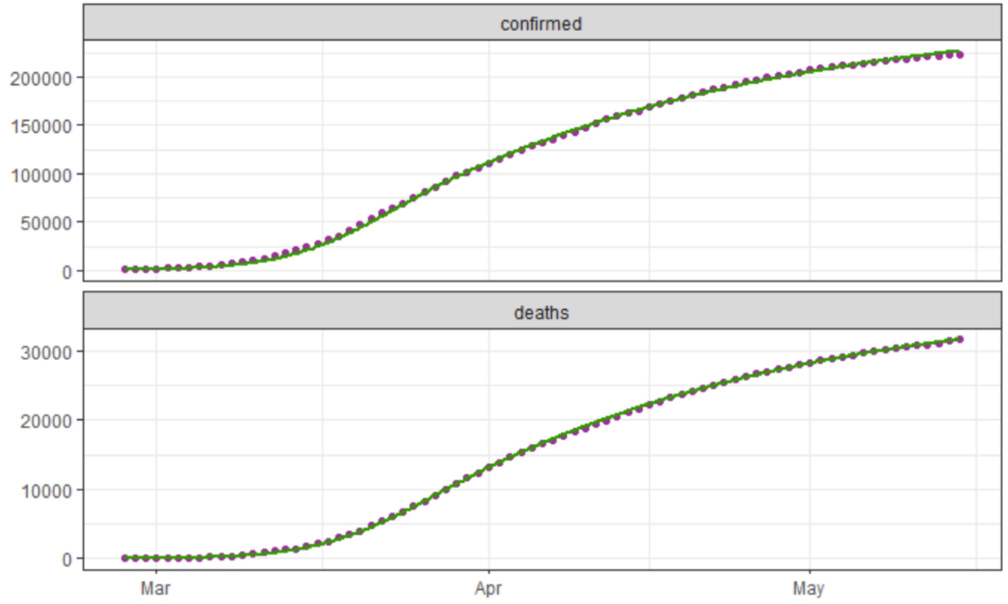
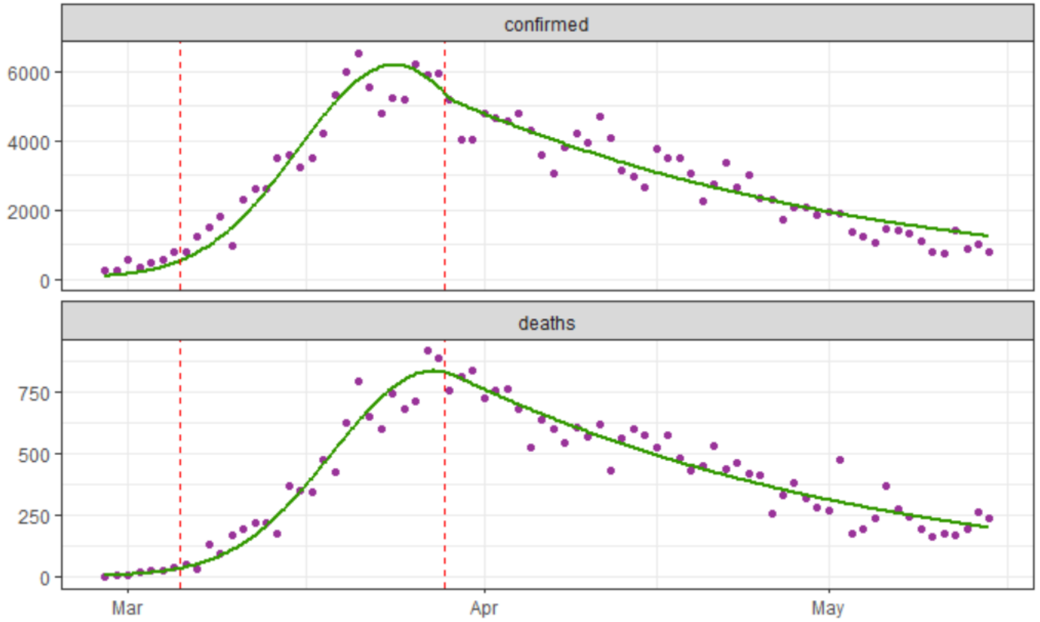


Daily numbers



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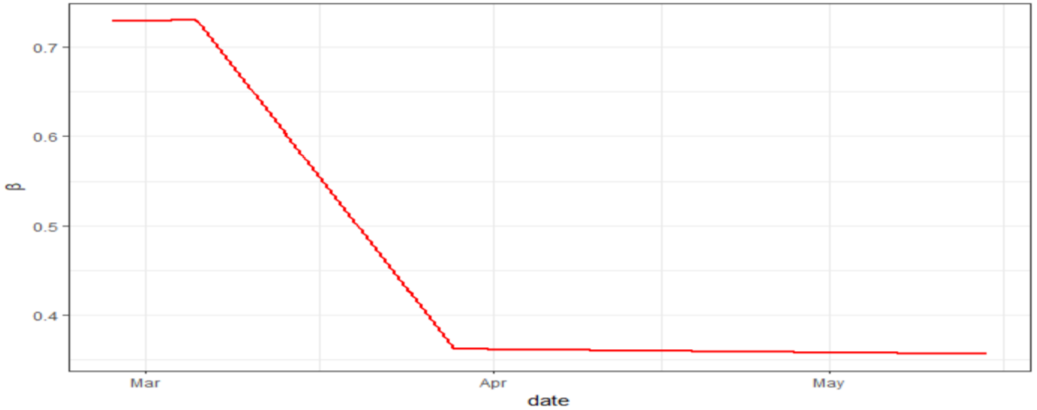
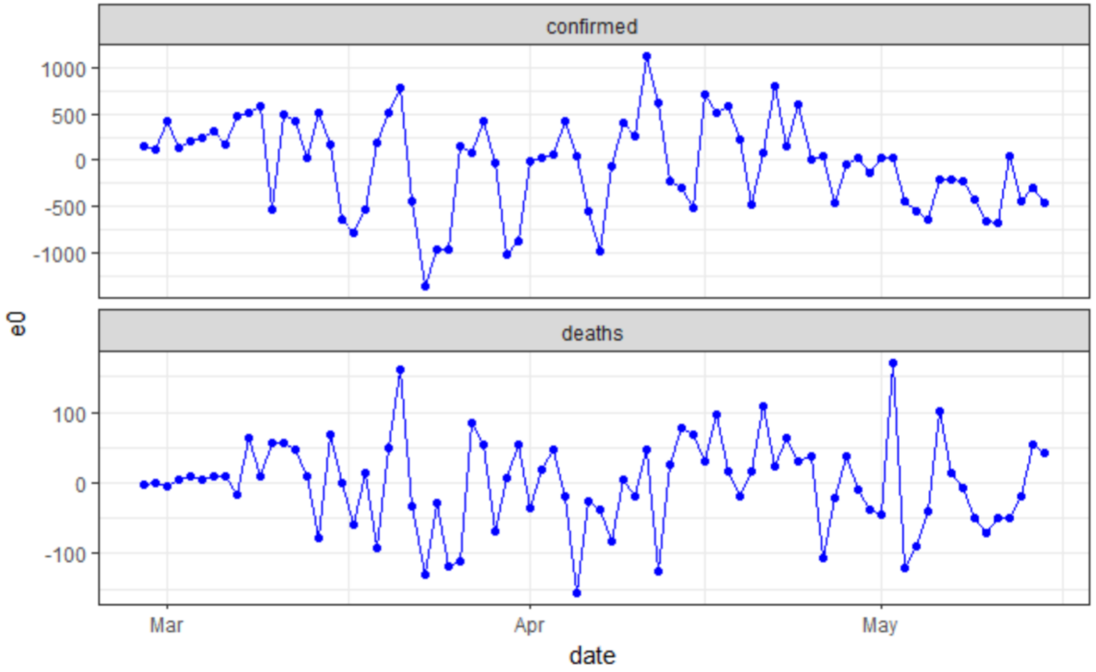


Fitting the Italian data

The residuals (daily numbers)



Fitting the Italian data

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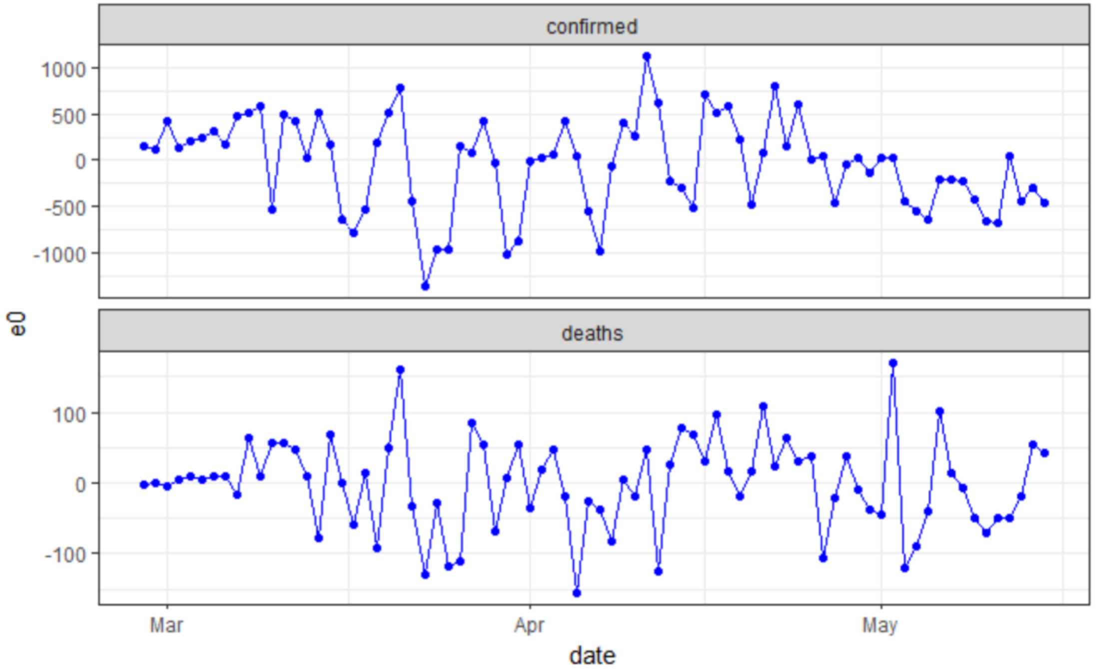

The residuals errors exhibit a weekly periodic component:
the observation model should include this periodic component.

Fitting the Italian data

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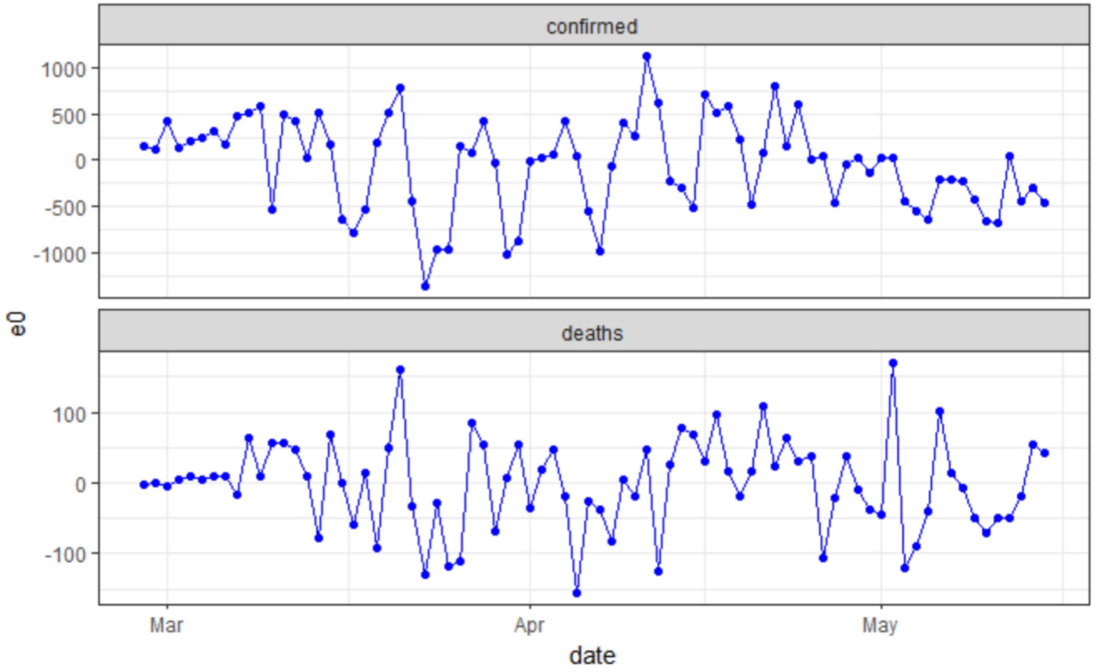
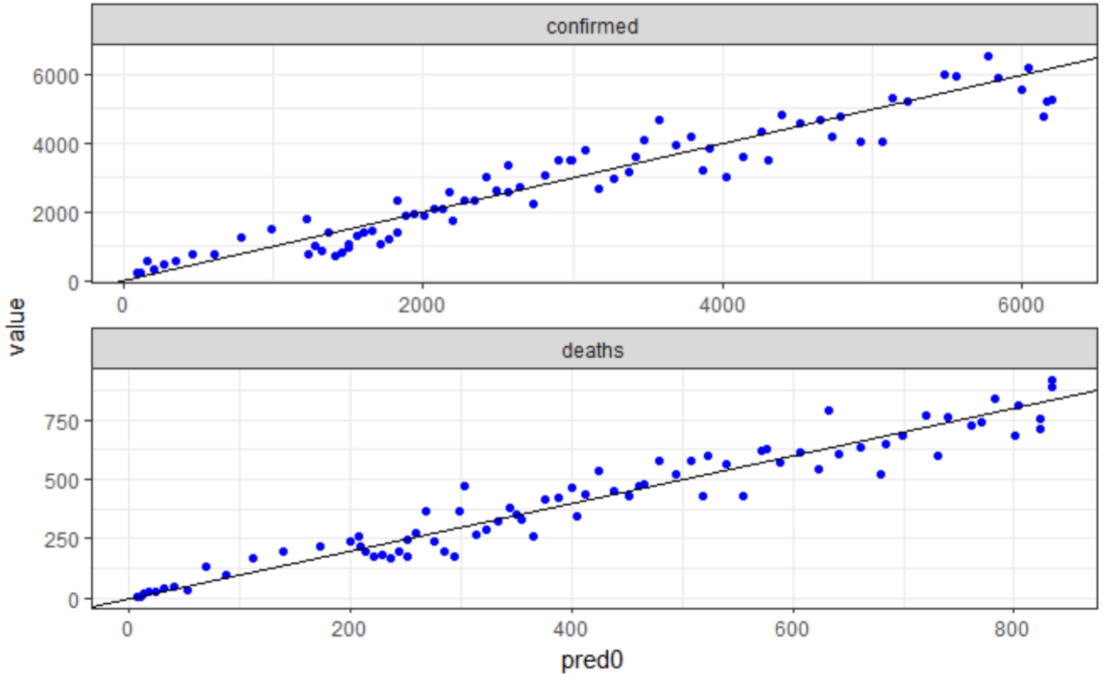


Observations vs predictions (daily numbers)



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Fitting the Italian data

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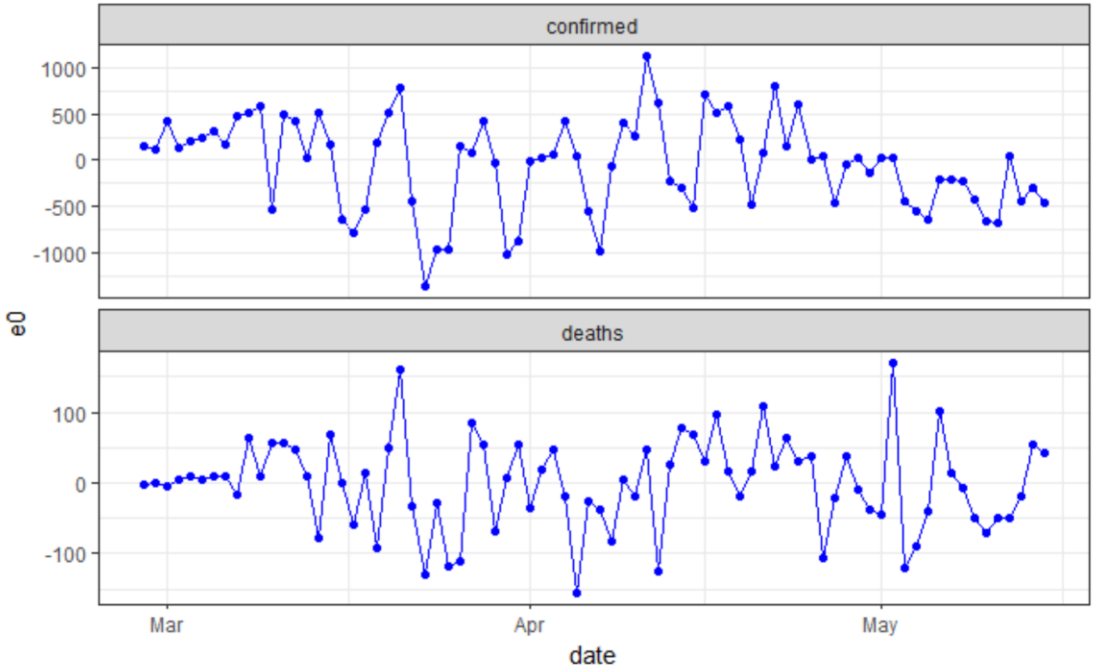

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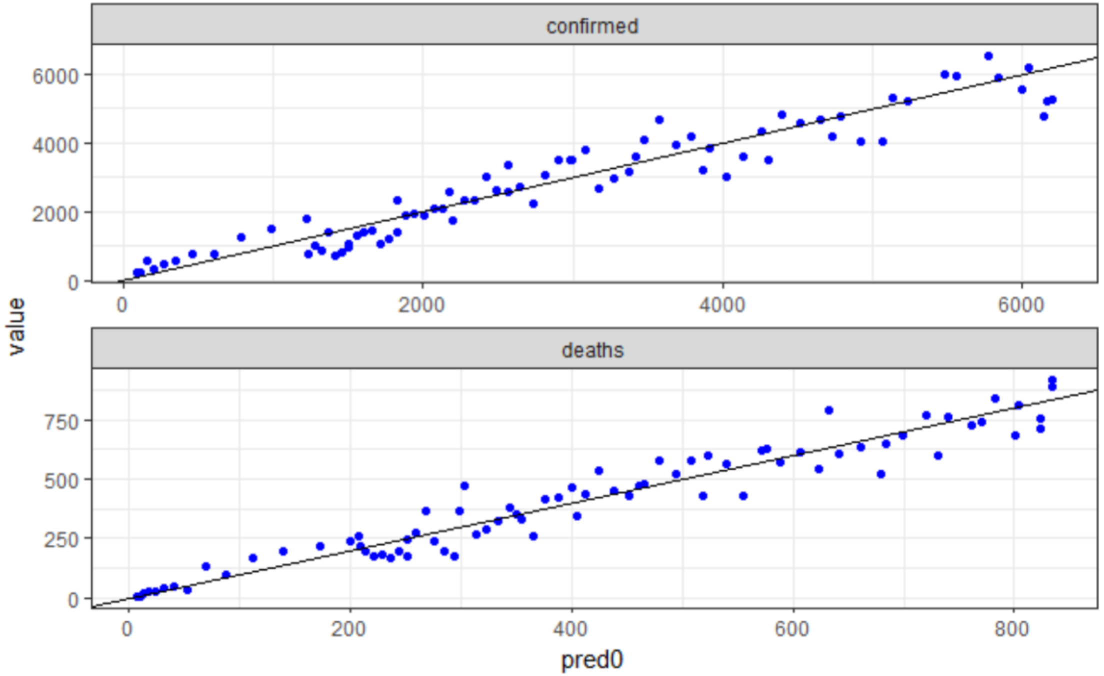

The residuals errors exhibit a weekly periodic component:
the observation model should include this periodic component.

The magnitude of the errors increase with the prediction:
the observation model should include a proportional error model

The observation model

A second statistical model for the daily counts:

$$w_j - w_{j-1} = (W(t_j) - W(t_{j-1}))\left(1 + A\cos(\frac{2\pi}{7}t_j + \phi)\right)(1 + e_j)$$

$$e_j \sim \mathcal{N}(0, \sigma_e^2)$$

$$d_j - d_{j-1} = (D(t_j) - D(t_{j-1}))\left(1 + B\cos(\frac{2\pi}{7}t_j + \phi)\right)(1 + u_j)$$

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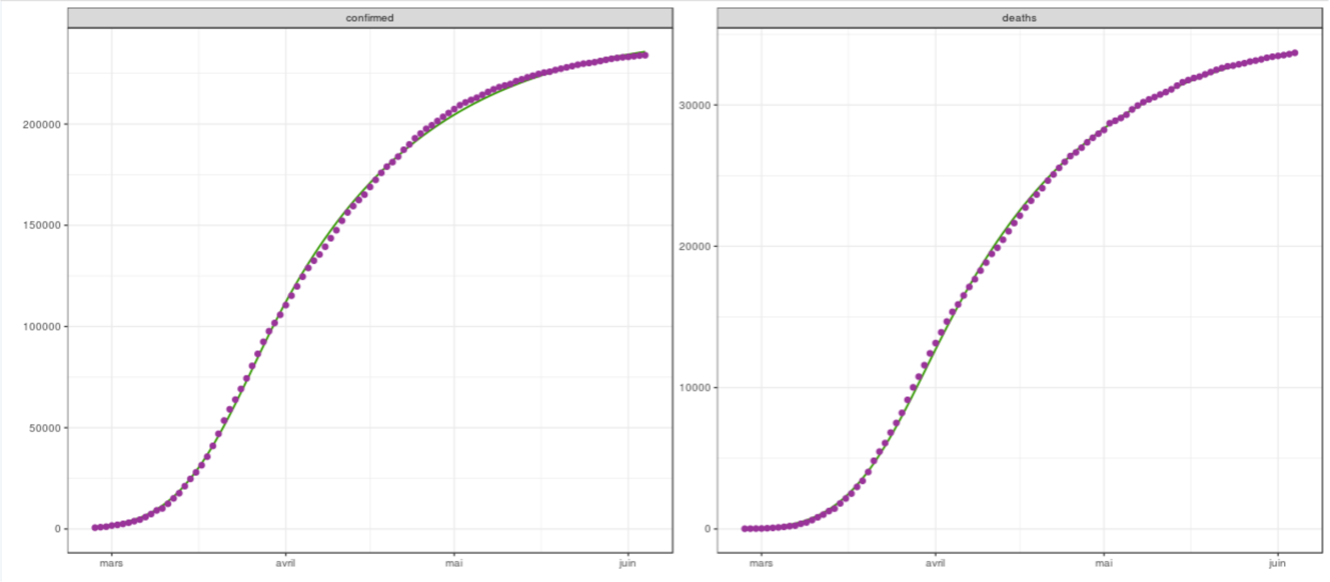

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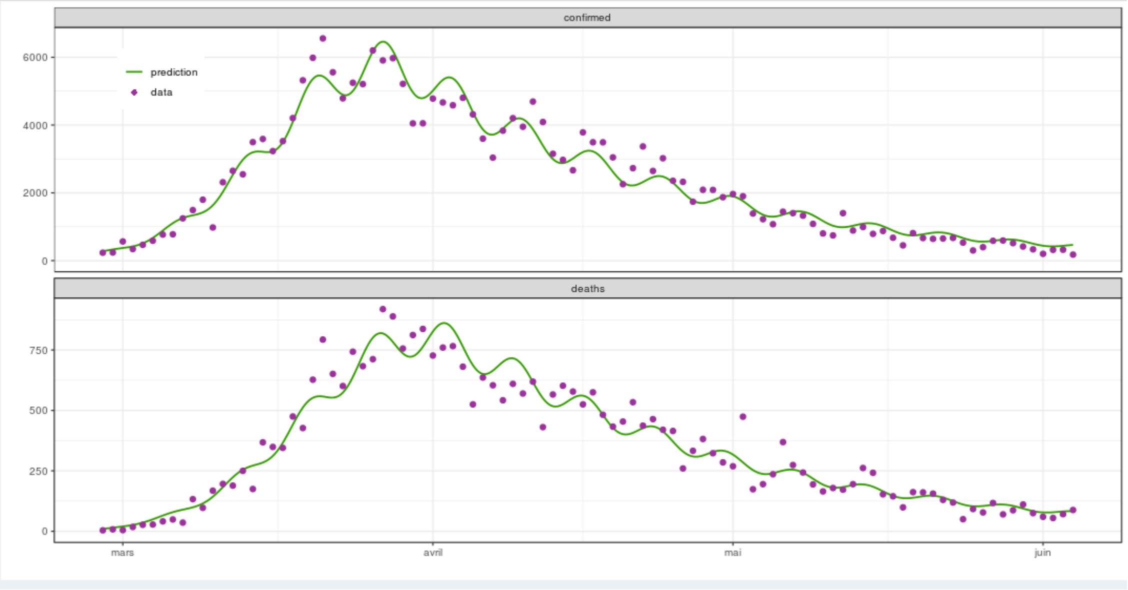
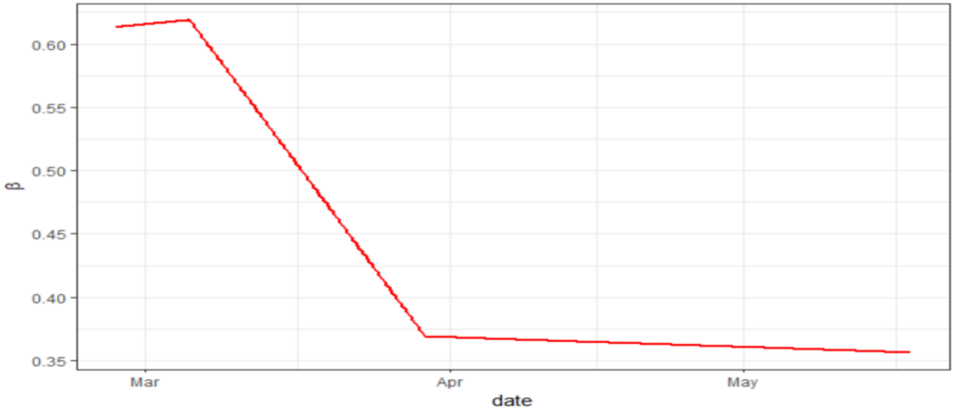
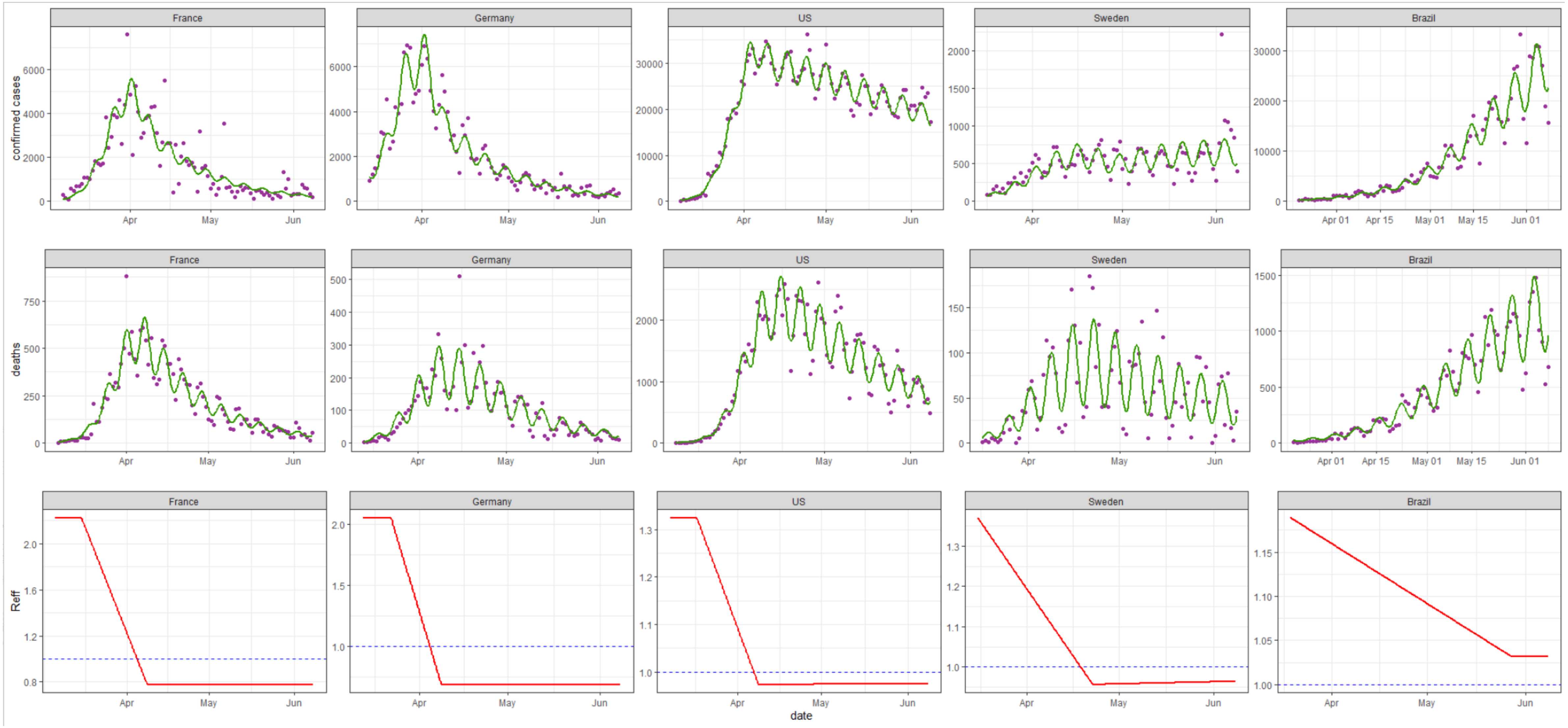
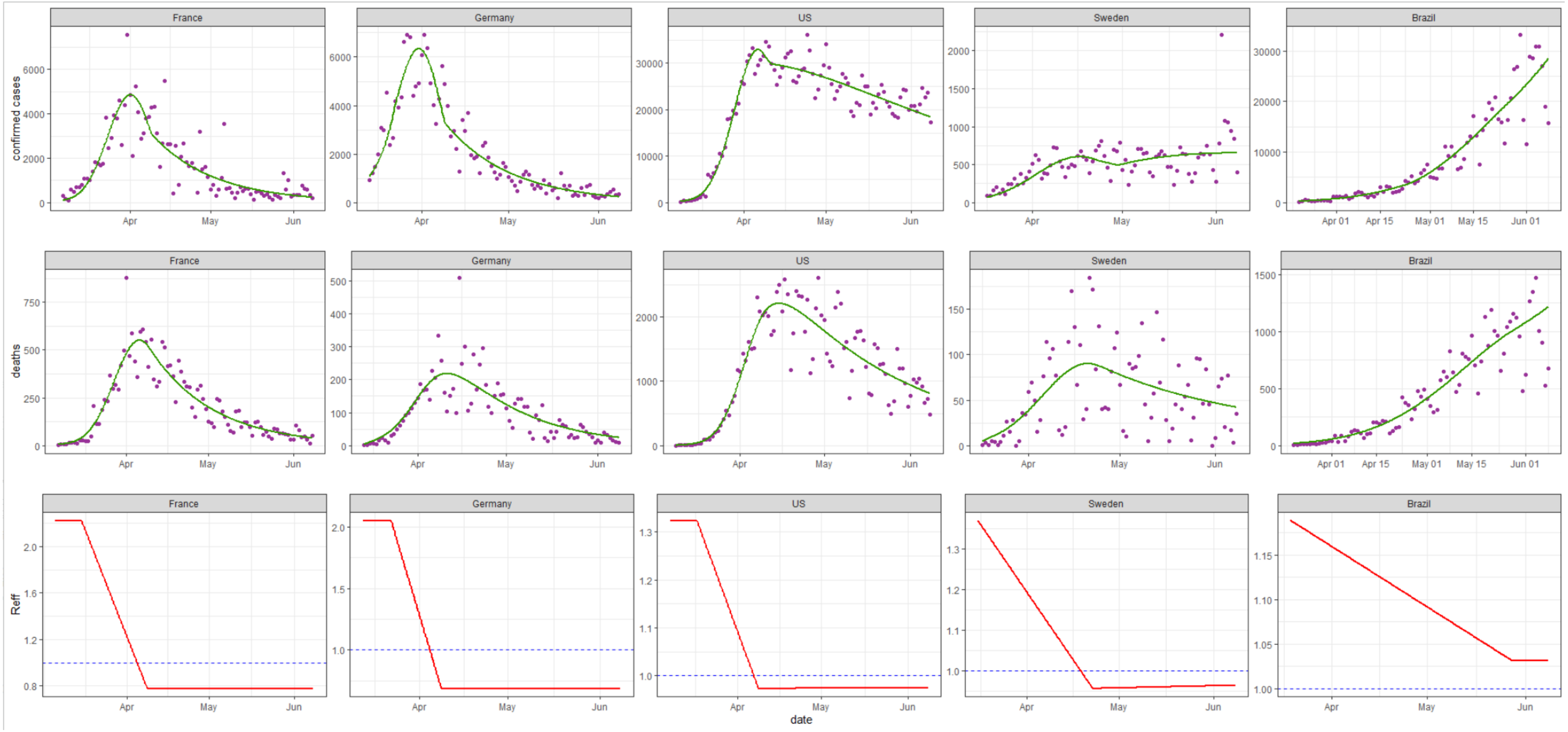


Transmission rate





Some fits with the periodic component



Some fits without the periodic component

About the basic reproduction number

$$\dot{I}(t) = \beta(t)I(t) - \mu I(t) - \nu I(t)$$

$$R_0 = \frac{\beta(t)}{\mu + \nu}$$

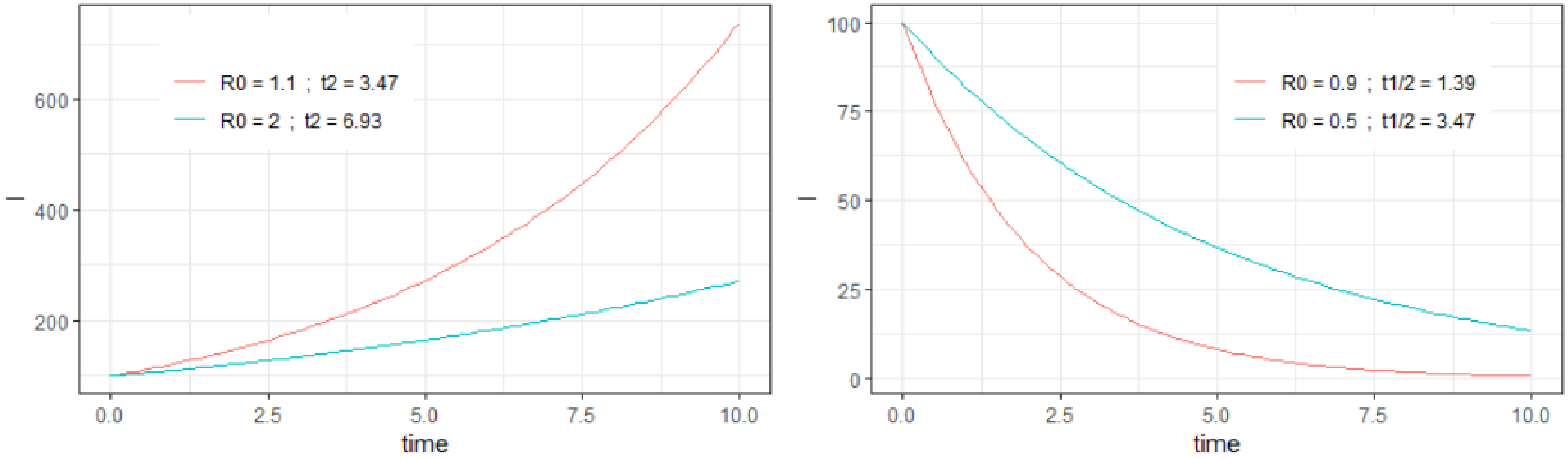
- Not so easy to understand (at least for me)
- Seems to depend on the model (and not only on the parameter values)

The difference $\beta(t) - \mu + \nu$

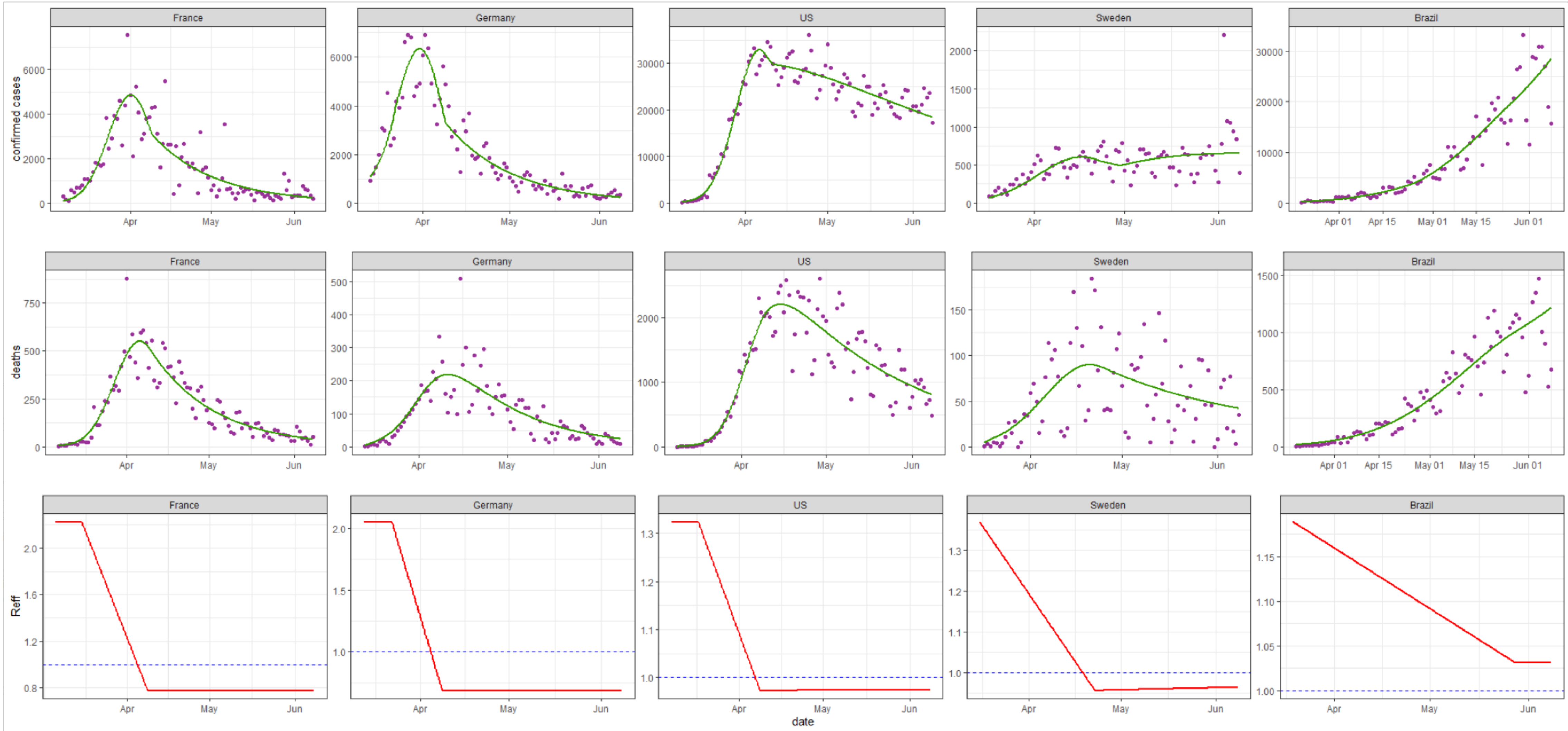
- (maybe) more informative than the ratio $\beta(t)/(\mu + \nu)$
- easy to interpret, as related to the "half-life"

$$t_2 = \log(2)/(\beta - \mu + \nu)$$

$$t_{1/2} = -\log(2)/(\beta - \mu + \nu)$$



R0 = 1.1 ; t2 = 3.47
R0 = 2 ; t2 = 6.93
I
600
400
200
0.0
2.5
5.0
7.5
10.0
time
100
75
50
25
0
R0 = 0.9 ; t1/2 = 1.39
R0 = 0.5 ; t1/2 = 3.47
I
0.0
2.5
5.0
7.5
10.0
time



t2	2.9	4.7	2.6	4.4	6.9
t1/2	16.1	15.7	31.4	44.1	-

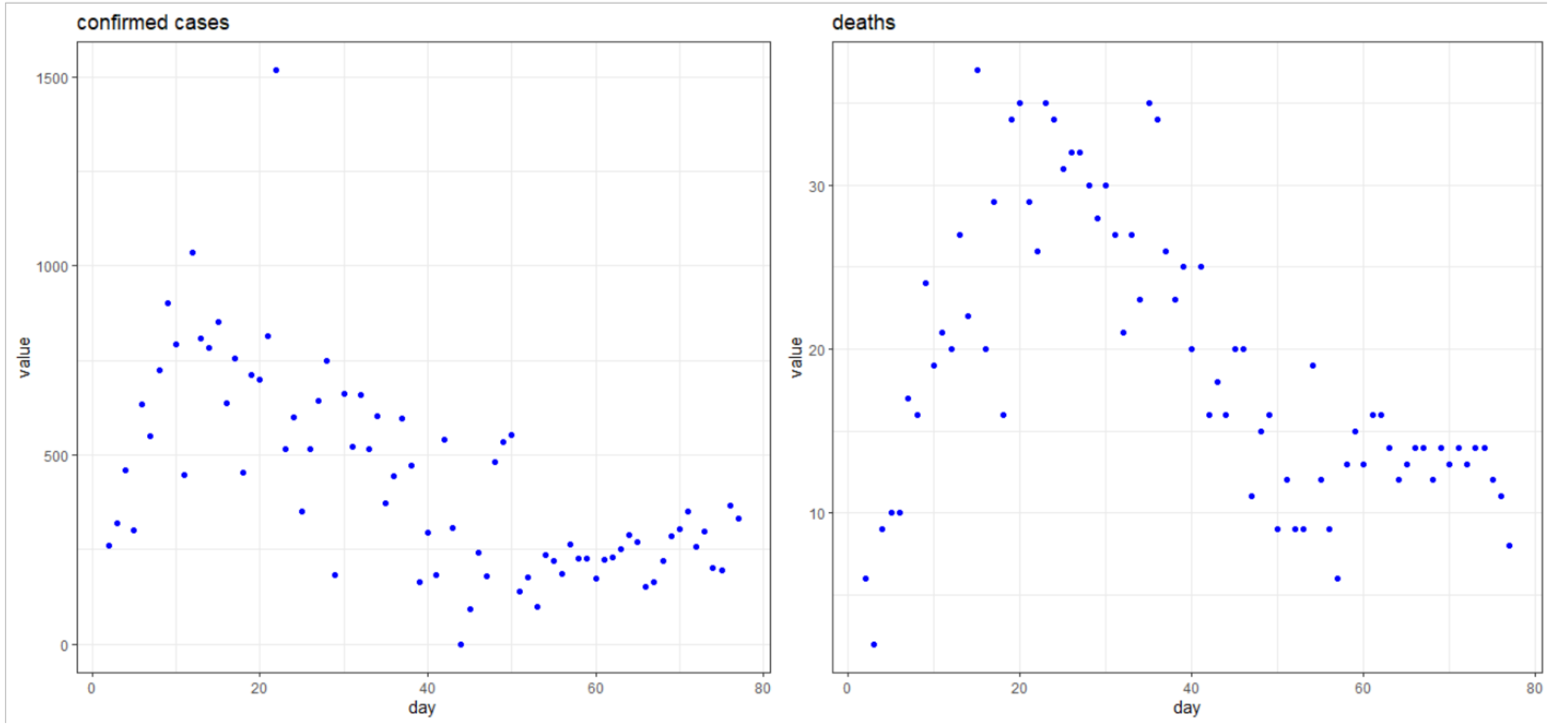
	Increase		Peak of daily deaths		Decrease	
Country	t4 (↑)	t2 (↑)	Date	n	t1/2 (↓)	t1/4 (↓)
Denmark	12	8	4/3/2020	16	25	50
Portugal	19	15	4/11/2020	32	24	41
Switzerland	16	11	4/5/2020	58	19	29
Netherlands	13	10	4/4/2020	155	28	46
Germany	19	14	4/13/2020	226	22	37
Belgium	21	15	4/15/2020	268	17	27
France	15	11	4/5/2020	532	20	34
Italy	15	10	3/27/2020	835	25	47
Spain	16	12	4/3/2020	839	17	33
United Kingdom	19	13	4/13/2020	927	27	50

Maximum daily number of deaths predicted by the model. For each country, t4 (↑) and t2 (↑) are, respectively, the number of days it took to multiply the number of deaths by 4 and 2 ; t1/2 (↓) and t1/4 (↓) are, respectively, the number of days it took to divide the number of deaths by 2 and 4.

A monitoring tool

This tool can be useful for detecting unexpected changes in the dynamics of the epidemics.

Portuguese data:



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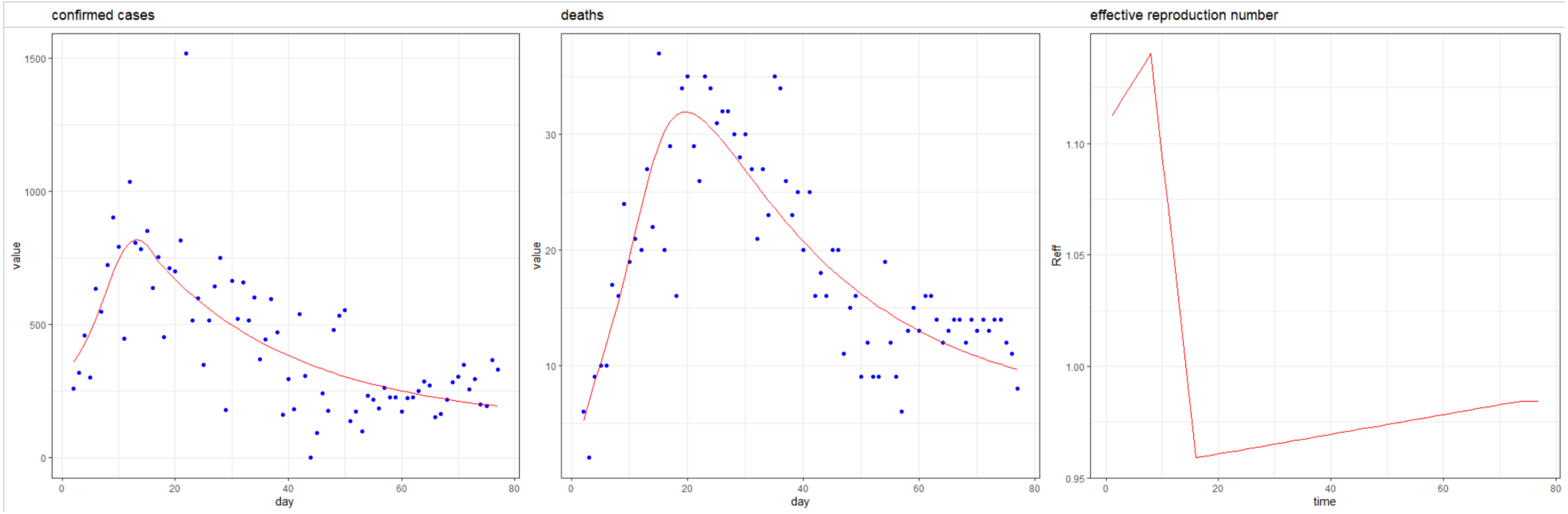

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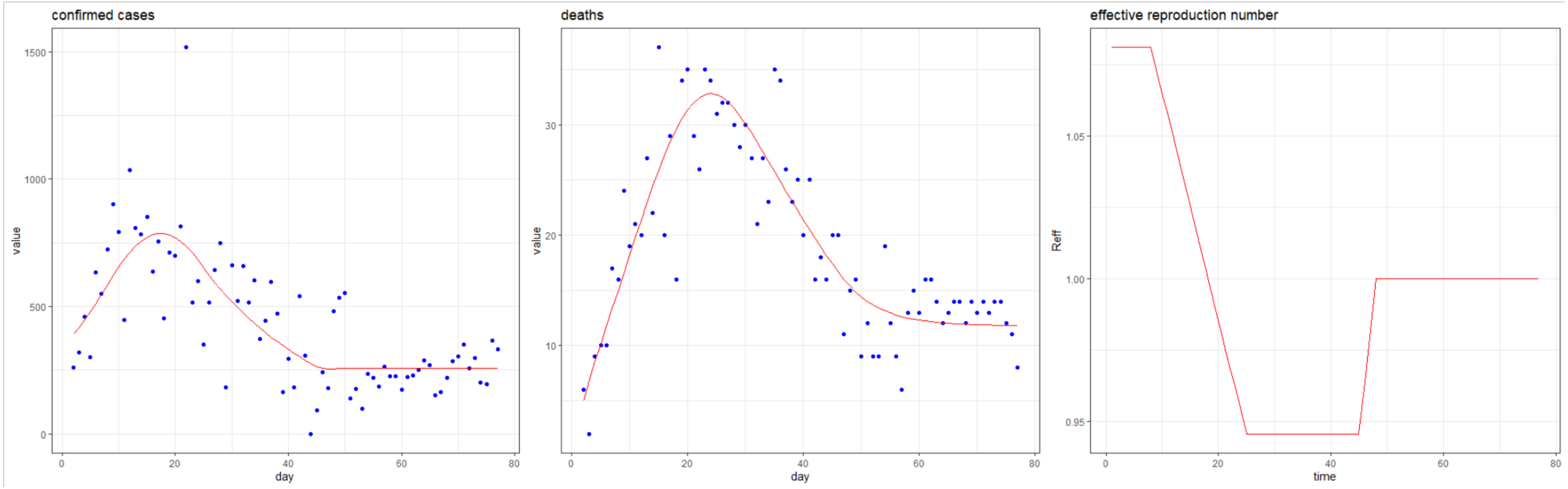

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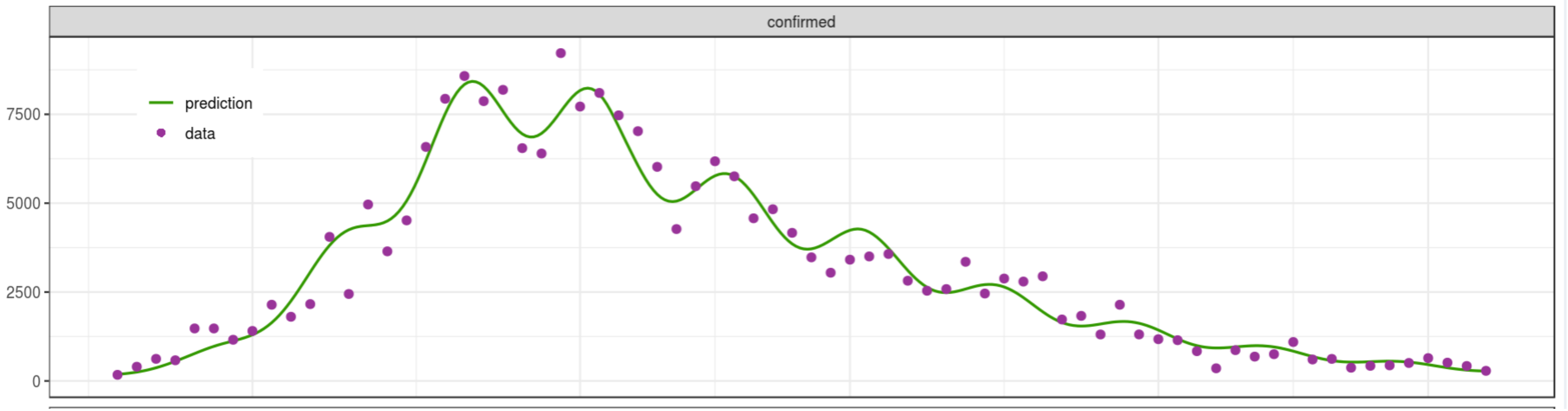
Spanish data:



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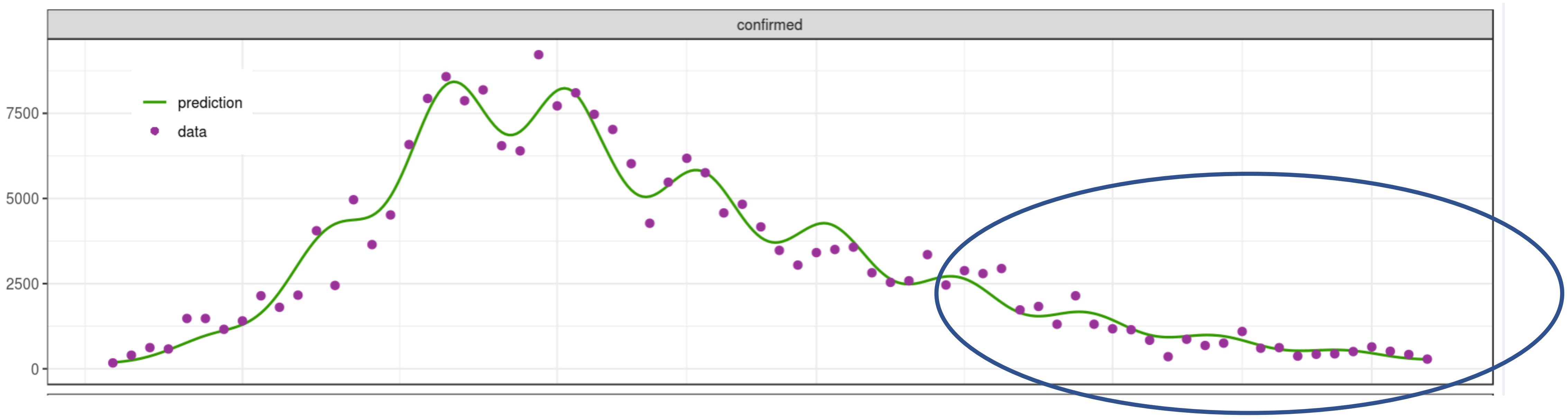

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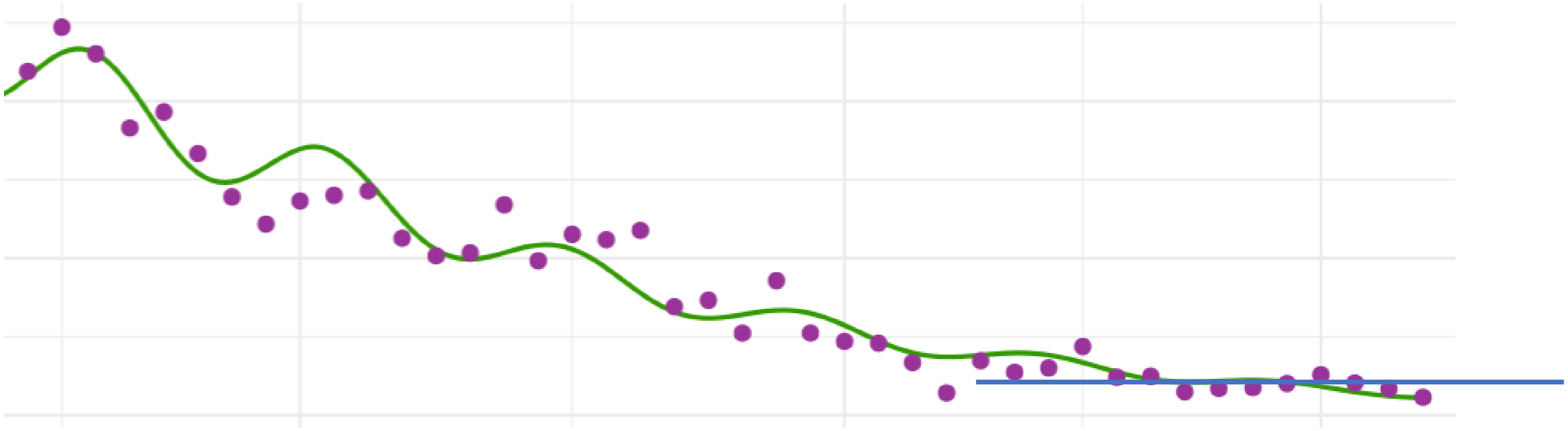

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Actualité › Fiches › Guide Vie quotidienne › Coronavirus

Coronavirus dans le monde : hausse inquiétante des décès aux USA, les chiffres

La Rédaction, Mis à jour le 11/06/20 17:35

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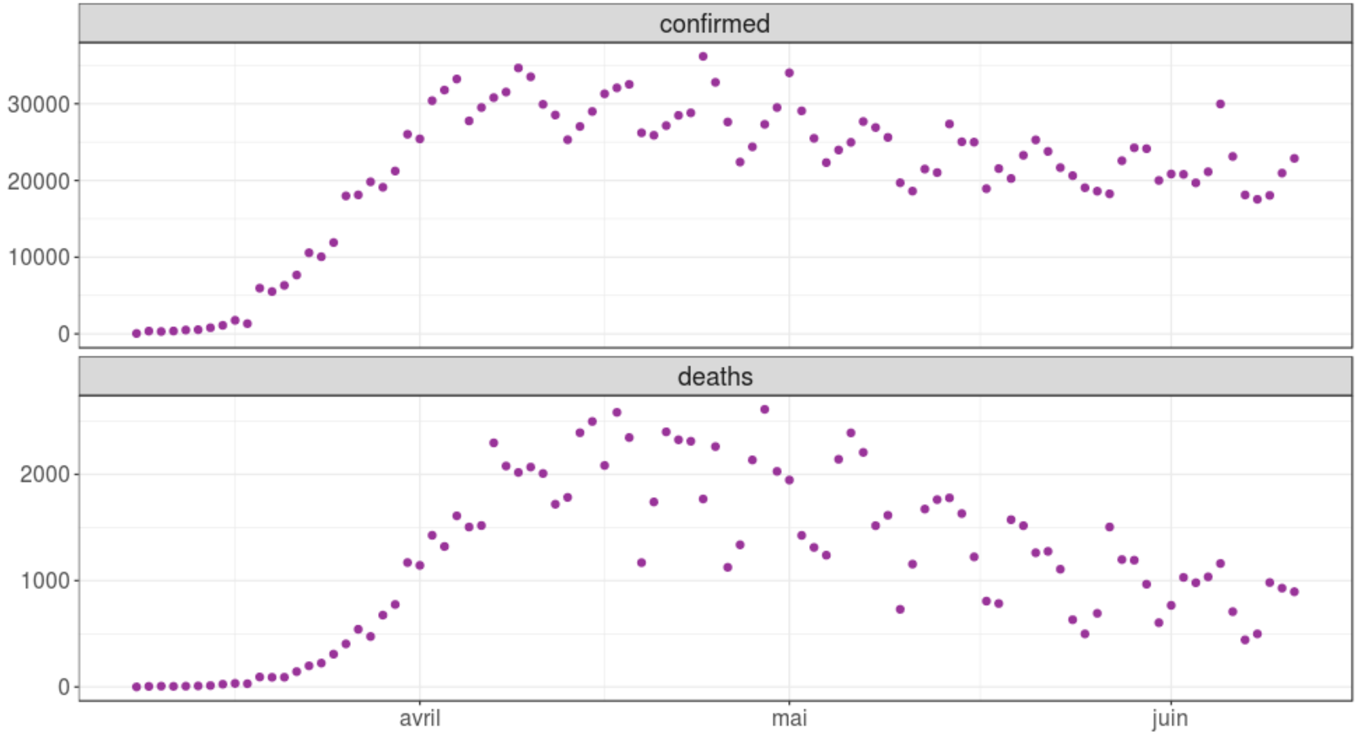
CORONAVIRUS. Le nombre de contaminations et de morts liés au Covid-19 semble repartir à la hausse aux Etats-Unis, selon le dernier bilan en date. De nombreux autres pays craignent ou constatent une résurgence du nombre de cas. Le point sur la pandémie dans le monde.



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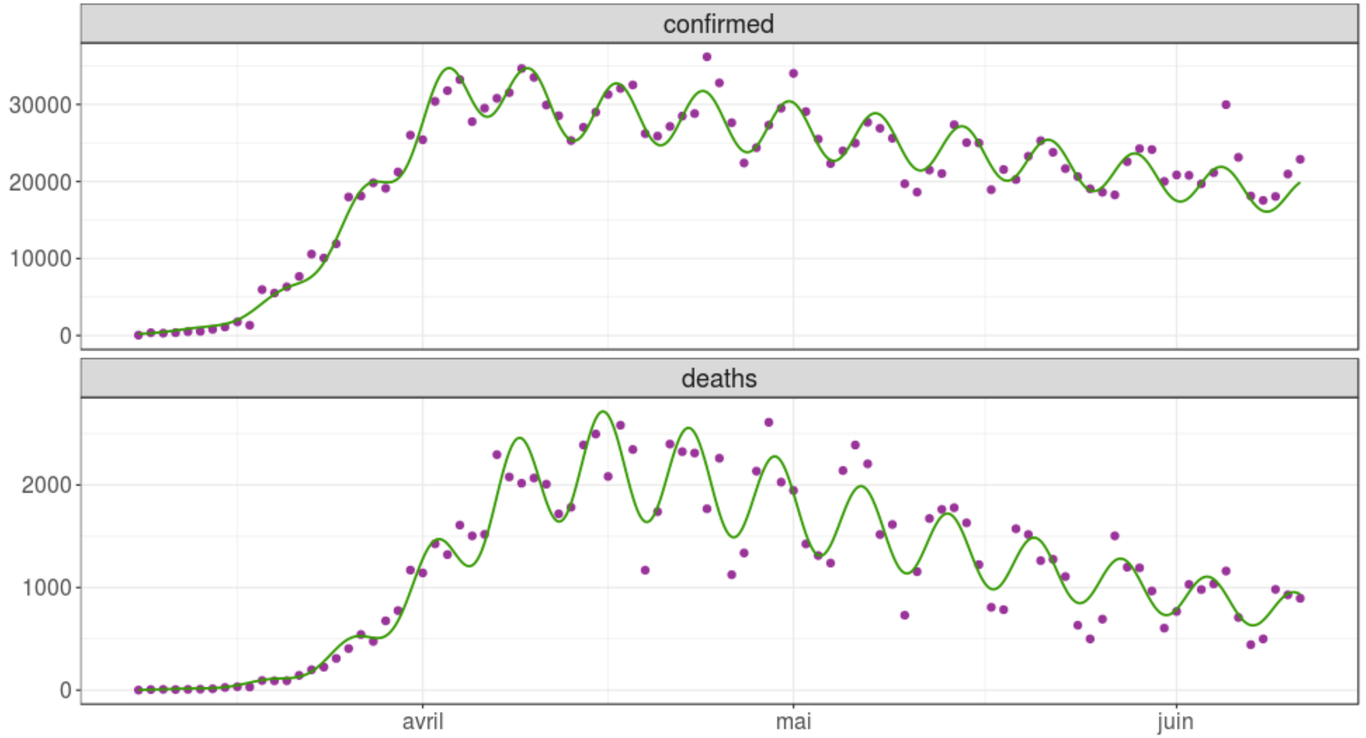

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HOME BREAKING NEWS BUSINESS SPORTS HEALTH MIX

Home › Breaking News › Notable rebound in Germany of new cases and deaths from coronavirus

Breaking News

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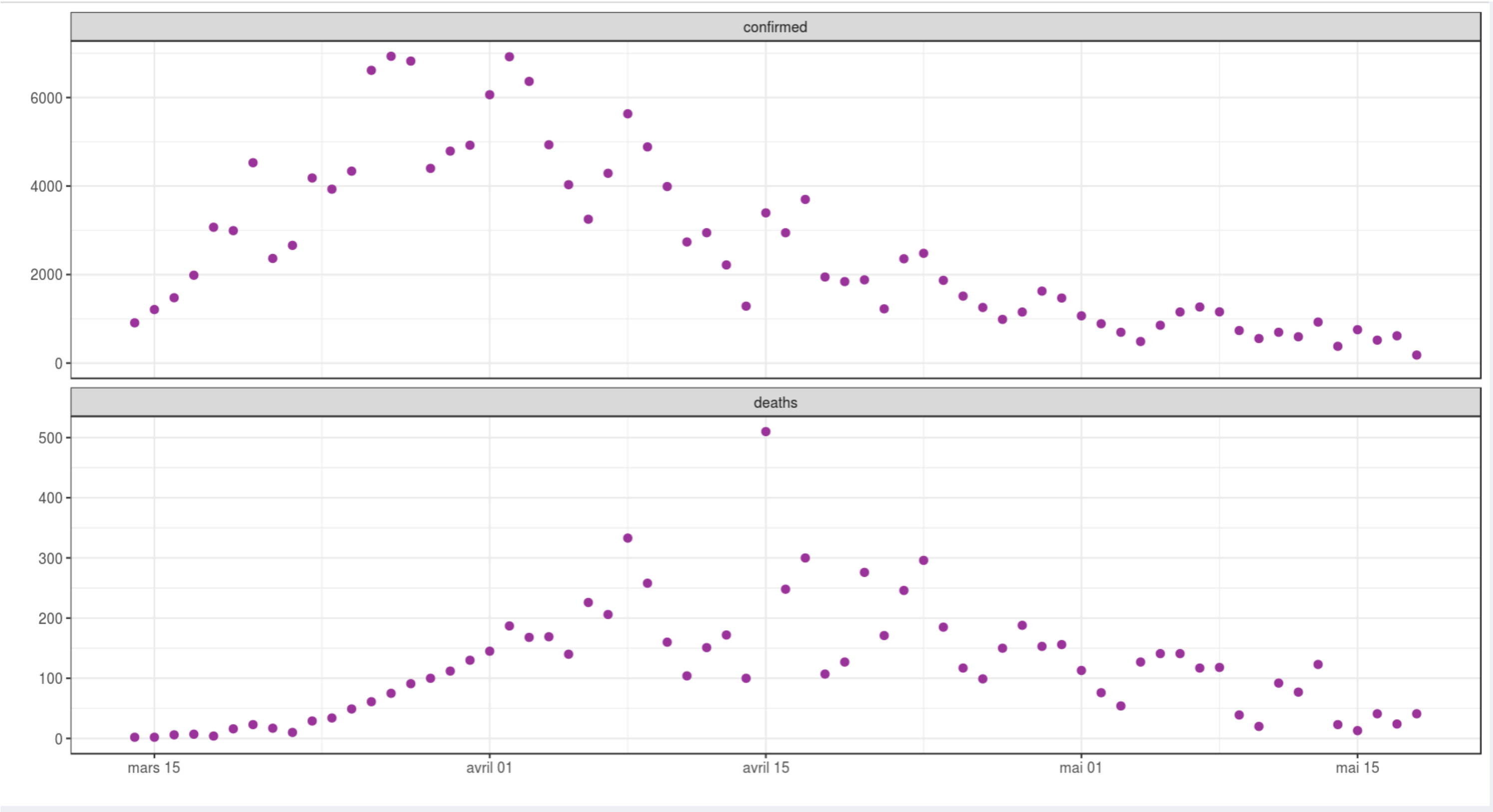
May 12, 2020



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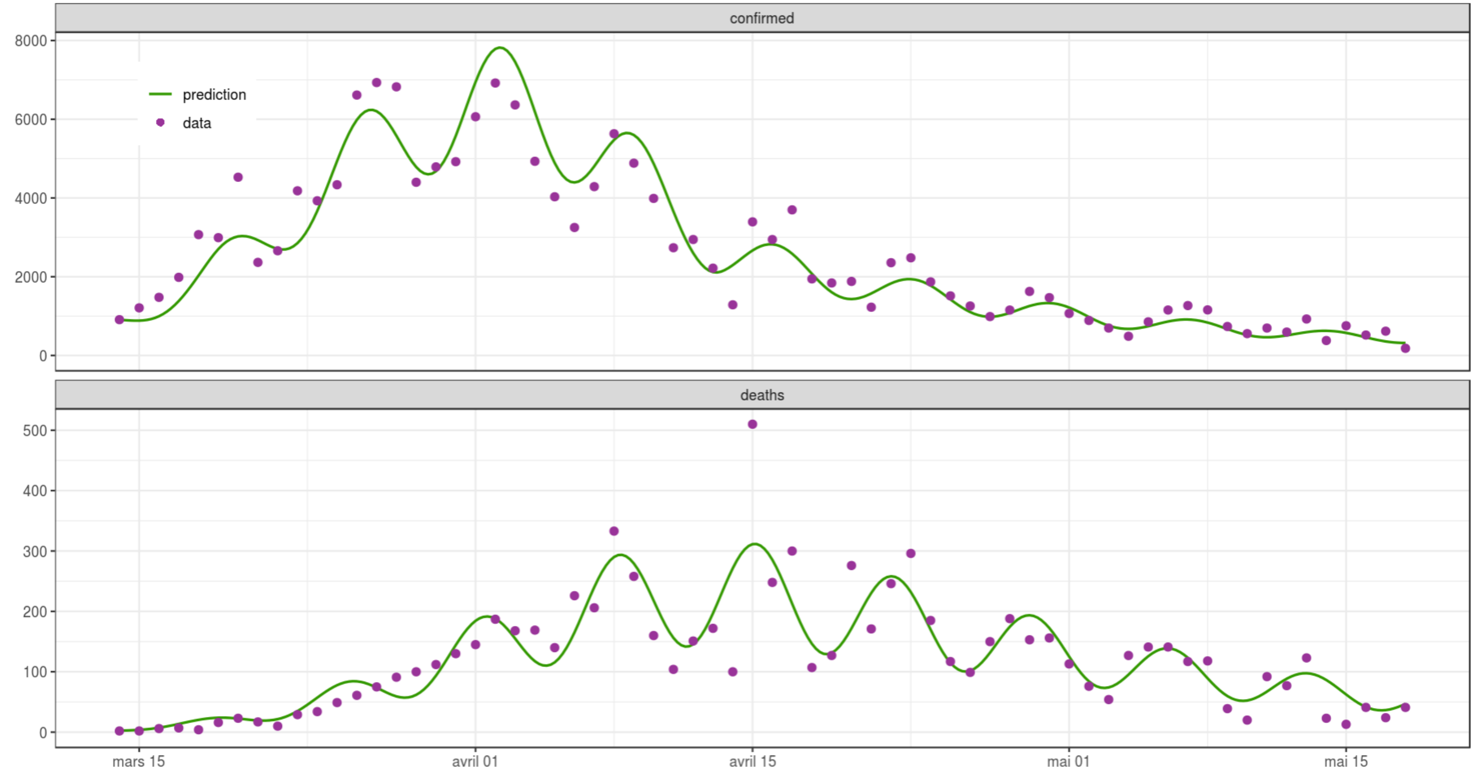
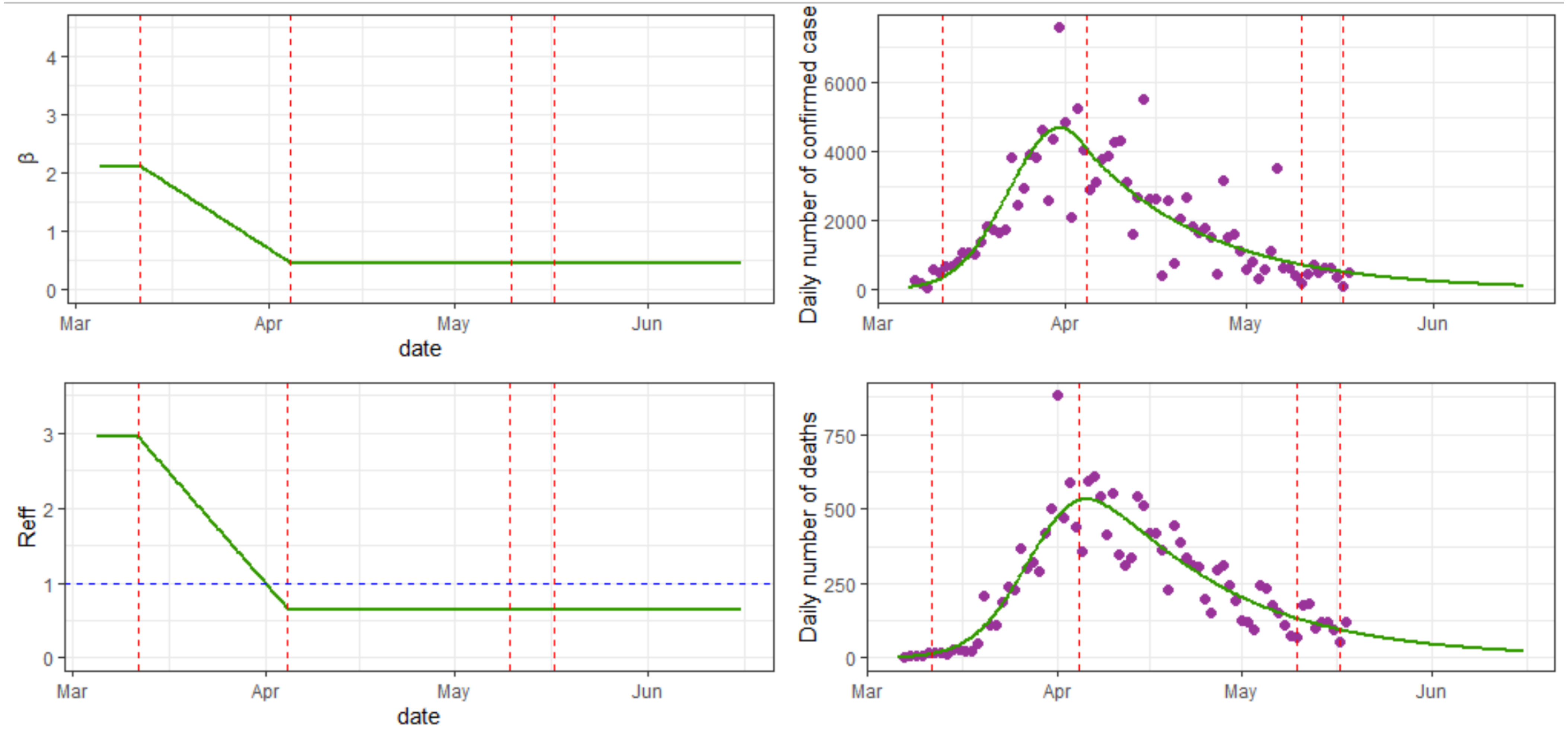


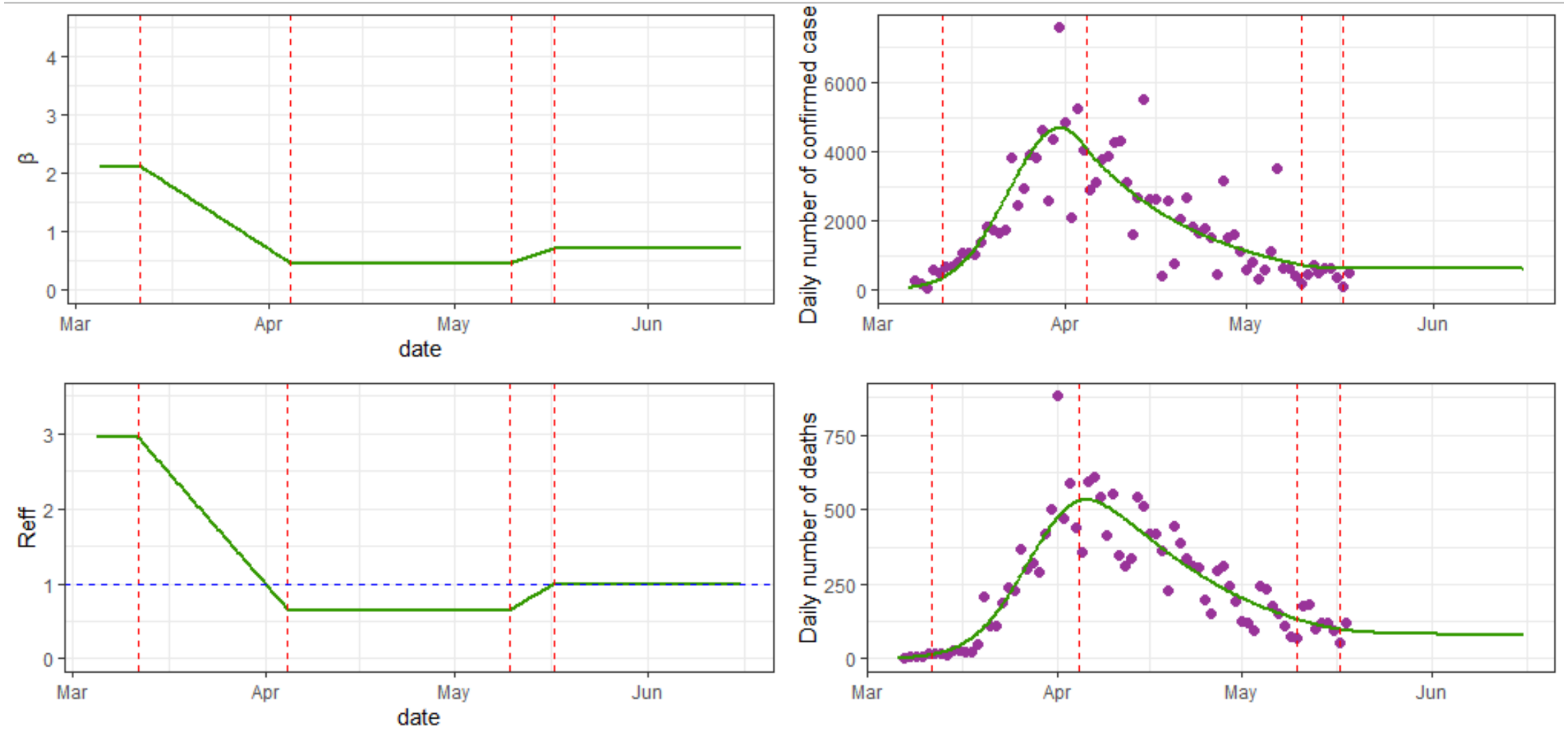
Possible scenarios after the end of the lockdown

1) The transmission rate remains the same



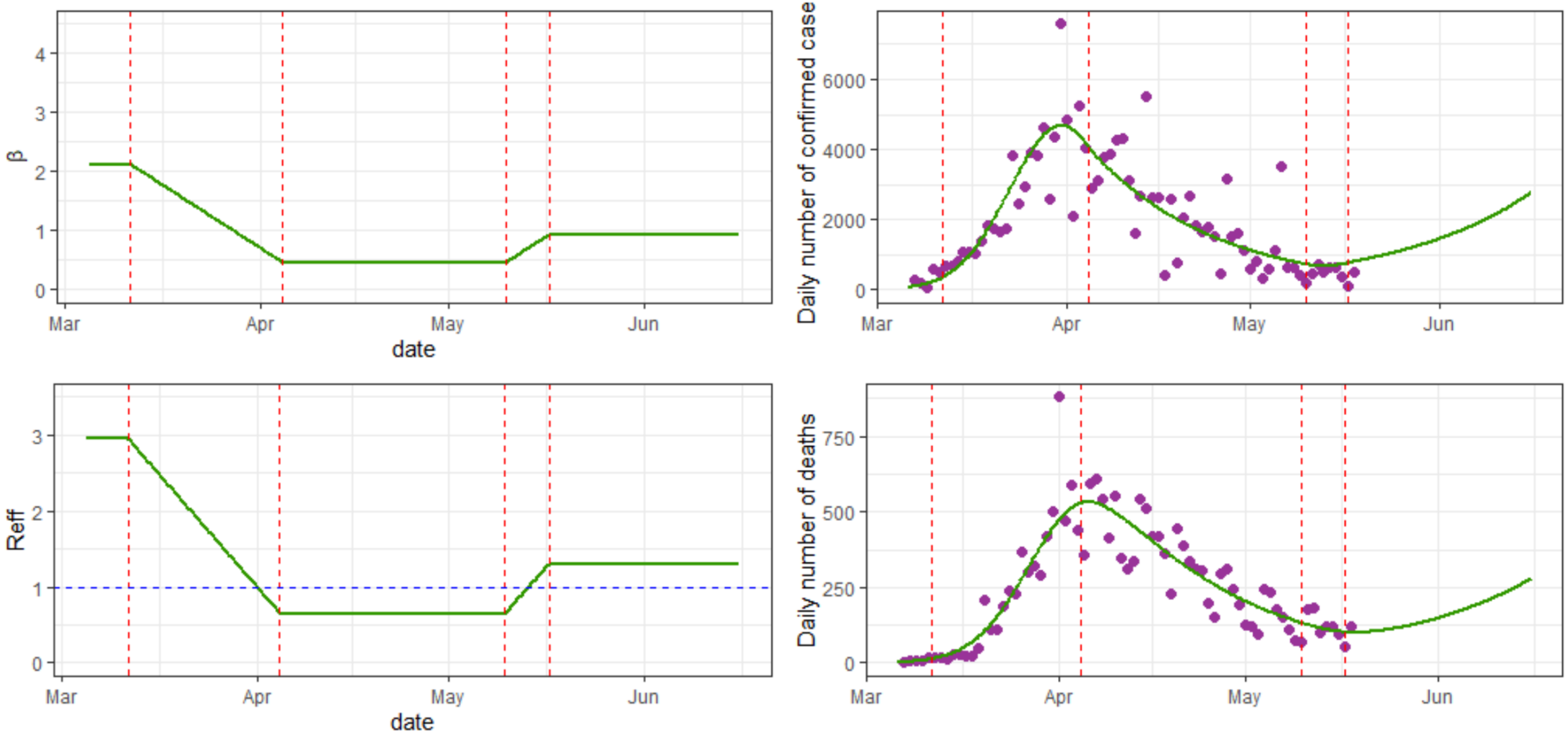
Possible scenarios after the end of the lockdown

2) The transmission rate is multiplied by 1.5



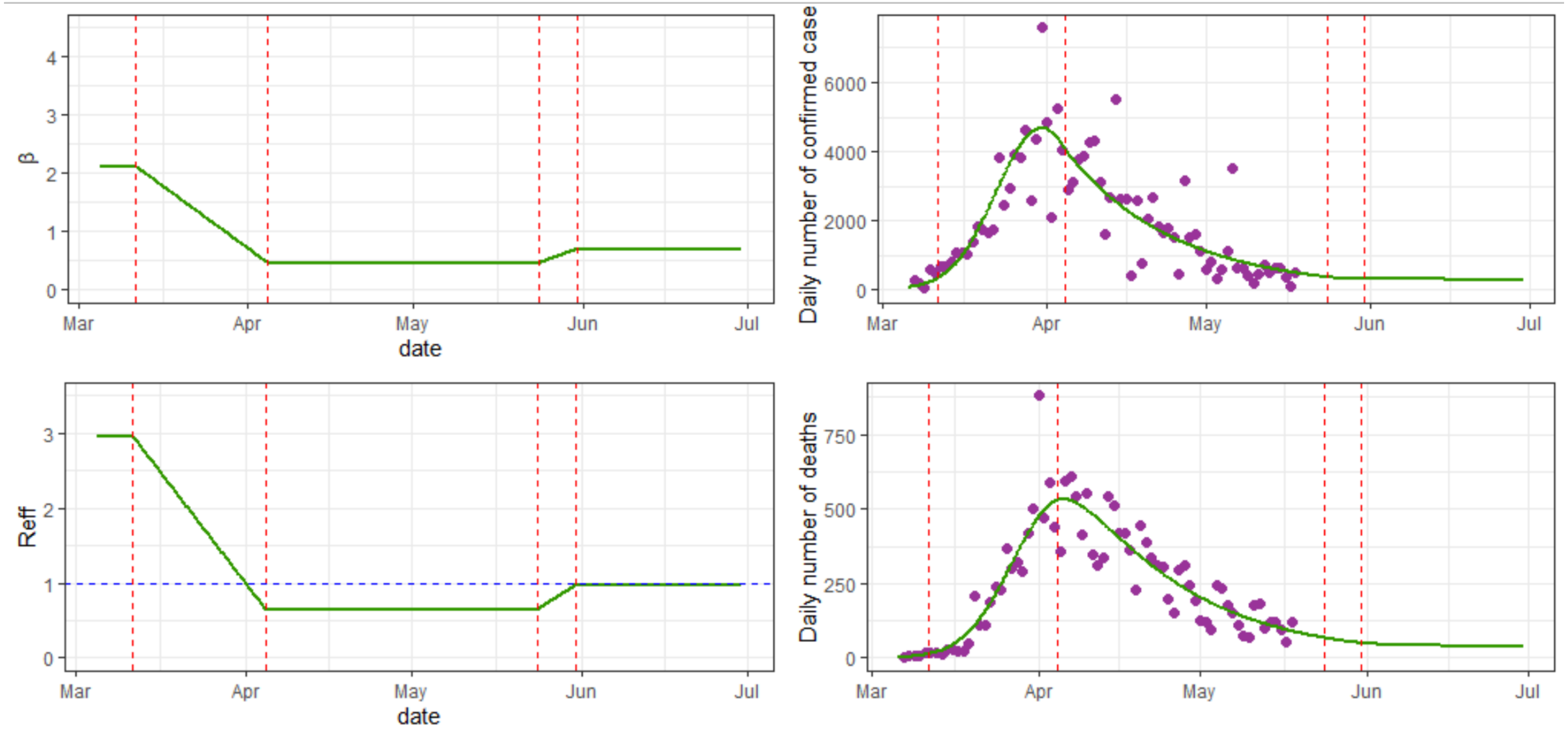
Possible scenarios after the end of the lockdown

3) The transmission rate is multiplied by 2



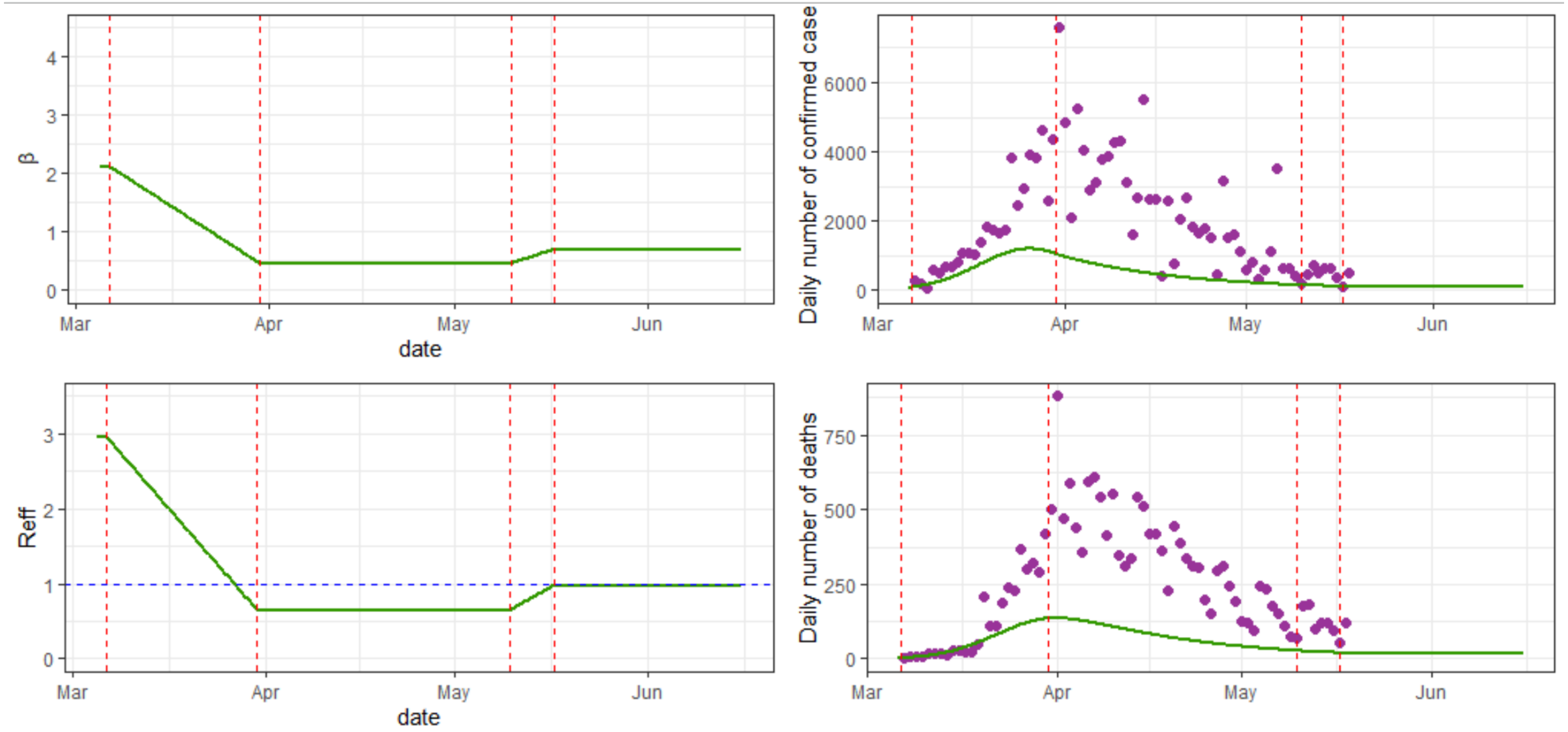
Possible scenarios after the end of the lockdown

4) The lockdown ends 2 weeks later (May 25)



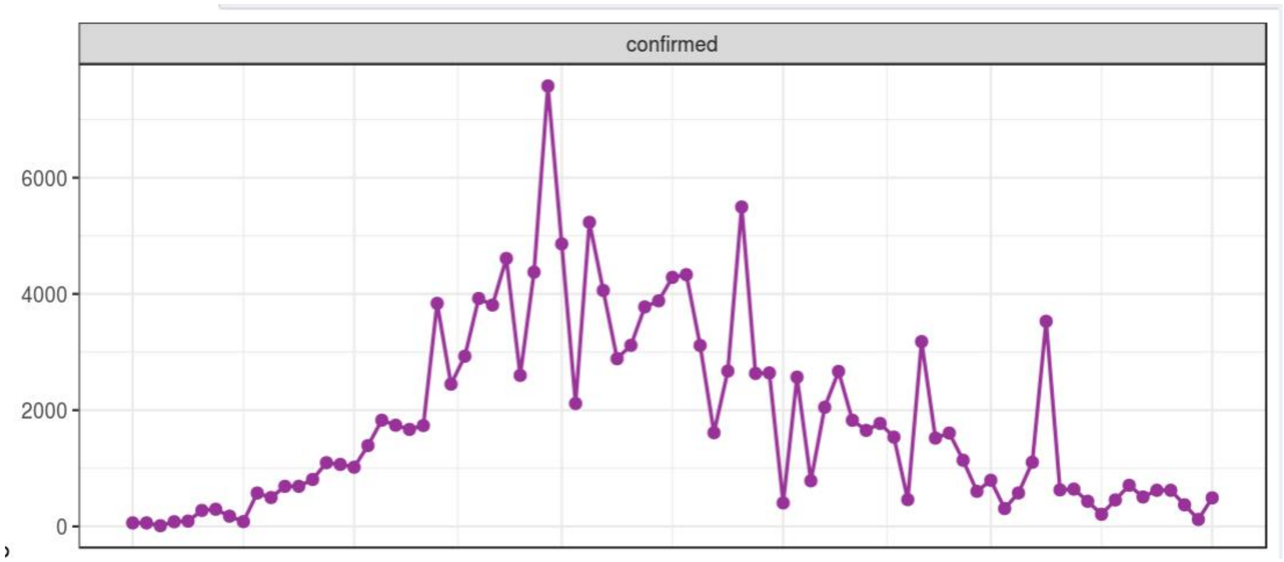
Possible scenarios before/after the lockdown

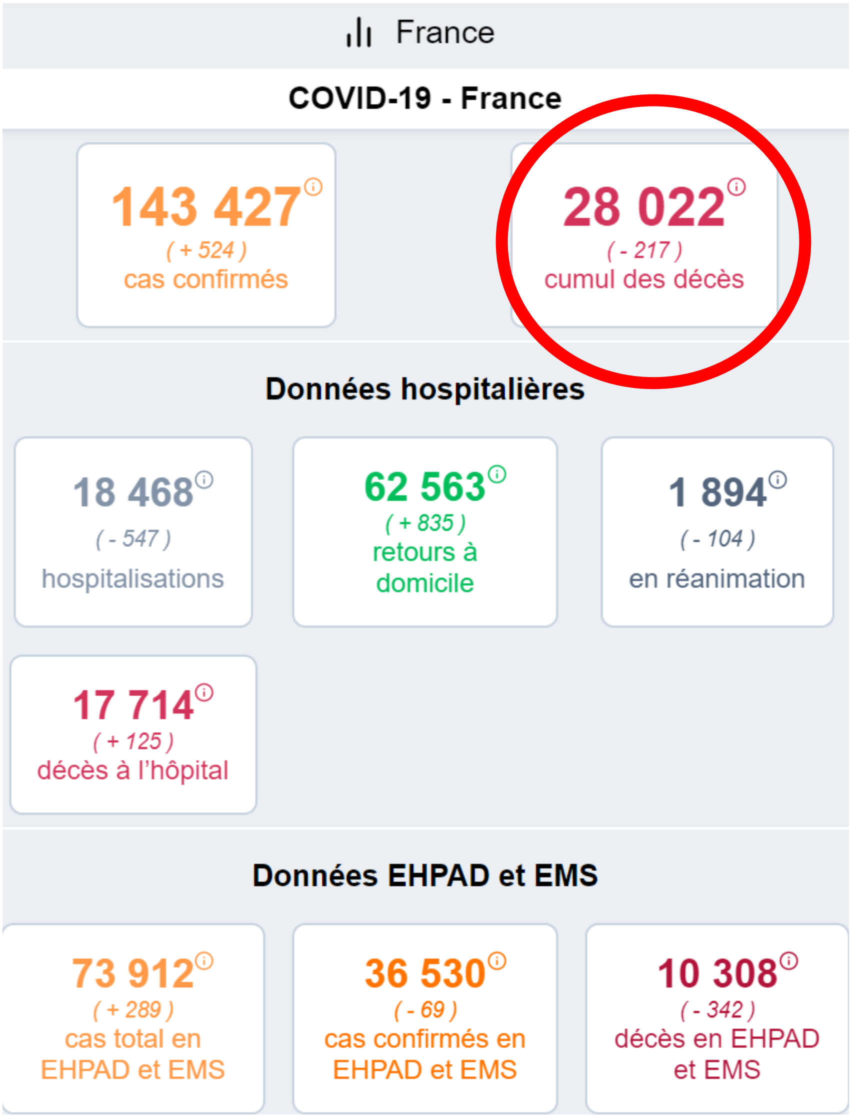
5) The lockdown starts one week before (March 10)



About the data

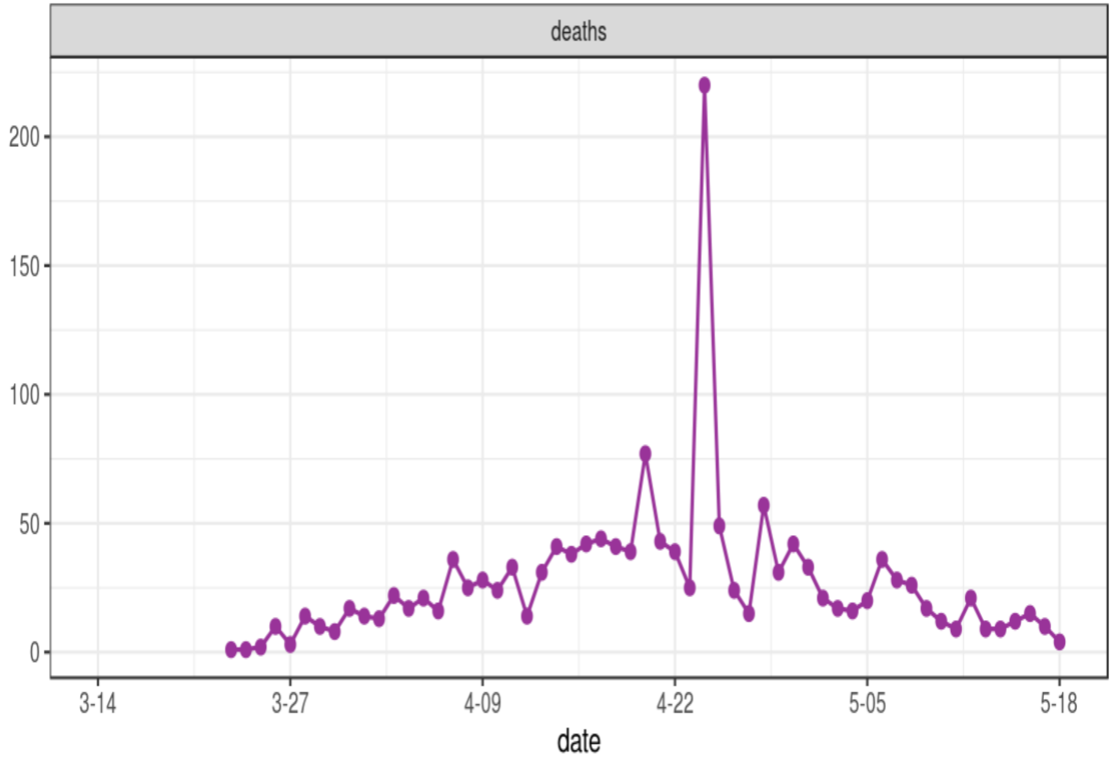
Some French data…

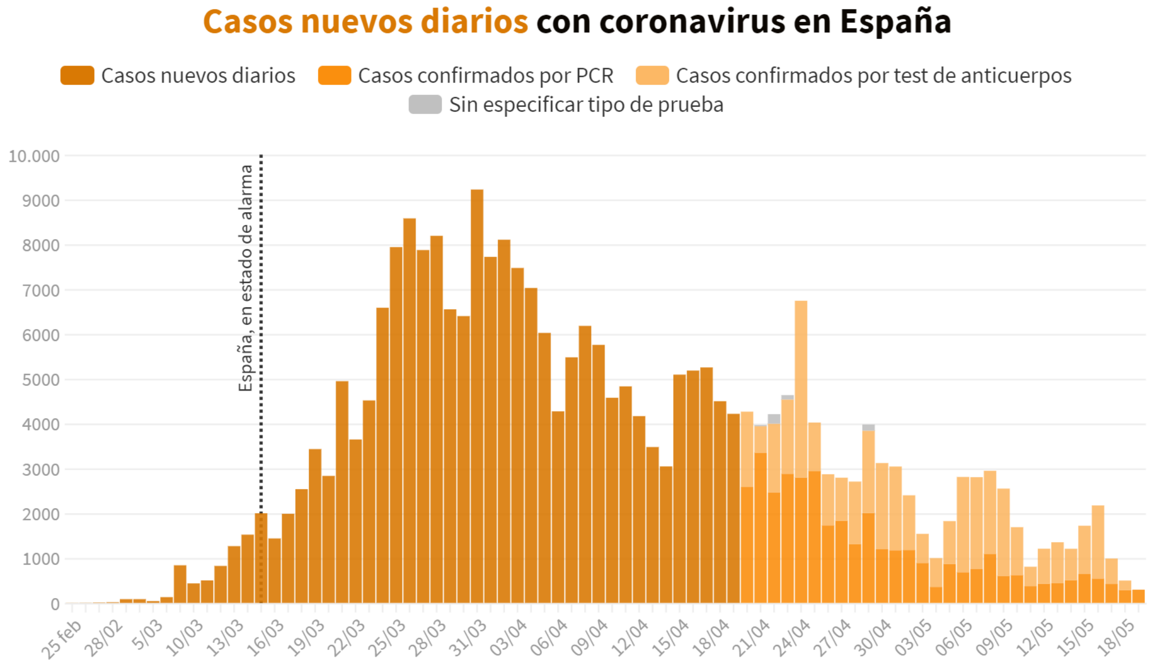




About the data

Ireland:





About Bayesian methods

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… but it's often used in extremist ways:

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Thank you !