SUPPLEMENTAL MATERIAL

Analysis of the number growth of ICU patients with Covid-19 in Italy and Lombardy updated to 17-March, Day #25 evening

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Prepared for ESA, the European Society of Anesthesiology

March 18th, 2020

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Abstract

This document is a **reproduction** of a report prepared by the Author for Italian and foreign Anesthesia and Resuscitation doctors and any decision makers responsible for the public health under the COVID-19 emergency.

This document is updated to data released by the Italian Ministry of Health on the evening of March 17th, 2020.

Keywords: COVID-19, ICU, historical trends, exponential growth, doubling time.

Analysis and discussion

This report is based on the dynamic analysis of the number of beds necessary to ICU patients infected by COVID-19.

This report analyzes only Italian and Lombardy data to find some quantitative dependency of ICU patients with COVID-19 as a function of time. Real (i.e. experimental) data are made available by the **Italian Health Ministry** on a daily basis at 6 PM (CET).

Italy has 60.5 million of inhabitants, Lombardy is a northern region of Italy and has 10 million inhabitants (as of 2018, Eurostat).

Data were collected for Italy since 22-Feb-2020 and for Lombardy since 29-Feb-2020.

Day-1 is assigned to 22-Feb-2020. Consequently, Day-10 was 2-Mar-2020 and Day-25 was 17-Mar-2020 (see also Table 1).

Table 1: correspondence between day numbers and dates

1	22-feb
2	23-feb
3	24-feb
4	25-feb

5	26-feb
6	27-feb
7	28-feb
8	29-feb
9	01-mar
10	02-mar
11	03-mar
12	04-mar
13	05-mar
14	06-mar
15	07-mar
16	08-mar
17	09-mar
18	10-mar
19	11-mar
20	12-mar
21	13-mar
22	14-mar
23	15-mar
24	16-mar
25	17-mar

Here following, one can observe the trends of Italy and of Lombardy respectively.

For the sake of clarity, cyan data are real (i.e. experimental data), whilst orange data are forecast data. The dashed cyan straight line is the linear interpolation in the semilog plane. A semilog diagram features a Y-axis with Log_{10} values of data and an X-axis with linear values of time (where every unit is a day).

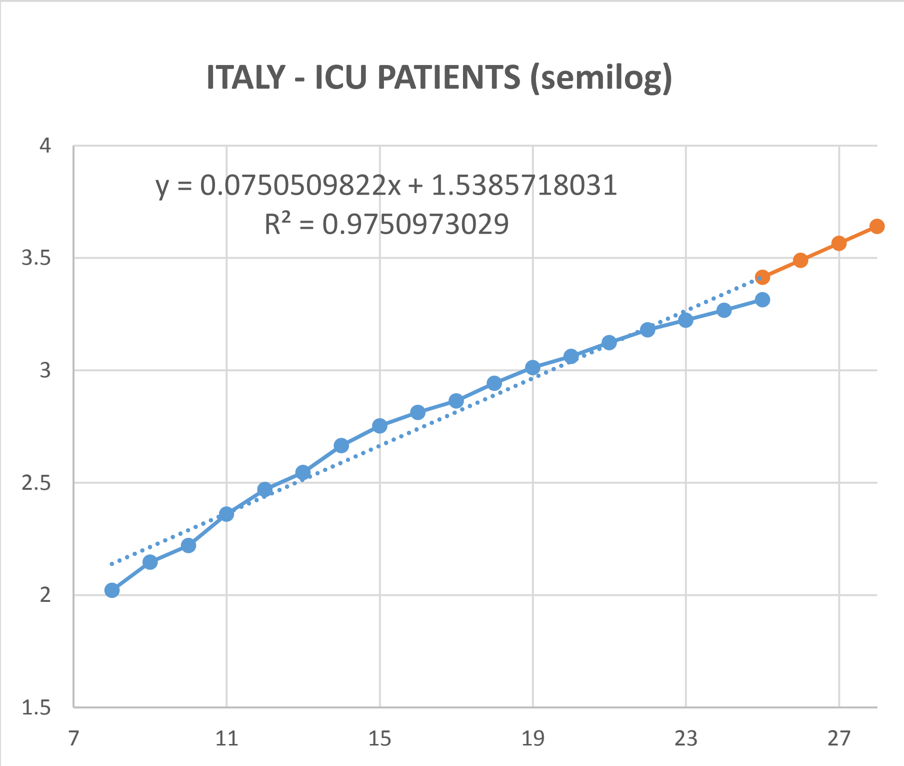

Figure 1: Cyan points ICU patients from 29-Feb to 17-Mar in Italy (semilog coordinates. Y-axis Log10, X-axis linear). Orange points prediction from 17-Mar to 20-Mar. Dashed cyan line linear interpolation of real data.

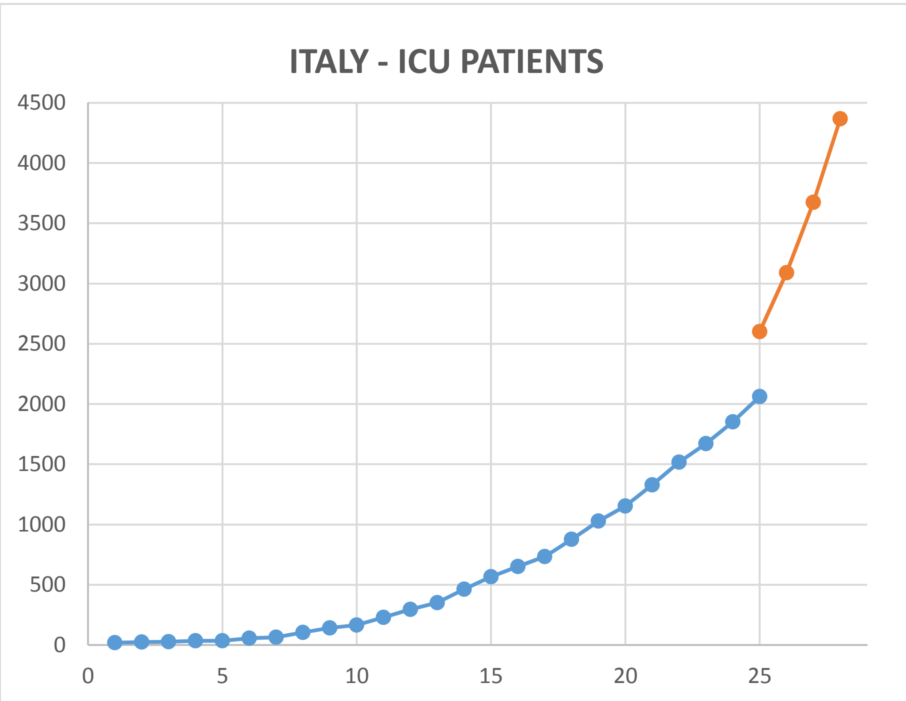

Figure 2: ICU patients from 22-Feb to 17-Mar in Italy. Orange points prediction from 17-Mar to 20-Mar.

From Figure 1 and Figure 2 one can observe that the initially exponential trend of the curve is progressively relaxing. The correlation index of the linear regression in semilog coordinates in Figure 1 is still rather high (i.e. $R^2 = 0.9751$). The higher the value the higher the consistency of data points with an exponential phenomenon. Nonetheless, every day there is a small improvement that moves away from the purely exponential trend and decreases the slope of the regression line.

Same trends can be observed in the data from Lombardy. Somehow, we can anticipate that Lombardy has a higher relaxation trend respect to Italy as the restrictive laws intended to separate people and some hotspots of viral diffusion (see Codogno and Lodi) were enacted before and produced some anticipated effect respect to the rest of Italy.

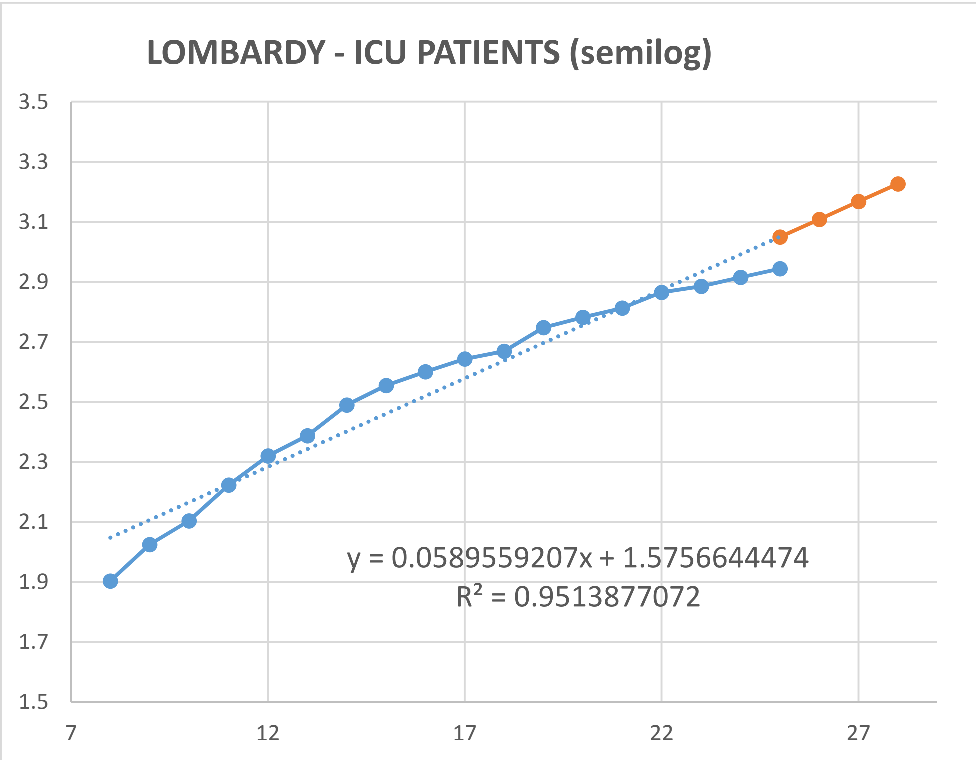

Figure 3: Cyan points ICU patients from 29-Feb to 17-Mar in Lombardy (semilog coordinates. Y-axis Log10, X-axis linear). Orange points prediction from 17-Mar to 20-Mar. Dashed cyan line linear interpolation of real data.

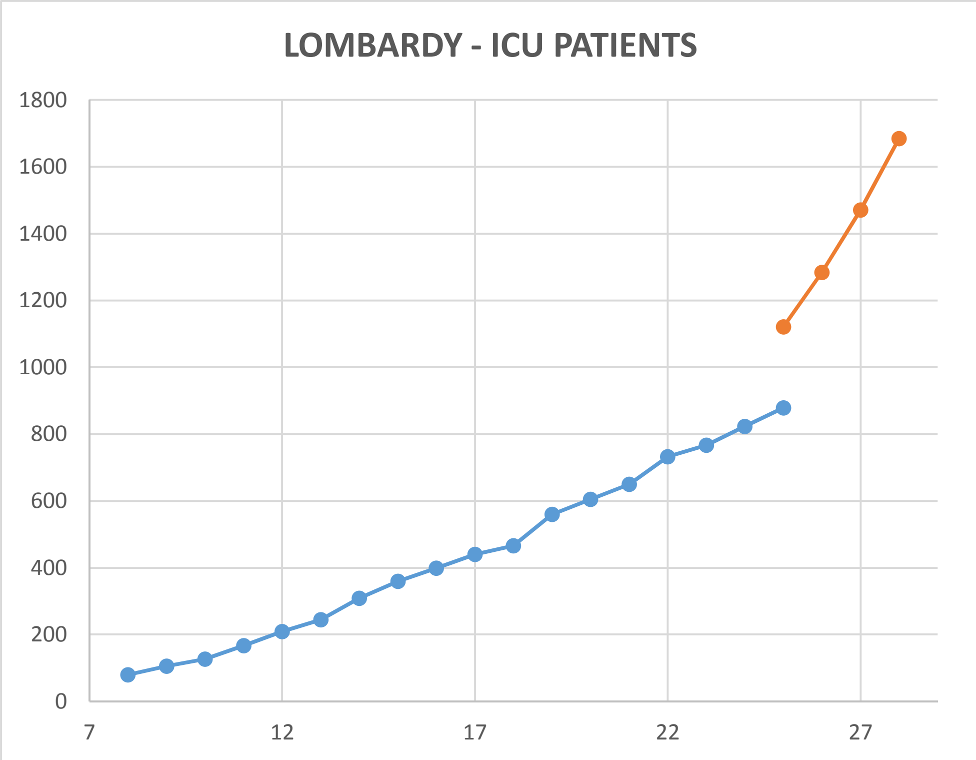

Figure 4: ICU patients from 29-Feb to 17-Mar in Italy. Orange points prediction from 17-Mar to 20-Mar.

It is therefore interesting to improve the model about the trend of ICU patients both in Italy and Lombardy.

For instance, over a shorter and more recent time interval, one can observe that data are leaving (hopefully) the linear trend on the semilog diagram (which means an exponential phenomenon of original data) to follow a smoother trend as shown in Figure 5. That trend can be approximated to a quadratic trend (i.e. a parabola) on the semilog diagram. Actually, the correlation coefficient approaches the ideal value of 1, indeed we have $R^2 = 0.9978$.

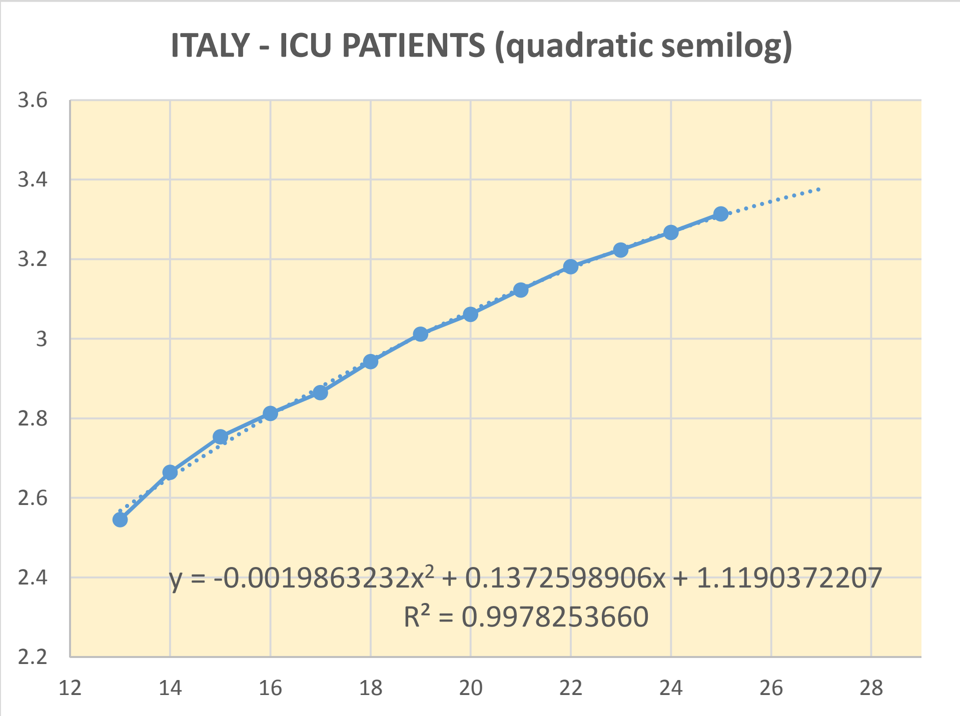

Figure 5: Cyan points ICU patients from 5-Mar to 17-Mar in Italy (semilog coordinates. Y-axis Log10, X-axis linear). Dashed cyan line quadratic interpolation of real data.

In linear coordinates, we have:

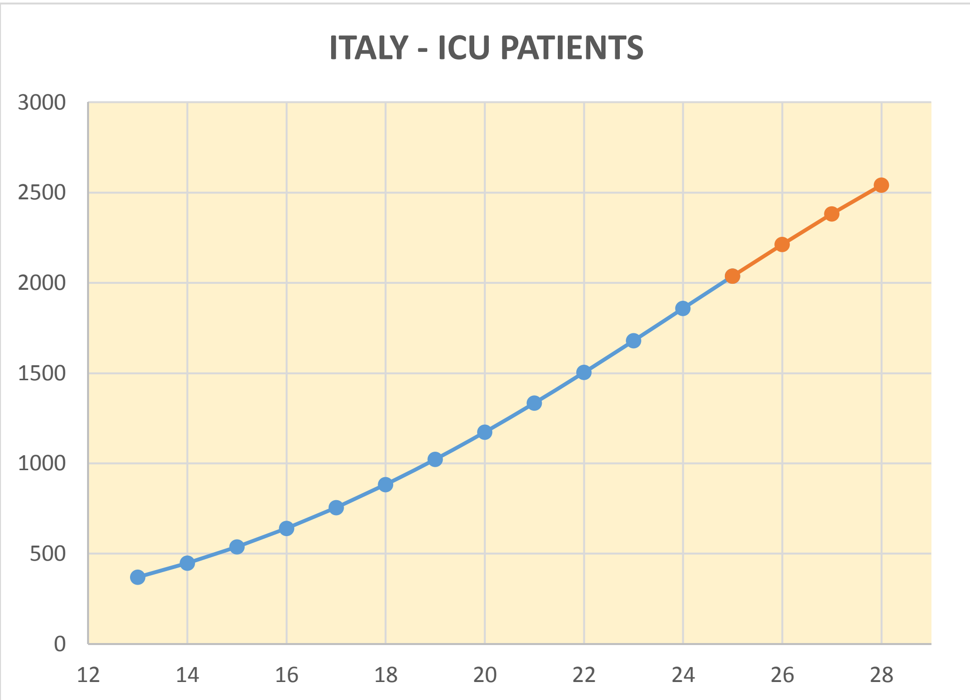

Figure 6: ICU patients from 5-Mar to 17-Mar in Italy. Orange points prediction from 17-Mar to 20-Mar.

If the trend is respected in the next days this would mean that the phenomenon is leaving its initial exponential trend and is moving towards the intrinsic behaviour of epidemic models (such as SIR models) which can be approximated by a logistic (i.e. sigmoid) curve. For the sake of correctness, SIR models do not produce logistic curves. However, SIR models can be approximated to logistic curves. The important point is that such models show an inflection point and approach an asymptotic value after a rather long time.

Same words can be spent for Lombardy, as shown in Figure 7 and Figure 8.

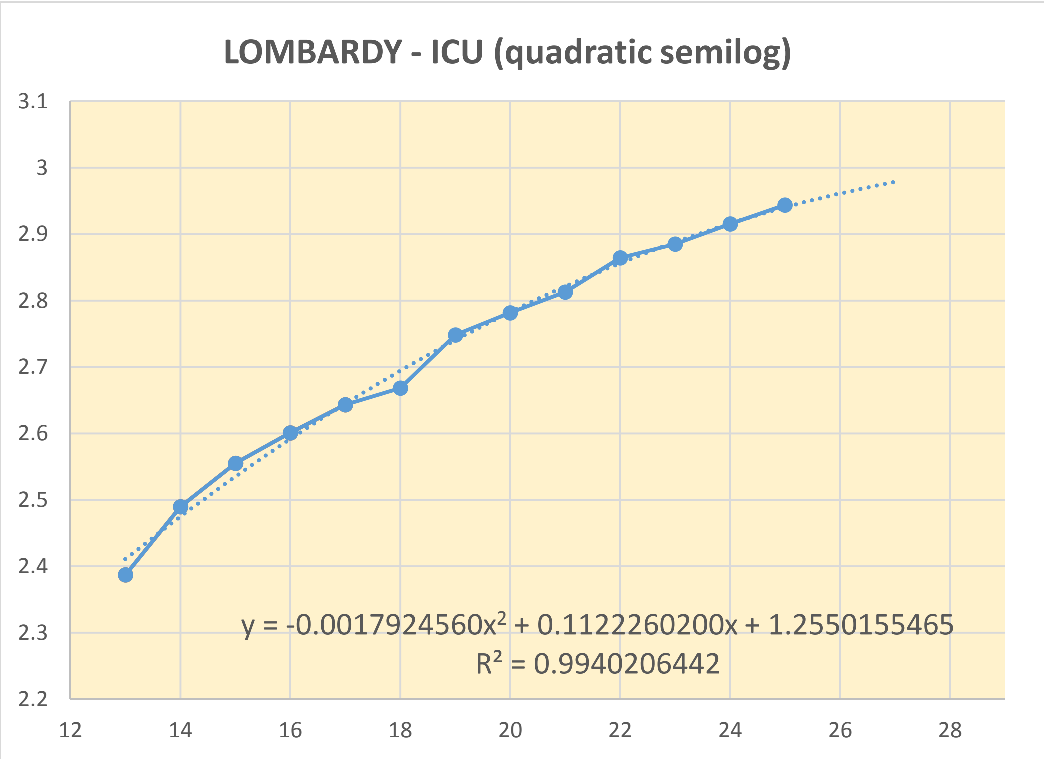

Figure 7: Cyan points ICU patients from 5-Mar to 17-Mar in Lombardy (semilog coordinates. Y-axis Log10, X-axis linear). Dashed cyan line quadratic interpolation of real data.

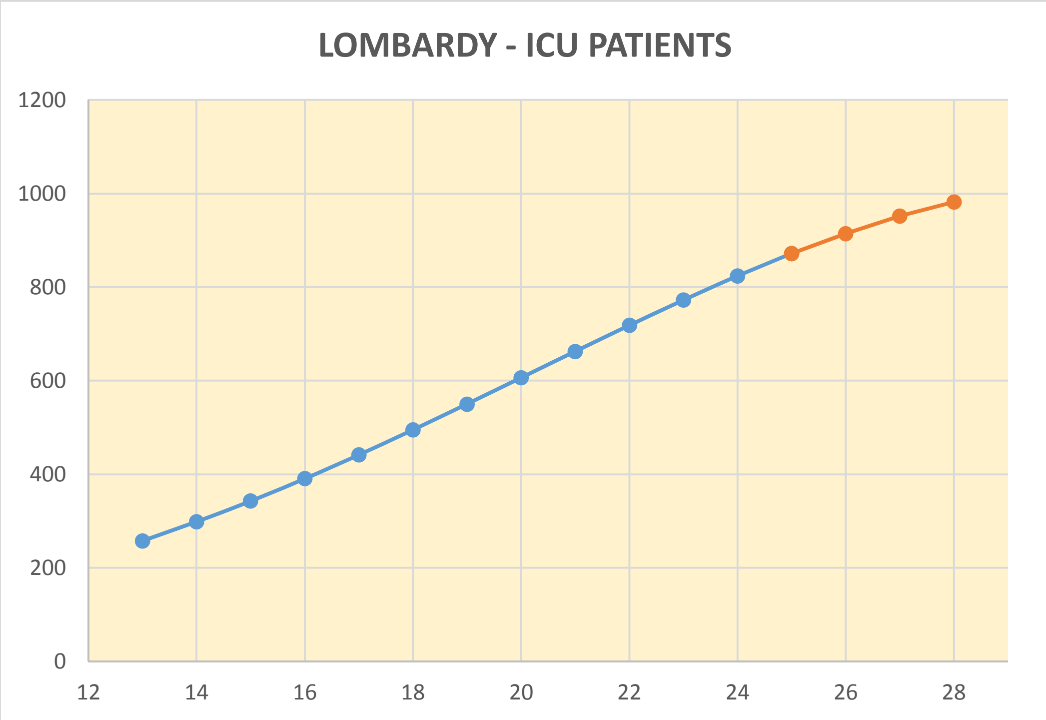

Figure 8: ICU patients from 5-Mar to 17-Mar in Lombardy. Orange points prediction from 17-Mar to 20-Mar.

These assumptions, i.e. either linear or quadratic trend over the semilog diagram of experimental (real) data, allow identifying two trends that are the lower and upper bounds of the predictions of ICU patients (i.e. extrapolation of the models). In other words, it is possible to identify two models that can be extrapolated and contain the real value of ICU patients. These models are tailored (i.e. regressed) to either Italy or Lombardy predictions.

For the sake of simplicity, let us call the upper bound model, which overestimates the real values, the pessimistic model. Equally, let us call the lower bound model, which underestimates the real values, the optimistic model.

Just to provide an example of these optimistic (i.e. lower) and pessimistic (i.e. upper) models, these are the values calculated on 12-Mar and predicted for 13-Mar-2020:

	Real value 12-mar	Upper model (pessimistic) following day	Lower model (optimistic) following day
ITALY-ICU	1153	1646	1267
Delta Italy		493	114
LOMBARDY-ICU	605	840	638
Delta Lombardy		235	33

Indeed, the following day (i.e. **13-Mar-2020**) the real (i.e. measured) data of ICU patients in Italy and Lombardy were **1328** and **650** respectively.

This means that the distance between the real data and the optimistic model was respectively of 1328-1267 = 61 patients for Italy, and 650-638 = 12 patients for Lombardy (with relative errors of 4.6% and 1.8% respectively).
Conversely, the table above reports the "Delta Italy" and "Delta Lombardy" values in terms of predicted increment of patients on a national and regional basis from 12 to 13-Mar-2020.

Another quite important value that can be quantified (as far as the phenomenon is in the exponential phase) is the **time required to double the value**. For the sake of clarity, that time is the one that is required for a given number of ICU patients to become double. If the phenomenon is exponential, that time remains constant when we double the number and from that number we double it again, and over and over.
On 13-Mar (Day #21), the time to double was respectively 3 d and 13 h for Italy and 4 d and 9 h for Lombardy.
The good news is that those times increase (although slowly) from day to day as the phenomenon slows down and moves (hopefully) towards a sigmoid curve.

A new update of both pessimistic and optimistic models is available for real data of 13-Mar and extrapolated (i.e. predicted) values for 14-Mar for either Italy or Lombardy as reported in the following table:

	Real value 13-mar	Upper model (pessimistic) following day	Lower model (optimistic) following day
ITALY-ICU	1328	1673	1450
Delta Italy		345	122
LOMBARDY-ICU	650	856	688
Delta Lombardy		206	38

This means that for the following day (i.e. 14-Mar) respect to 13-Mar we had to expect an increase of ICU patients between 38 and 206 beds in Lombardy and between 122 and 345 beds in Italy. The good news is that the pessimistic model continues to overestimate the real values by far. In addition, every day the divergence from the pessimistic model increases, which means that we can observe a departure from the exponential phenomenon in favor of an inflection and decrease of the growth velocity. Hopefully, this means that the ICU phenomenon is moving towards a sigmoid dynamics.

Notes

The author is responsible for any misprints, mistakes, and wrong interpretations of information and phenomenon reported in this short communication.

Acknowledgments

The author acknowledges the valuable and continuous discussions with medical doctors: Dario Caldiroli (Head of Anesthesiology and Resuscitation at Neurological Hospital in Milan), Enrico Storti (Head of Anesthesiology and Resuscitation at Lodi hospital), Piergiorgio Villani (Resuscitation doctor at Lodi hospital), Giovanni Mistraletti (ICU MD at San Paolo hospital of Milano), and Edoardo De Robertis (Head of Anesthesiology and Resuscitation at Perugia Hospital) all involved in the Covid-19 emergency.

Short bio

Davide Manca is professor of Process Systems Engineering at Politecnico di Milano in Italy and is the Head of PSE-Lab at the Chemical Engineering department. His research topics are on physiologically based pharmacokinetics and pharmacodynamics for individualized treatment and optimal administration of drugs. Specifically, he is now active on automated closed-loop control of IV anesthesia based on a model predictive approach to dynamically titrate both anesthetic and analgesic as a function of patient's features while monitoring BIS, MAP, and HR parameters. He is author of more than 250 peer-reviewed papers, book chapters, and books most of them indexed in Scopus, WOS and PubMed. He has supervised a number of PhD and master degree students in PBPK and PD applied to automated control of IV anesthesia based on model predictive control and online decision support systems for IV anesthesia. PSE-Lab was granted with a few European and National research grants.

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