Data-Driven Study of the COVID-19 Pandemic via Age-Structured Modelling and Prediction of the Health System Failure in Brazil amid Diverse Intervention Strategies

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Overview

COVID-19 Overview (Motivation)

Our SIRD model

Modelling the ICU demand

Initializing and Calibrating the Model

Is an Intense Quarantine Necessary in Brazil?

If so... Is it Urgent?

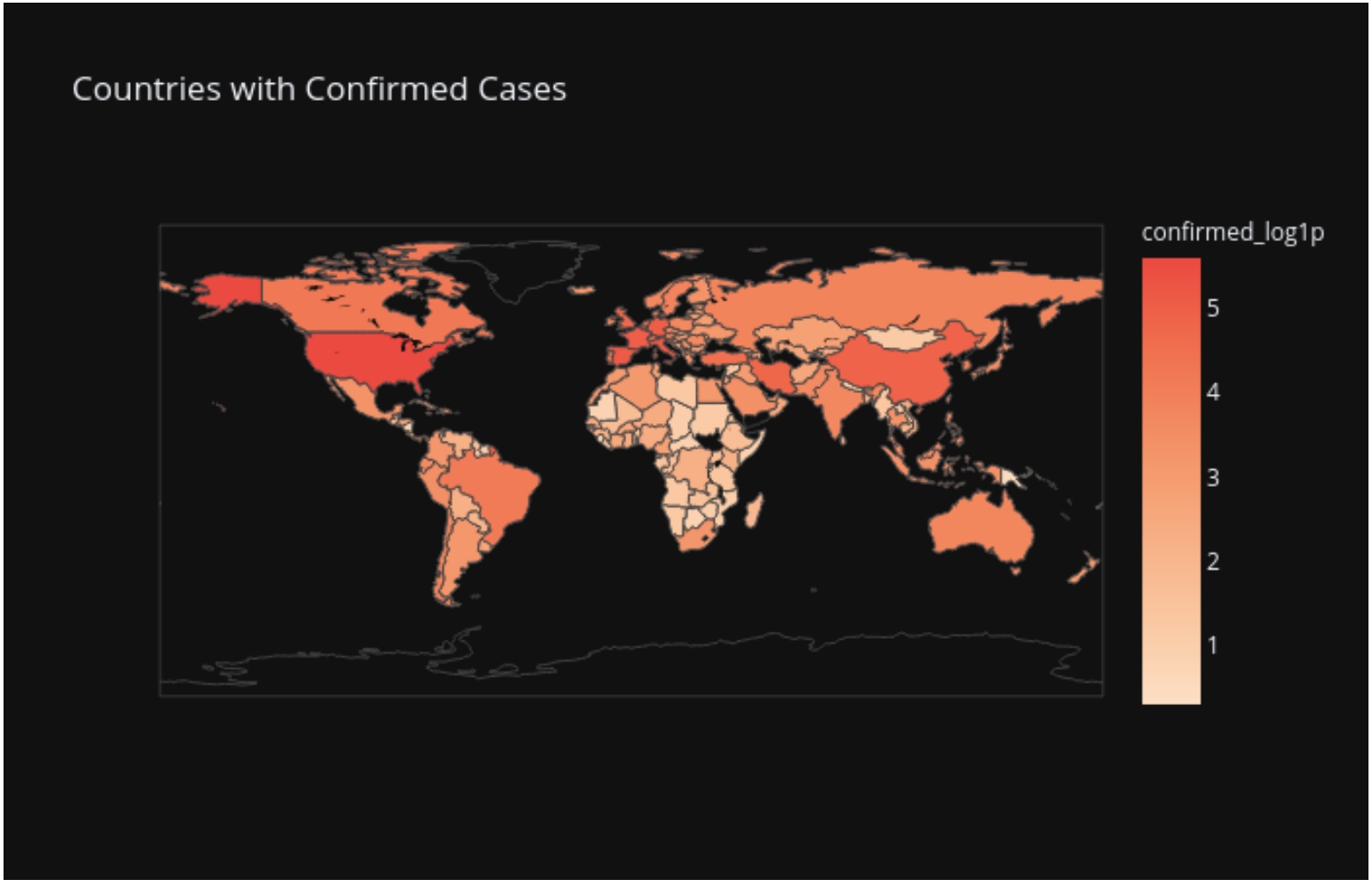
Concluding Remarks

What is SARS-CoV-2? What is COVID-19?

- Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2) is the name given to the 2019 **novel coronavirus**;
- COVID-19 is the name given to the **disease associated with this virus**;
- SARS-CoV-2 is a new strain of coronavirus that has **not been previously identified in humans**;
- Coronaviruses are viruses that circulate **among animals** with some of them also known to **infect humans**, triggering human-human infection;

Why is it a treat for health systems?

- The concern about COVID-19 is that, unlike influenza, there is **no vaccine and no specific** treatment for the disease;
- It also appears to be **more transmissible** than seasonal influenza;
- Asymptomatic person may **transmit** the disease;
- As it is a new virus, **nobody has prior immunity**, which means that the **entire human population** is potentially susceptible to SARS-CoV-2 infection;
- The treat is real! Almost **2M infected** and about **127K deaths** since December 2019;
- A considerable percentage of infected persons needs **intensive care unit** (ICU) admission!


Countries with Confirmed Cases
confirmed_log1p
5
4
3
2
1

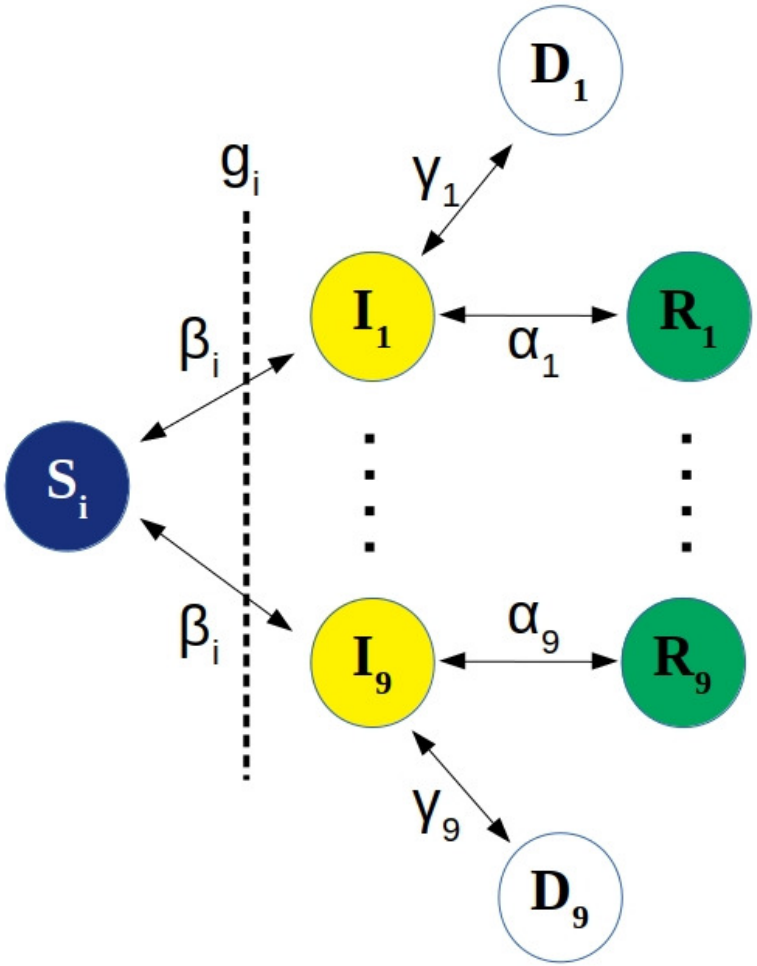


Figure: Individuals can be susceptible (S_i) to infected (I_i) with rate β_i, who can recover (R_i) at a rate α_i or die (D_i) at a rate γ_i.

Let us define $S(t)$, $I(t)$, $R(t)$, $D(t)$, the number of susceptible, infected, recovered and dead individuals, respectively, at time t in a population of size N. The model looks like:

$$\frac{dS_i(t)}{dt} = -\frac{\beta_i}{N}(g_i S_i)I, \quad (1)$$

$$\frac{dI_i(t)}{dt} = \frac{\beta_i}{N}(g_i S_i)I - \alpha_i I_i - \gamma_i I_i, \quad (2)$$

$$\frac{dR_i(t)}{dt} = \alpha_i I_i, \quad (3)$$

$$\frac{dD_i(t)}{dt} = \gamma_i I_i, \quad (4)$$

where $i \in [0, 1, ..., 9]$, corresponding to the age groups.

Our primary goal is to model the ICU demand:

$$\frac{dH}{dt} = \sum_{i=1}^{9} c_i I_i, \tag{5}$$

H means the healthcare demand due to hospitalized cases requiring critical attention in ICU.
So Eqs. (1) to (5) give our model.

Age	Group (i)	Population	Sch. or Univ.
0 to 9	1	13.8 %	$\approx 75\%$
10 to 19	2	15.0 %	$\approx 60\%$
20 to 29	3	16.1 %	$\approx 4\%$
30 to 39	4	16.3 %	$\approx 4\%$
40 to 49	5	13.7 %	$\approx 2\%$
50 to 59	6	11.3 %	$\approx 2\%$
60 to 69	7	7.6 %	0
70 to 79	8	4.0 %	0
80 +	9	2.2 %	0

Table: Distribution of the population and percentage of the corresponding population currently attending school or university.

(i)	g_i(No NPI)	g_i(CSU)	g_i(SD60+)	g_i(VHQ)	g_i(IQ)
1	1	0.25	1	0.5	0.25
2	1	0.40	1	0.5	0.25
3	1	0.96	1	0.5	0.25
4	1	0.96	1	0.5	0.25
5	1	0.98	1	0.5	0.25
6	1	0.98	1	0.5	0.25
7	1	1	0.25	0.5	0.25
8	1	1	0.25	0.5	0.25
9	1	1	0.25	0.5	0.25

Table: Diverse non-pharmaceutical interventions modelled by the parameter g_i.

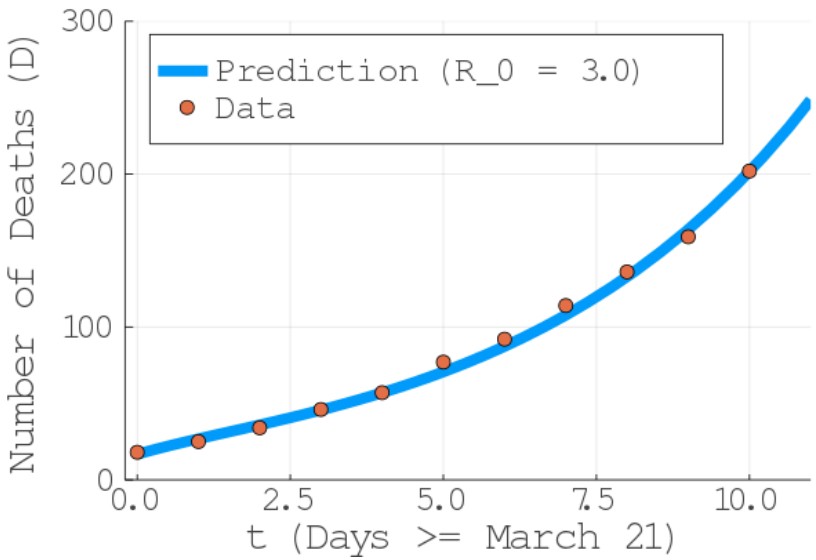
Age Range	$p[I_i(0)]$ (%)	$p[D_i(0)]$ (%)
0-9	0	0
10-19	0.2	0.04
20-29	0.2	1.1
30-39	0.2	3.4
40-49	0.4	4.3
50-59	1.3	8.2
60-69	3.6	11.8
70-79	8	16.6
80+	14.8	18.4

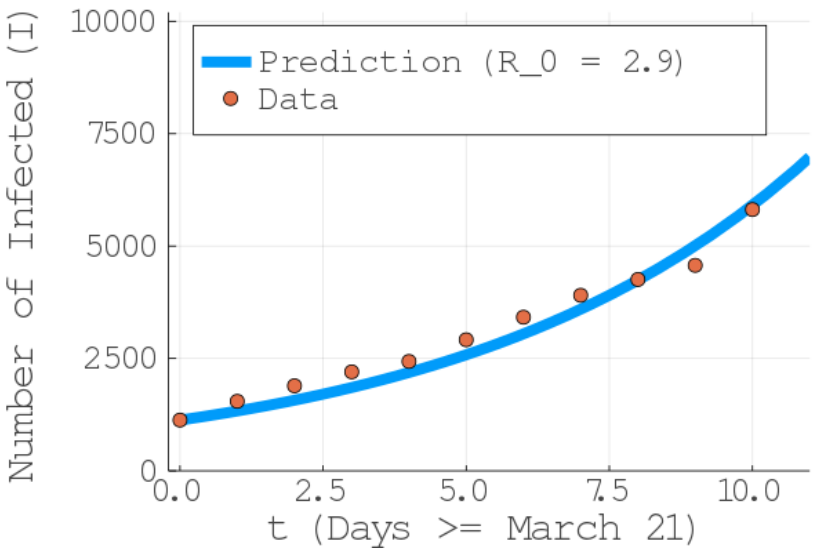
Table: Infected and Death percentages per age group in Brazil as of 21th March, 2020.

Age Range	Fatality (γ)	Hospitalised (c)
0-9	0.002 %	0.005 %
10-19	0.006 %	0.015 %
20-29	0.03 %	0.06 %
30-39	0.08 %	0.16 %
40-49	0.15 %	0.31 %
50-59	0.6 %	1.25 %
60-69	2.2 %	4.55 %
70-79	5.1 %	10.5 %
80+	9.3 %	19.36 %

Table: Mortality and Critical Hospitalized percentages per age group.

Determining R_0





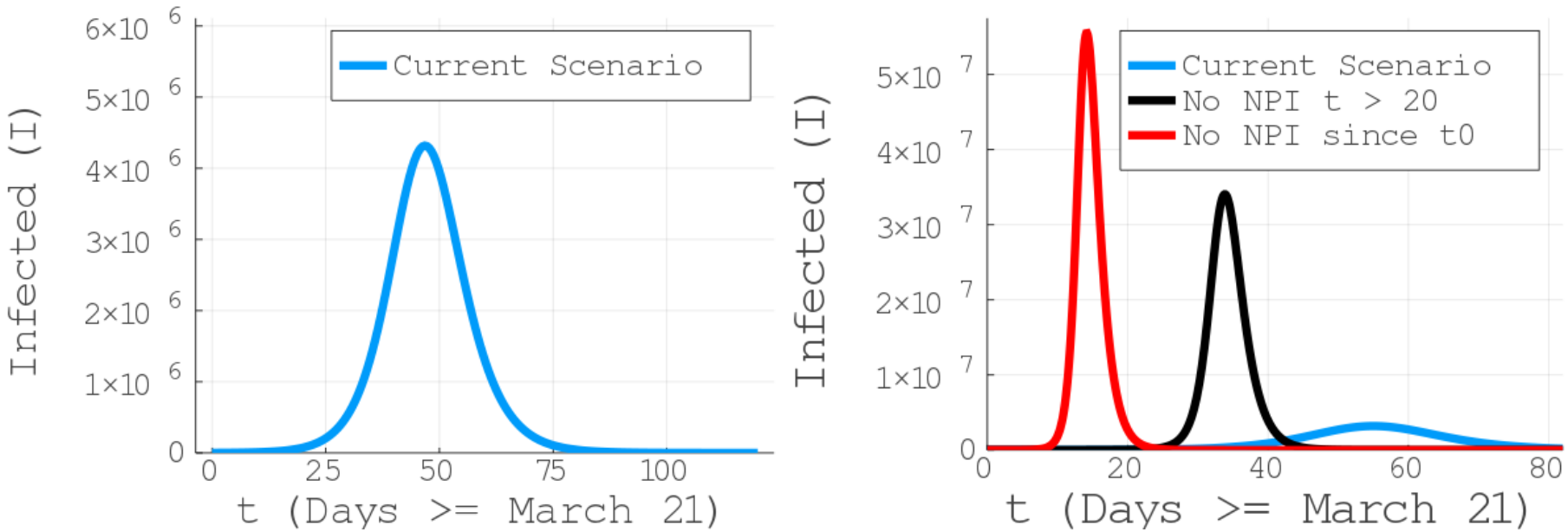


Figure: Infected individuals as a function of time.

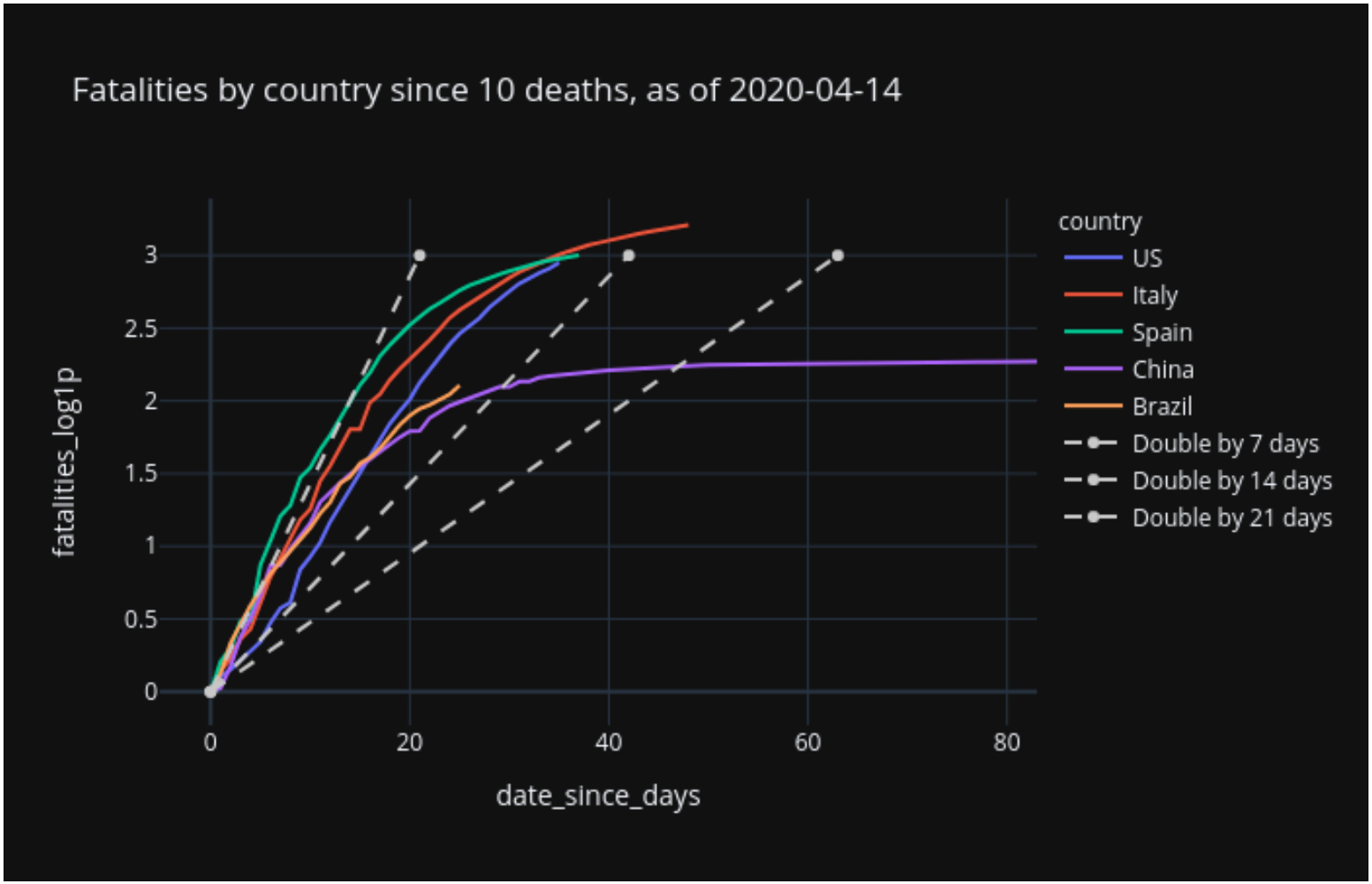


Figure: Log of deaths as a function of time.

Is it Urgent?

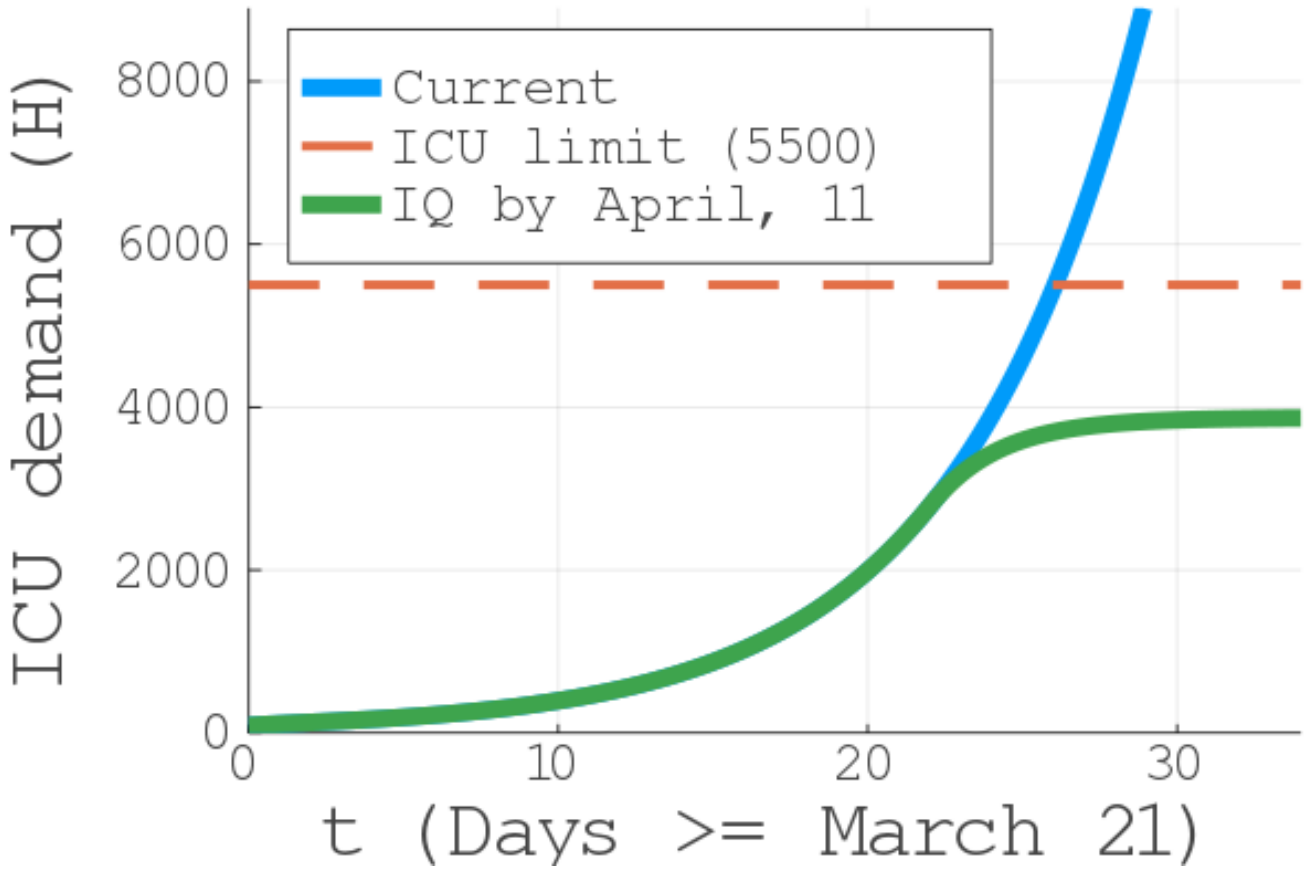


Figure: ICU beds demand.

Keeping track...

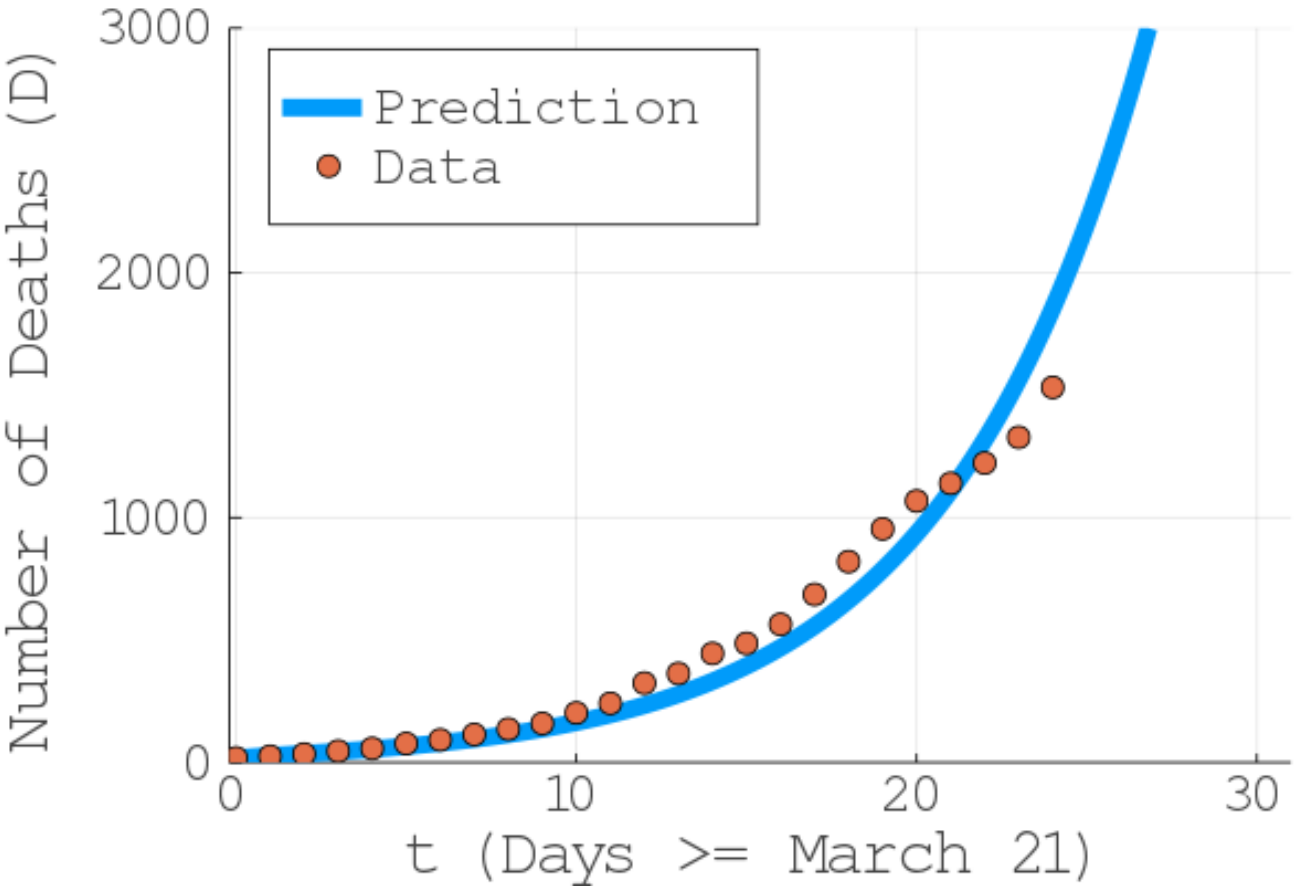


Figure: ICU beds demand.

Distinct Scenarios

Age	Cur.	(No NPI)	(CSU)	(SD60+)	(VHQ)	(IQ)
0-9	140	590	230	600	350	0
10-19	700	1930	1090	1900	1200	2
20-29	4.5K	10.4K	9.8K	10K	6500	15
30-39	12K	28K	26.3K	27K	17.5K	40
40-49	19K	44K	42K	43K	27.5K	65
50-59	63K	145K	138K	142K	91K	210
60-69	86K	357K	342K	146K	223K	280
70-79	104K	433K	414K	176K	270K	350
80+	44.8K	738K	550K	248K	203K	450
Total	**393K**	**1.45M**	**1.38M**	**723K**	**905K**	**1300**

Table: Estimated number of deaths D_i

- We have done a good job so far, but it seems not enough;
- An intense quarantine is justifiable and urgent in Brazil;
- Suitable level is around 75%;
- It seems to be impossible to minimize economic damages and number of deaths at the same time.

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