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Abstract

On 4 November 2020 the Italian government introduced a new policy to address the second wave of Covid-19. Based on a battery of indicators, the 21 administrative regions of Italy were assigned a risk level among yellow, orange, red, and, starting on 6 November 2020, different type of restrictions were applied accordingly.

In this work, we extract the daily growth rate of new cases, hospitalizations and patients in ICU from official data using an unobserved components model and assess if the different restrictions had different effects in reducing the speed of spread of the virus.

1. Introduction

In October 2020 Italy found itself in the second wave of Covid-19 infections. New cases were increasing with daily rates above 5% and hospitals were quickly reopening Covid-19 wards closed during the Summer and preparing new intensive care units (ICU). On 24 October the Italian government introduced a new regulation (Presidenza del Consiglio dei Ministri, 2020a) that imposed many restrictions, the more important being the use of masks everywhere outside private households, the closing time for restaurants, cafes and pubs set at 6 PM, the closure of gyms, swimming pools, game rooms, forbidding public events, introducing limitations on the number of students allowed into high schools and universities, stopping private visits in nursing homes, limiting the attendance to weddings and funerals.

On 4 November 2020, the government issued a new ordinance (Presidenza del Consiglio dei Ministri, 2020b) to come into effect on 6 November that introduced three different policies to be implemented in regions according to their local risk as measured by pooling 21 indicators. The 21 indicators[1], computed for each

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[1] The source of many of these indications is not public.

of the 21 regions[2], provide information about the probability/speed of spread, the impact on hospitals, ICU and nursing homes, the resilience of the regional health system and the reliability of available data.

The main points of the three policies introduced by the ordinance, named yellow, orange and red, are synthesized below (we report the synthesis produced by the International Centre for Theoretical Physics, 2020).

Yellow.

- Between 10 PM and 5 AM, exclusively persons with valid work (e.g. commuting to/from work), health or other urgent reasons may be out of home. In any case, it is strongly recommended at any point of the day that persons do not leave their homes except for work, health or other urgent reasons or to engage in physical activity or to make use of any ongoing services. Streets or squares in urban centers prone to the formation of crowds may be closed all or part of the day, though allowing access to legitimate commercial activities and private residences.

- Pre-school and primary school (i.e., the first eight years of schooling) teaching activities will continue to be held in person, but secondary schools and higher education will adopt distance learning for 100% of the students.

- Commercial activities may continue as long as an interpersonal distance of at least 1 meter is ensured, entrances are regulated and customers are not allowed to remain inside longer than the time needed to make a purchase. However, malls, shopping centers, and markets are closed on weekends and holidays; pharmacies, newsstands, tobacco shops and shops selling foodstuffs inside shopping centers and markets may remain open.

- Arcades, betting rooms, bingo halls, and casinos are closed and such activities are prohibited in any other type of facility.

- Museums, theaters, cinemas and other cultural institutions are closed.

- Trains, trams, and buses may be filled to a maximum of 50% capacity.

- Cruise services of Italian-flagged passenger ships are suspended.

Orange. Like *yellow* but with the following further restrictions.

- Nobody is allowed in or out of the region, except for work, health or other urgent reasons; for school attendance as allowed by the present decree; or to return to one's legal residence. Passing through orange zones to reach one's legal residence is allowed.

[2]Italy has 20 administrative regions, however since the Region Trentino-Alto Adige, for historical and linguistic reasons, is split into two provinces with a very high degree of autonomy, in official statistics data from these two provinces are often recorded separately.

- Likewise, leaving one's municipality is also not allowed, except for the above stated reasons.
- Food service activities (including cafes, restaurants, pubs, ice cream parlors, and pastry shops) are suspended. However, delivery continues to be allowed at all times and takeaway until 10 PM. Food service activities at rest stops along highways, in hospitals, and in airports may continue.

Red. Like *orange* but with the following further restrictions.

- All movements are prohibited except for work, health or other urgent reasons, for school attendance as allowed by the present decree, or to return to one's legal residence. Passing through red zones to reach one's legal residence is allowed.
- Commercial activities are suspended, with the exception of those selling foodstuffs and basic necessities. Markets are also closed, with the exception of stands exclusively selling food. Newsstands, tobacco shops, and pharmacies remain open.
- Pre-school and primary school teaching activities will continue to be held in person, but secondary schools (from the 2nd year of middle school, i.e., the 7th year of schooling in Italy) and higher education will adopt distance learning for 100% of the students.
- Foodservice activities (including cafes, restaurants, pubs, ice cream parlors, and pastry shops) are suspended. However, delivery continues to be allowed at all times and takeaway until 10 PM. Foodservice activities at rest stops along highways, in hospitals, and in airports may continue.
- Outdoor sports clubs and centers are closed. Individual outdoor exercise is exclusively allowed in the near vicinity of one's residence and with the use of a mask
- Personal services are suspended, with few exceptions. Activities suspended include hair salons, barber shops, and beauty salons.
- Public employers shall reduce in-person activities to those that cannot be postponed and cannot be performed remotely.

On 6 November 2020 each of the 21 regions was assigned one of three colors and, until 29 November 2020, regions were to keep their starting color or move to a stricter policy color according to the values of 21 indicators.

Using this event and the official data published by *Dipartimento di Protezione Civile* we want to measure the effect of the different policies on the speed of spread of the virus and rate of growth of hospitalizations in regular wards and ICUs.

The paper is organized as follows. Section 2 introduces the method we use to extract the growth rates of the number of new cases, hospitalizations and patients in ICU. Section 3 contains the results of the analysis. Section 4 draw some conclusions.

2. Methods

Let y_t, for $t = 1, 2, \ldots, n$, be the daily time series of interest (number of new cases, number of hospitalized patients, number of patients in intensive care units). Since official time series tend to show a weekly seasonal pattern and, for various reasons, can be very noisy, we assume y_t to be the product of three components: the level m_t, the weekly seasonal factor g_t and the noise e_t,

$$y_t = m_t g_t e_t, \tag{1}$$

or, equivalently

$$\ln(y_t) = \mu_t + \gamma_t + \varepsilon_t, \tag{2}$$

with $\mu_t = \ln(m_t), \gamma_t = \ln(g_t), \varepsilon_t = \ln(e_t)$.

In our analysis we are interested in the daily rate of growth of the level m_t, which is given by[3]

$$\beta_t = \mu_{t+1} - \mu_t = \log\left(\frac{m_{t+1}}{m_t}\right) \approx \frac{m_{t+1} - m_t}{m_t}. \tag{3}$$

Since ours is as short-term analysis and we want to be model-agnostic and just use this setup to extract the signal from available data, we will not assume any compartmental epidemic model. We relay on a unobserved components model just as a tool for signal extraction. In particular, we assume β_t to evolve as a random walk, $\beta_{t+1} = \beta_t + \zeta_t$, where ζ_t is Gaussian white noise with variance σ^2_ζ. So, the specification for the log-level is that of an *integrated random walk* (also called *smooth trend*):

$$\begin{aligned} \mu_{t+1} &= \mu_t + \beta_t \\ \beta_{t+1} &= \beta_t + \zeta_t, \quad \zeta_t \sim NID(0, \sigma^2_\zeta), \end{aligned}$$

where $NID(\mu, \sigma^2)$ has to be read as *normally independently distributed with mean μ and variance σ^2*.

For the weekly seasonal component we rely on the stochastic dummy approach, in which the sum of seven consecutive values is equal to a Gaussian white noise:

$$\gamma_t = -\gamma_{t-1} - \gamma_{t-2} - \ldots - \gamma_{t-6} + \omega_t, \quad \xi_t \sim NID(0, \sigma^2_\omega).$$

Finally, the noise component for the additive model is, again, a Gaussian white noise: $\varepsilon_t \sim NID(0, \sigma^2_\varepsilon)$.[4]

[3] Notice that we are using $\beta_t = \mu_{t+1} - \mu_t$ instead of the more common $\beta_t = \mu_t - \mu_{t-1}$ because we have to cast the model in state space form.

[4] In this model $\ln(y_t)$ is assumed Gaussian and, thus, y_t is log-normal. Of course the observations are counts an log-normality can only be considered an approximation. We estimated also a model in which y_t is negative binomial with mean $\exp(\mu_t + \gamma_t)$, but the results where virtually identical and, so, we decided to proceed with the computationally simpler log-normal model.

This model can be easily cast is state space form, the variances σ^2_ζ, σ^2_ω, σ^2_ε estimated by maximum likelihood and the unobserved components extracted using the smoother (for details refer to the monographs by Harvey, 1989; Durbin and Koopman, 2012; Pelagatti, 2015). In particular, conditionally on the estimated variances, the smoothing algorithm compute the following quantities

$$\boldsymbol{a}_{t|n} = \mathbb{E}\left(\boldsymbol{\alpha}_t | y_1, y_2, \ldots, y_n\right)$$
$$\boldsymbol{P}_{t|n} = \mathbb{E}\left(\boldsymbol{\alpha}_t - \boldsymbol{a}_{t|n}\right)\left(\boldsymbol{\alpha}_t - \boldsymbol{a}_{t|n}\right)^\top$$

where $\boldsymbol{\alpha}_t$ is the vector containing all the unobserved components: in our application $\boldsymbol{\alpha}_t = \begin{bmatrix}\mu_t & \beta_t & \gamma_t\end{bmatrix}^\top$.

As example, Figure 1 depicts the time series of the number of new cases, hospitalizations and Covid-19 patients in ICU[5] in Lombardy with the extracted component m_t and the daily rate of growth β_t for the time span 24 Feb 2020 – 15 Dec 2020[6]. The number of cases during the first wave appears to be much lower than the one in the second wave, however the number of tests carried out during the first wave was significantly smaller. During the period we are going to analyze (6 November - 13 December) the number of tests has been roughly constant around 200,000 per day (country wise).

3. Effects of the risk-zones policy

The risk-zones (yellow, orange and red) where introduced on 6 Nov 2020 and, until 29 Nov 2020, the risk class of every region either remained unchanged or switched to a severer risk.

In particular, all the five red regions and the two orange regions remained such until 29 Nov 2020, while 9 out of 14 yellow regions switched color. The color assignments of 6 Nov and their later switches are synthesized in the second column of Table 1 using the following notation:

[initial color] [date of change] [new color] [date of change] [new color]

As all changes took place in November 2020, in [date of change] we report only the day of the month.

We grouped the 21 regions according to the following rules:

- **yellow**: regions that remained in the yellow zone from 6 Nov to 29 Nov;
- **to-orange**: regions assigned to the yellow zone on 6 Nov, which ended up in the orange zone;

[5]Data are published by *Dipartimento di Protezione Civile* and available at `https://github.com/pcm-dpc/COVID-19`. The variables we analyze are *nuovi_positivi* (new cases), *ricoverati_con_sintomi* (hospitalized) and *terapia intensiva* (ICU).

[6]Analogous estimates for all the regions of Italy are updated on a daily basis on the website `https://matteopelagatti.shinyapps.io/Covid19_report/`

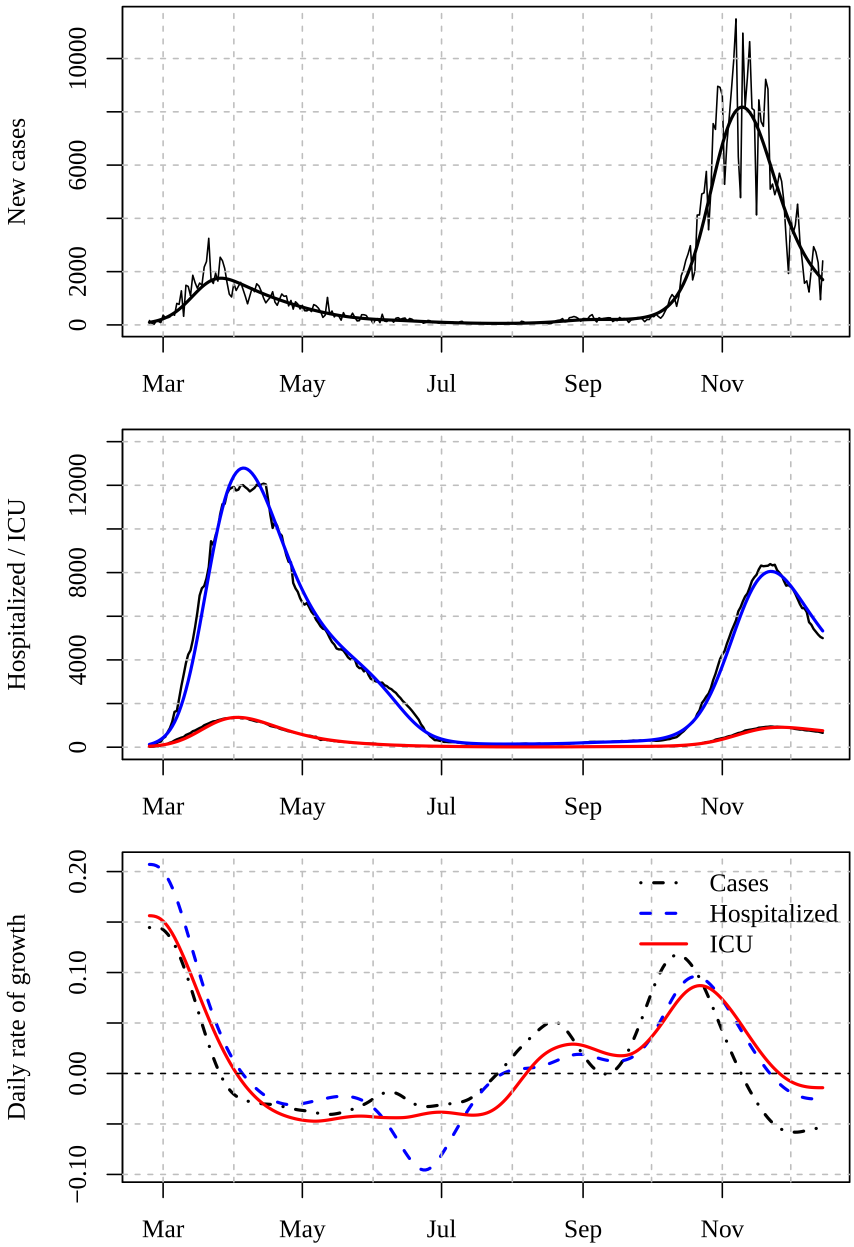

Figure 1: Components extracted on the number of new cases in Lombardy. Top: new cases with level. Mid: hospitalized and ICU with levels. Bottom: daily rates of growth.

		Rate reduction (%)		
Region	Zones	Cases	Hosp.	ICU
Basilicata	y 11 o	8.8	5.4	10.2
P.A. Bolzano	r	7.5	8.7	7.7
Piemonte	r	7.5	6.5	7.7
Calabria	r	7.4	6.0	9.3
Lombardia	r	7.3	8.0	7.3
Valle d'Aosta	r	7.2	7.2	6.7
Abruzzo	y 11 o 18 r	7.0	3.9	5.6
Toscana	y 11 o 15 r	6.7	6.1	5.8
Campania	y 15 r	6.4	3.7	4.1
Molise	y	6.0	4.9	6.2
Emilia-Romagna	y 15 o	5.5	4.4	4.9
Lazio	y	5.1	3.7	2.9
Umbria	y 11 o	5.0	3.9	6.0
Sicilia	o	4.9	4.3	4.9
Liguria	y 11 o	4.5	5.0	6.4
Sardegna	y	4.1	1.9	3.1
Puglia	o	4.0	3.7	5.2
Friuli Venezia Giulia	y 15 o	3.8	5.7	3.0
Marche	y 15 o	3.8	5.6	5.4
Veneto	y	2.8	4.3	4.4
P.A. Trento	y	2.2	7.4	8.6

Table 1: Reduction in the daily growth rate of new cases, hospitalizations and ICU ordered by rate reduction of new cases. Zones column entries have to be interpreted as region's color on 6 November followed by day (of November) of change and color of landing. For instance, Toscana since 6 Nov was yellow, since 11 Nov was orange and since 15 Nov was red.

- **orange**: regions that remained in the orange zone from 6 Nov to 29 Nov;
- **to-red**: regions assigned to the yellow zone on 6 Nov, which ended up in the red zone;
- **red**: regions that remained in the red zone from 6 Nov to 29 Nov.

Then, we analyzed the daily rate of growth (the β_t of Equation 3) of new cases, hospitalizations and patients in ICUs for each region over two different time spans. Since almost every region shifted to a lower risk zone on 29 Nov 2020, we observed the number of new cases over the period 6 Nov – 29 Nov. For the number of Covid-19 hospitalizations in regular wards and ICUs, we extended the observation period by 14 days, since in our data we can observe an average delay of the peak of these time series with respect to new cases of approximately 14 days. For example, in Lombardy this delay can be observed in the bottom graph of Figure 1: in November the blue (dashed) line and the red (continuous) line cross the x-axis later than the black (dash-dot) line. Thus, hospitalizations and ICU patients are monitored over the period 6 Nov – 13 Dec.

The average daily rates of growth in each group for the three time series are plotted in Figure 2. All the rates where positive and decreasing on 6 Nov. All (average) growth rates of new cases fell below zero in the observed time span, so at the end of this period the number of new Covid cases were geometrically decreasing. Regions in the red and to-red zones were the first to reach the peak (i.e., growth rate crossing the zero level), followed by regions in the to-orange, yellow and orange zones. The behaviors of the average growth rates of hospitalizations and ICU patients appear similar: four time series fall below zero, while the rate of the yellow zone stops at zero. Hospitals in yellow zones reached the peak of hospitalizations but this peak looks like a plateau: the number of patients in regular wards and ICU remains constant. In these two cases, the order of zero-crossing is the expected one: red zones first, orange zones second and the yellow zone last.

In order to assess how effective were the various zones in reducing the rates of growth of the three time series, we computed the cumulative rates of growth as $\beta_{start} - \beta_{end}$, where *start* is 6 Nov for all time series and *end* is 29 Nov for new cases and 13 Dec for the other two time series[7]. The last three columns of Table 1 report these (growth rate reduction) values for all time series. Regions are decreasingly ordered by growth rate reduction of new cases. With the exception of Basilicata[8], all regions in top rows belong to the red zone (positions 2 through 6) or ended up in the red zone (positions 7 through 9). The growth rate reduction for hospitalizations and ICU patients are a bit more variable.

Figure 3 depicts box-plots of the reductions in growth rates for the three quantities under analysis grouped by zone. In the same graphs we report the p-value of the Welch test for the null hypothesis that all mean reductions are equal across zones[9]: the null is rejected for all time series at 5% level. Red and to-red regions seem to have been very effective in reducing new cases, while for hospitalizations in regular wards and ICU only those regions in the red zone from the beginning where superior in reducing the growth rate. Regions in the other four groups showed similar reduction rates. The yellow group has highest dispersion, followed by the to-orange group. In those regions local governments have sometimes implemented further restrictions that may explain this difference among regions in the same risk zone. Moreover, some of these regions may have enjoyed positive side-effects from neighbors in stricter policy-zones.

[7]Since β_t are continuously compounded returns, they have the nice property of being additive: the composite rate is obtained as sum of the daily rates. We computed also discrete-time rates and (as expected) results are almost identical.

[8]Partially inconsistent data provided by Basilicata made the Scientific Committee of the Government doubt about their quality (cf. Basilicata24, 2020). Indeed, the placement and the figures of Basilicata in Table 1 seem to confirm the anomaly.

[9]The Welch test is an alternative to ANOVA F-test that relaxes the hypothesis of equal variances in the groups (Welch, 1951).

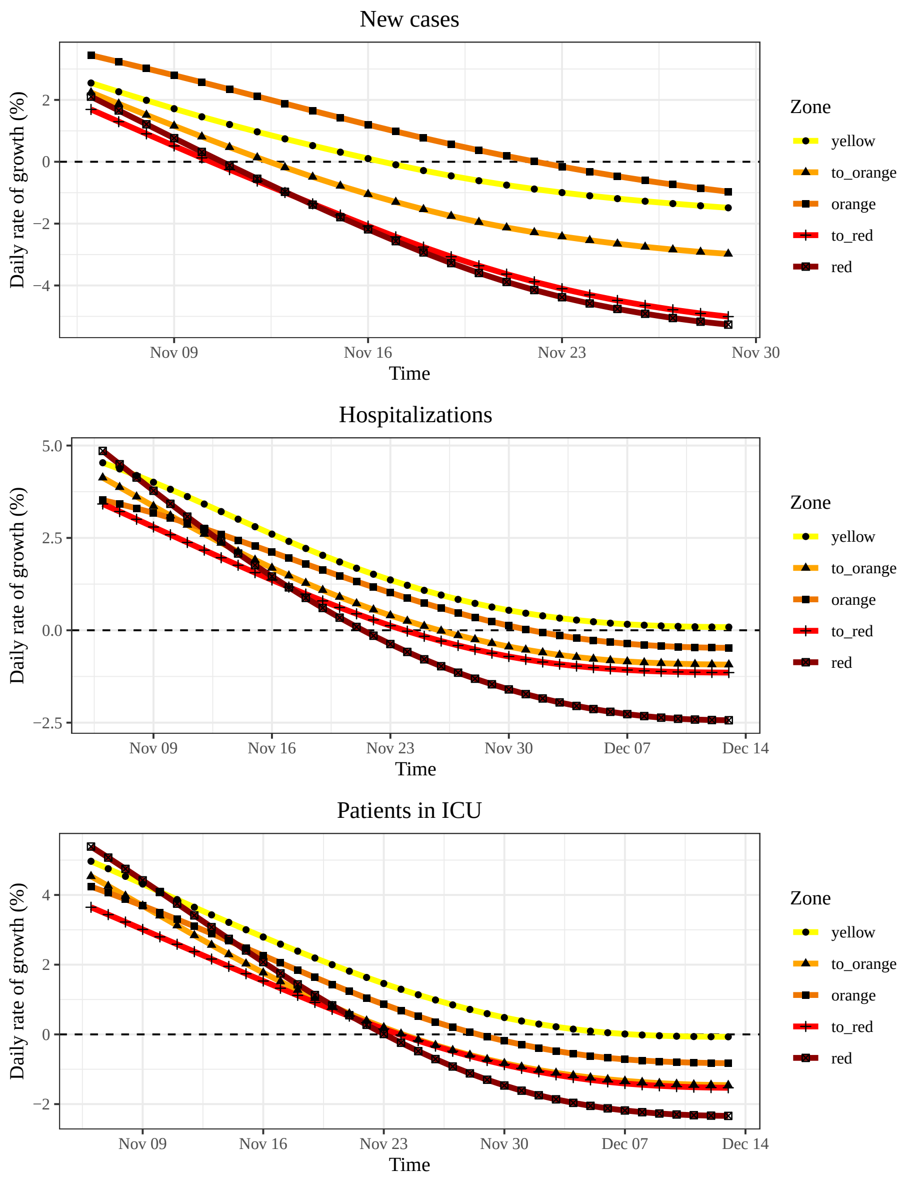

Figure 2: Mean growth rates by risk zone.

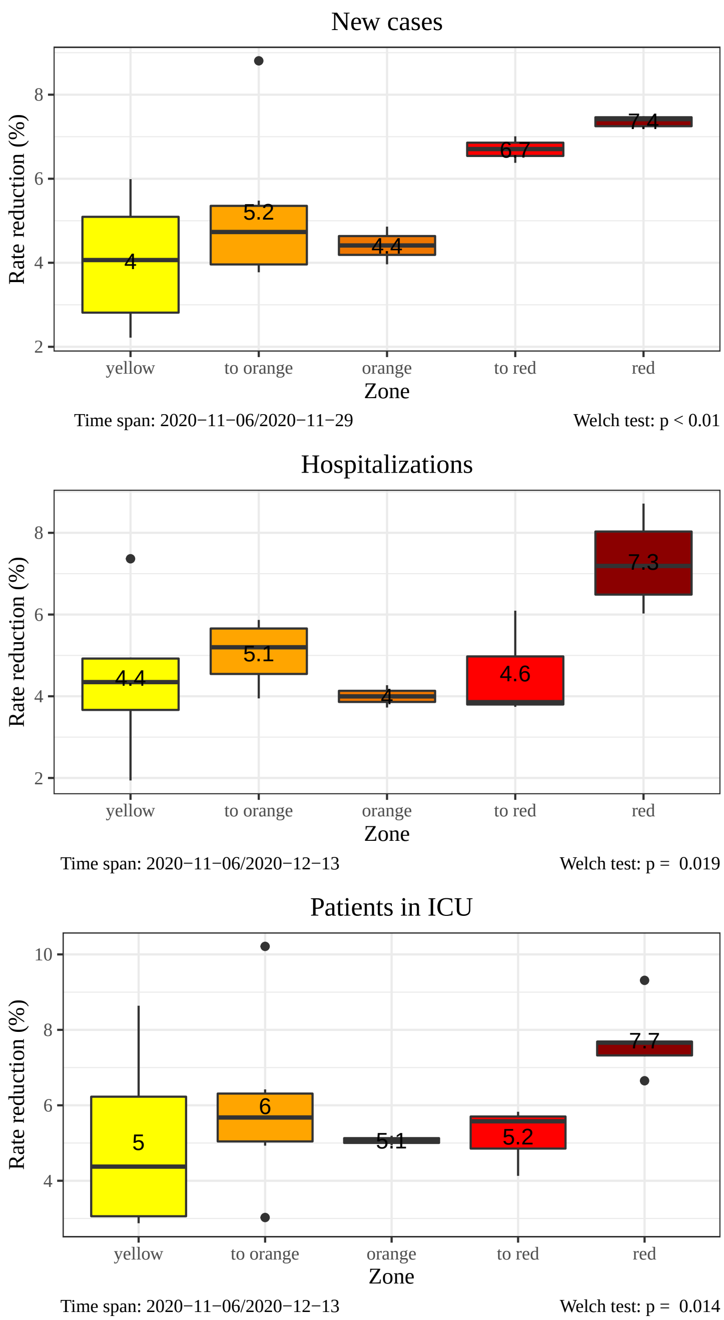

Figure 3: Distribution of regional growth rates by risk zone.

4. Conclusions

Our aim was measuring the effect of the Italian government three-color policy on the speed of spread of Covid-19 during the second wave. The limitations of our study are due to the following confounding factors.

- At the beginning of the period under study, starting on 6 November, all rates of growth were already decreasing. This first slowdown was very probably due to the restrictions promulgated in the 24 October decree (Presidenza del Consiglio dei Ministri, 2020a). Furthermore, few regional governments had implemented stricter limitations on school attendances.

- Only 11 out of 21 regions kept the same color during the whole period, while the others changes color once or twice (cf. Table 1). Our regrouping of these 10 regions cannot take into account all their slightly different histories.

- Regions following stricter policies (as red regions) may have brought benefits to neighboring regions in a couple of ways: movements between regions of different colors were not allowed (with some exceptions), hospitals close to red region boundaries received a decreasing number of patients from those regions.

This said, from our analysis we can conclude that the red zone policy was far the most successful in reducing the rate of growth of new cases, hospitalizations in regular wards and ICUs. We found no significant difference in the effects of the yellow and the orange policies. In particular, considering the 23 days under scrutiny, the decrease in rate of growth was very close to 7.4% for all red regions. If we scale this value to a single week, the average reduction is around 2.3% per week, even though the reduction has been quicker in the first two weeks (cf. Figure 2). For new cases, regions that ended in red (i.e., to-red regions) had almost the same behavior as regions that were red from the beginning. The difference of in rate of growth of red regions with respect to yellow, to-orange and orange regions is, on average, circa 3%.

If we consider the longer time span (37 days) for hospitalizations (also in ICU), the average reduction in red zones is, again, around 7.5%, even though the dispersion is slightly higher. The average reduction over time is 1.4% per week, even though the first three weeks show a quicker decrease. In these last two cases, to-red regions are similar to yellow and orange regions.

We can conclude that the package of measures contained in the red policy well responds to the need of quickly reducing the speed of transmission of Covid-19 and consequent hospitalizations. The yellow and orange policies show variable effects in the regions of application and, on the average, tend to have similar outcomes. This suggests that the effect of closing restaurants and cafe also at Noon is mostly negligible. In some of the regions in yellow zones new cases and hospitalizations tend to reach their maximum in the form of a plateau rather than a sharp peak. Thus, the measures contained in the yellow policy should be used in situations, in which hospitals and ICU are not close to saturation in order to let the virus circulate at a manageable speed.

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