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POLICY BRIEF

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FLATTENING CURVES & LIFTING LOCKDOWNS in EUROPE
A better method for estimating infection rates

Alexandra Campmas, Paolo Giudici, Andrea Renda, Joël Ruet

This paper presents a comparative analysis of the COVID-19 outbreak across ten major European countries. It identifies the best and worst performing countries in flattening the curve and promotes a new statistical method for estimating the 'reproduction rate' (known as 'R0') **to analyse individual countries and specific regions, to better target lock-down or easing of lock-down policies and explore the best, fastest and most secure policies, as we prepare for a possible second wave.**

The most important criteria for successfully flattening the curve have been early lockdowns. This has had a determining effect on the "epidemic reproduction rate" R0. There remains a significant divergence between the R0s which European governments are reportedly basing their policy decisions on, and the figures presented in this paper. This means that several European countries may under-estimate the extent to which their infection rates are being curtailed and their outbreaks are under control.

Our alternate method to estimating the R0 differs from conventional epidemiological methodologies because it takes into account evolving containment measures, how strictly a population adheres to these new lock-down rules, and is exactly tailored to the physical realities for each country. Statistical models like this can be of great use and should be discussed more by epidemiologists.

In terms of containing the outbreak, Greece is the best performing country in Europe followed by Czechia. While some countries keep struggling with R0s that fluctuate above 1 (Spain, The Netherlands, Germany) or are converging toward 1 (UK, Belgium Romania, Italy), Greece is well below 1 since the beginning of April, whereas Czechia and France have been below 1 since the second week of April.

KEY POINTS

- The worst performing countries are mostly explained by the delay in implementing proper lockdown and social distancing measures. Spain has emerged as the country of greatest concern. Although France shows a worrying upward trend, the French reproduction rate seems to be under control. On the other hand, Spain has overtaken Italy and the "first" steps towards lifting the lockdowns must be monitored with extreme caution. The UK is still witnessing an increase of the number of confirmed cases and deaths and the R0 the government is reportedly using (R0 = 0.7) differs substantially from the R0 we have estimated (R0 = 1.06).

- Greece is the most effective country in Europe in controlling the spread of the disease. It implemented full lockdown very early on and has slowed the pace of the outbreak substantially. Czechia also locked down early and shows similarly positive results, though less pronounced.

- Germany is an outlier. Though its lockdown measures have been implemented relatively later and not fully, the number of deaths has not reached the levels met by its neighbours but is still progressing quickly in relative terms. There is room for the situation to worsen, particularly as the healthcare system, while well equipped, is facing staff shortages.

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This Brief is based on earlier works:

- Ruet, J. (2020), Flattening the Curve, A pan-European comparative analysis of the COVID-19 outbreak, The Bridge Tank Special Report, http://thebridgetank.org/fr/2020/04/15/flattening-the-curve-a-pan-european-comparative-analysis-of-the-covid-19-outbreak-2/

- Agosto, A., Campmas, A., Giudici, P. and Renda, A. (2020), Monitoring COVID-19 contagion growth in Europe, CEPS Working Paper. https://www.ceps.eu/ceps-publications/monitoring-covid-19-contagion-growth-in-europe/

ON 'COMPARING COUNTRIES' on COVID-19

No government in Europe has full knowledge of the extent to which COVID-19 has taken hold of their population: data on the number of cases is incomplete. Death statistics have problems too (e.g. fatalities at home or in elderly care facilities might be under-reported. Germany only considers cases where Covid-19 is the only cause of death. France, Spain and Italy account all cases associated with Covid-19–in which the case may have so-called 'other morbidities'. In the UK there is a growing focus on "excess mortality." In short, Europe needs standardised reporting, but death statistics so far are the most reliable, so where possible we focus on these.

Here we promote two of the most useful measures: measuring the doubling time, and an alternate way of estimating the epidemiologic reproduction rate (R0) within a country.

Both are useful to compare countries in different positions, in order to constructively benchmark and draw inspiration from each other, at a time when most governments are hoping to de-escalate their lockdowns in the near future.

Our comparison focuses on relative performances in slowing down each country's epidemic. An increasing doubling time and a rapidly decreasing 'actual' reproduction rate measure the effectiveness of a lockdown, and both reflect an ability to decelerate the epidemics. We are hopeful this comparison can help European leaders exchange expertise, and identify solutions which may be contextual to their country, and those solutions which can be borrowed from other countries.

Depending on data availability, our alternative method of calculating the R0 could also model regional or metropolitan scenarios within countries. Armed with these insights, we can better target lock-downs, and also exiting of lock-downs. The family of statistical models our work has relied on, namely auto-regression models, produces results with fewer hypotheticals and uncertainties, and should be discussed by epidemiologists as a matter of priority.

METHODOLOGY[1]

In the paper "Flattening the Curve: A pan-European comparative analysis of the COVID-19 outbreak, we compared the 10 largest European countries by population. This covers countries with a combined population of nearly four hundred million people, representing around two-thirds of the population of Europe.

For reasons explained above, we focused on doubling rates with regards to deaths and confirmed cases. Doubling rates are the most appropriate way of evaluating a country's progress and also for comparing countries, because they rely on internal datasets generated within constant constraints of each country's policy and reporting regimes.

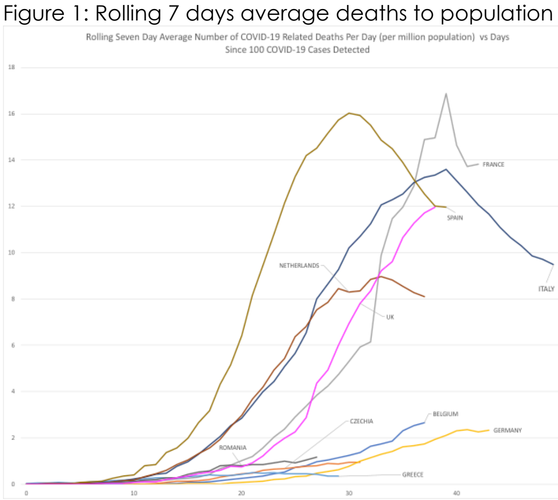
In this follow-up paper, we evaluate the R0, a virus's basic reproductive number. This is the classic epidemiologic metric used to describe the contagiousness of infectious agents. The R0 estimates how many new cases will offspring tomorrow from today's new cases. If the R0 is above one, each case is expected to infect at least one other person on average, and the virus is likely to keep spreading. If it is less than one, a group of infected people is less likely to spread the infection. Therefore, the reproduction rate should be interpreted along with the confirmed infected cases.

CALIBRATING NATIONAL TRAJECTORIES SINCE THEIR RESPECTIVE OUTBREAKS

Figure 1 shows rolling seven-day averages of COVID-19 related deaths per day per million population, plotted against the number of days since the first 100 recorded cases were recorded in each country. This allows us to understand trends in flattening the curve, and also allows for common time-lags in reporting of deaths.

There is significant disparity between those European countries which have been able to flatten the curve and those which have seen it climb significantly since their respective outbreaks began. Spain, Italy, the UK, France, The Netherlands are severely affected. All five countries also saw a rapid acceleration in numbers of deaths approximately two weeks after the start of their respective outbreaks.

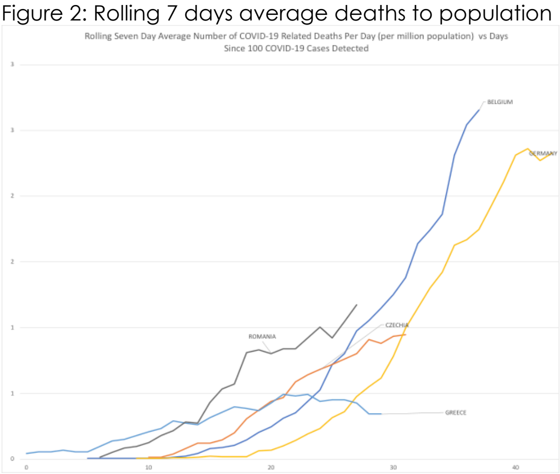
Figure 1: Rolling 7 days average deaths to population



1 For doubling times we used Oxford University's *Our World In Data* (with data from the European Centre for Disease Control & Prevention, and Worldometer (WHO data) when relevant data was only available there. R0 regressions use WHO data.

Figure 2 shows the trajectory of countries who have not seen such severe outbreaks, or are still in development. This is partly to make their trajectories more visible as the presence of France, Italy, Spain, the UK and The Netherlands above makes it hard to discern the relative performance of countries that are handling their outbreaks more effectively. Romania and Czechia are experiencing significantly worse outbreaks than Belgium or Germany were experiencing after the same number of days. Greece has effectively contained the virus.

Figure 2: Rolling 7 days average deaths to population



DOUBLING RATES – A PROXY METRIC FOR 'FLATTENING THE CURVE'

To assess the speed at which the outbreak is spreading, we have calculated the doubling rate – i.e. how many days it takes for the number of confirmed cases or deaths in each country to multiply by two. The doubling rate is an important measure for understanding the extent to which an outbreak is slowing down or speeding up. The doubling rate has the additional advantage of taking into account the testing regimes of each country. Having a longer doubling rate is better as it means the virus is spreading more slowly. Having a shorter doubling rate is worse as it means the virus is spreading faster. Having a doubling rate that steadily increases over time is a sign that the curve is getting actively flattened.

Figure 3 shows that between week one and week three, Greece has extended its doubling time the most, taking 3.2 days to double the number of cases when measured at one week (since its first 100 cases), but then 9.2 days when measured after three weeks. Czechia has extended its doubling time the most proportionally, from 2.5 days to 7.7 days. Italy starts with the shortest doubling time (1.7 days) of the countries surveyed, but after 3 weeks has improved its standing from the last place in the country ranking (with 1.7 days) to eighth place (with 4.1 days).

Figure 3: Cases Doubling time change from week 1 to 3

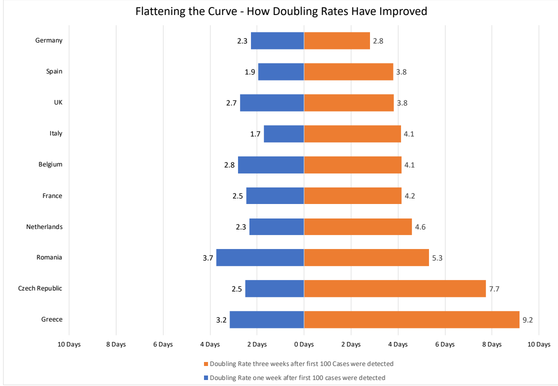


Figure 4 shows the country position after two weeks compared with the position after four weeks. Greece has extended its doubling rate even further to 19 days. Czechia (from 4.5 days to 13.2 days) and Romania (from 3.5 days to 9.6 days) have also extended their doubling rates to an impressive degree. The UK now ranks last in terms of doubling rate (4.6 days).

Figure 5 shows the country position after three weeks compared with the position after five weeks. Spain has improved its position while Germany, having been slower in reducing its doubling time, has moved back again to the bottom-3 fastest cases doubling time.

Figure 4: Cases Doubling time change from week 2 to 4

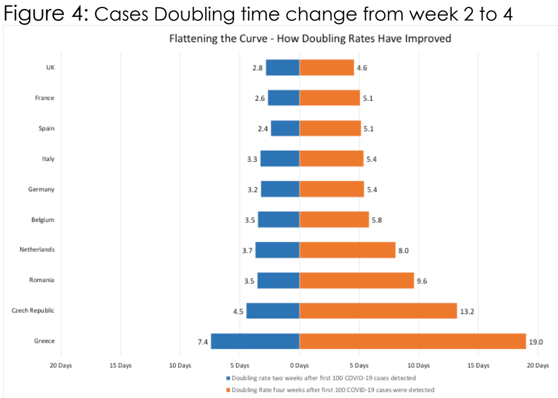
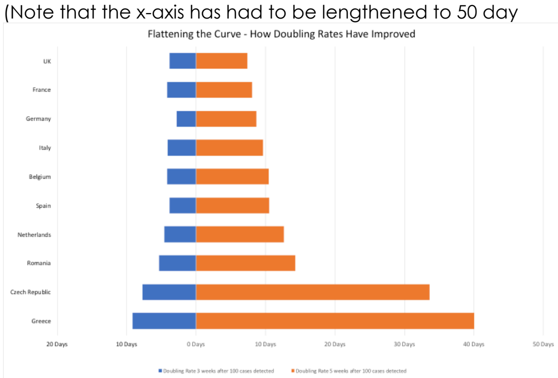
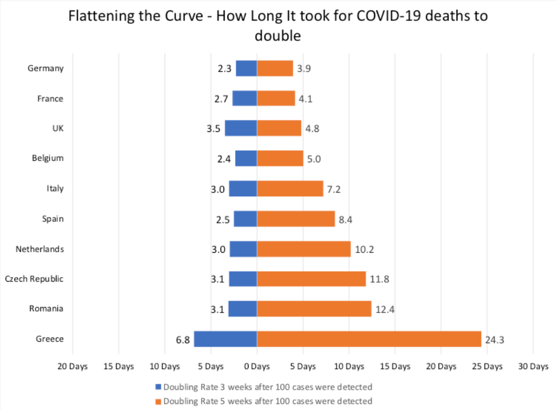


Figure 5: Cases Doubling time change from week 3 to 5 (Note that the x-axis has had to be lengthened to 50 day



Germany's struggle in containing the dynamics of the epidemics, that comparatively showed from Figures 3 to 5, is confirmed from the death doubling time comparison, which, at this stage of the epidemic outbreak is even more reliable than confirmed cases, as mentioned in introduction. Figure 6 shows that Germany, then France, then the UK were after five weeks had the fastest deaths doubling rates in Europe.

Figure 6: Deaths Doubling time change from week 3 to 5



However, there are substantial differences in how fast countries have been able to slow their outbreaks.

HOW QUICKLY COUNTRIES HAVE BEEN ABLE TO SLOW THEIR OUTBREAKS

A review of the average doubling rate for confirmed cases shows that in general, countries are seeing slower doubling rates as their outbreaks evolve, from 2.5 days after one week (from 100 confirmed cases detected, see Figures 7) through to 5.2 days after three weeks (again, from 100 confirmed cases detected, see Figure 9).

After one week (see Figure 7), two countries were seeing confirmed cases double every two days or less: Italy (1.7 days) and Spain (2 days). The countries with the longest doubling rates were Romania (3.7 days) and Greece (3.2 days). After two weeks (see Figure 8), most countries began slowing their doubling rate, although four countries saw relatively small changes (Romania with -0.2 days), UK with +0.1 days, France with +0.2 days and Spain with +0.44 days). Greece was able to extend its doubling rate the most (+4.26 days), while Czechia also performed well (+1.95 days).

After three weeks (see Figure 9), Germany had dropped to last place in terms of its doubling rate. Although it had still slowed its rate of growth, it also saw the lowest increase in doubling time (+0.53 days), while Greece (+6.01 days) and Czechia (+5.24 days) continued to see the greatest improvements in slowing the spread. After 4 weeks, tests saw a decrease and we rather focus on doubling time of deaths (Figures 10 to 13).

Figure 7: Doubling rate of cases after one week

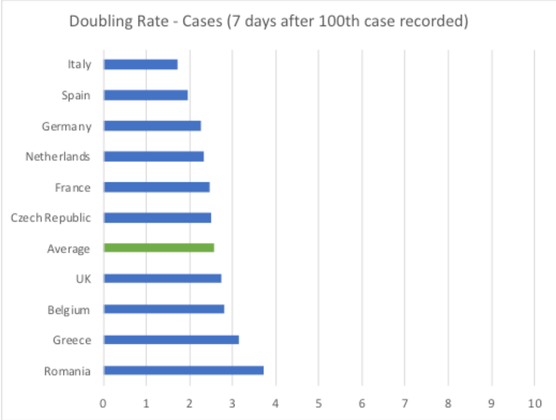


Figure 8: Doubling rate of cases after two weeks

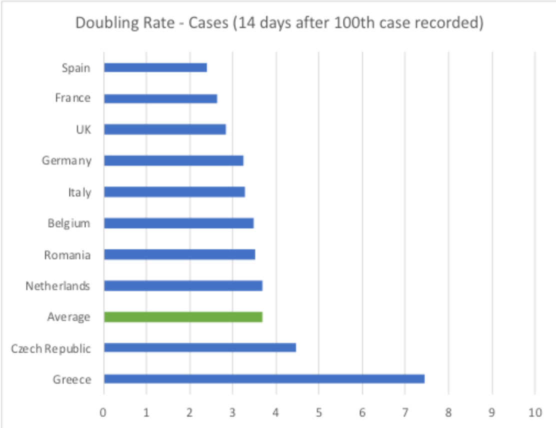
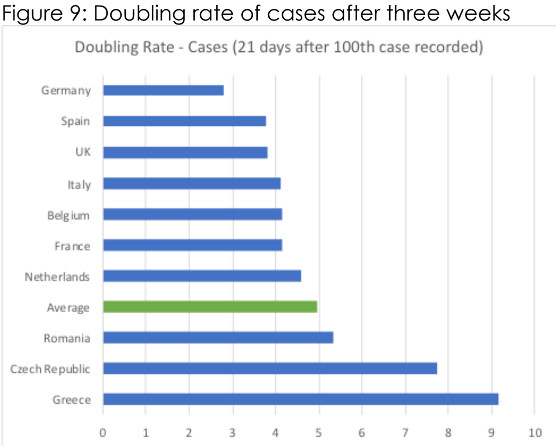


Figure 9: Doubling rate of cases after three weeks



There was little data recorded for the number of deaths seven days after the first 100 cases were recorded in each country. After 14 days, only six out of our ten countries had relevant data. However, we have presented the data below as it still provides useful insights.
Greece keeps on performing well, extending its doubling rate from 2.9 days when measured after 2 weeks through to 6.81 days when measured after 3 weeks, and then to 10.0 days when measured after 3 weeks. We also see average doubling times for deaths improve across Europe from 2.1 days when measured after two weeks (Figure 10) to 3.2 days when measured after 3 weeks (Figure 11) and finally to 4.8 days when measured after 4 weeks (Figure 12). Overall doubling time greatly

improved by 5 weeks (Figure 13, Note the lengthened x-axis).

Figure 10: Doubling rate of deaths after two weeks

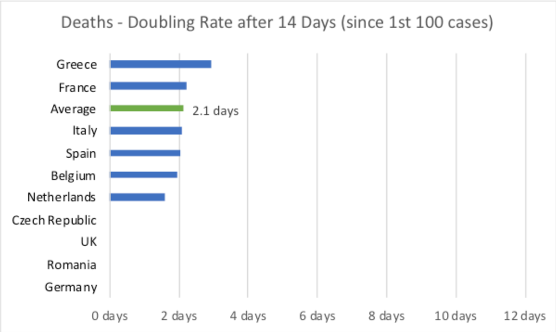


Figure 11: Doubling rate of deaths after three weeks

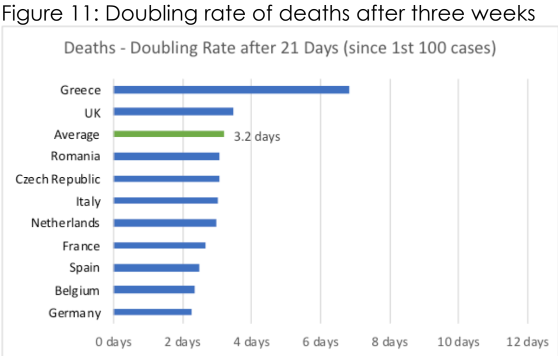


Figure 12: Doubling rate of deaths after four weeks

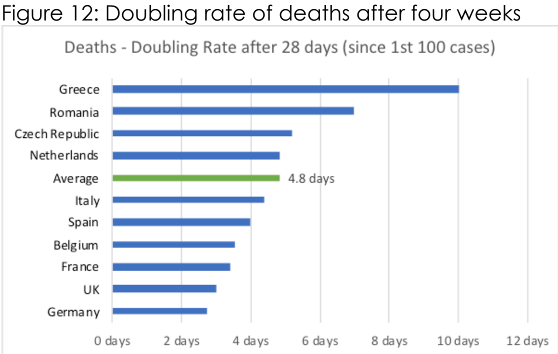
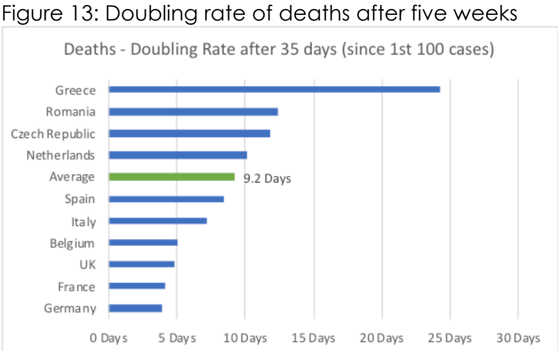


Figure 13: Doubling rate of deaths after five weeks



DOUBLING TIME ANALYSIS: WHEN LATE LOCKERS STRUGGLE

A notable difference between the 21-day and 28-day snapshots is the collapse in the UK's average ranking. In Figure 11, the UK ranks above the European average with a 3.5 day doubling rate. When measured a week later in Figure 12, the UK has dropped to second last place, with a 2.99 day doubling rate. While other countries in Europe have been able to substantially improve their doubling rates for deaths and reduce the speed of the spread, the UK seem to be struggling.

France is also struggling to control its doubling rate. After two weeks it stood at 2.2 days (see Figure 10), which was above the European average, but after 3 weeks it was only at 2.7 days, which was below the European average (see Figure 11). After 4 weeks (see Figure 12), it was ranking third worst in Europe with a doubling time of 3.4 days.

In short, countries that witnessed the outbreak in Italy and then reacted fast have performed well, while countries that were slow to implement lockdowns early on and with stringent terms, despite seeing Italy's struggle, have performed poorly.

REPRODUCTION RATE ANALYSIS

R0 is a measure of how infectious a disease is. It is defined as:

$\boldsymbol{R0} = \boldsymbol{f} * (\mathbf{1} - \boldsymbol{a}) * \boldsymbol{E}(\boldsymbol{T}) \,/\, \boldsymbol{h}$, where:

- for any individual in a population, f is the probability of becoming infected (infection rate);
- E(T) is the mean incubation time of the disease
- h is the probability of detecting the infected case (confirmation rate);
- a is the probability of isolating the contacts of the infected case (quarantine rate).

The calculation of the traditional R0 is based on the whole distribution and leaves little room to account for "local shocks" (e.g., daily specific changes in the contagion counts, such as the outburst of a cluster of cases in a new location, the application of a new policy measure or a decrease in compliance to measures).

A first problem with this approach, and others in the literature and on media discussions about the COVID-19, is that it introduces a bias in the measurement of f (the probability of being infected).

In other words, what is being estimated is not the infection rate f but the "instantaneous" reproduction rate $\boldsymbol{b} = \boldsymbol{f} * (\mathbf{1} - \boldsymbol{a})$, which "incorporates" a (the quarantine rate) and h (the probability of detection).

A second problem is that, while E(T) (the mean incubation time) and f (infection probability) may be considered as quite stable across different countries, a and b in fact can vary a lot, depending not only on the adopted prevention policies but also on to what extent people are compliant with them.

To address the first problem, we opt for a model capable of learning b, not f, directly from the data. Within this framework, the effect of policy making can be evaluated not in absolute terms, but relatively to the existing measures. To cope with the second problem, we estimate the instantaneous reproduction rate of a country, b, directly from its observed evidence, taking into account the need to incorporate sudden changes in contagion counts ("shocks") that may be due to changes in the parameters a and h[2].

An alternate way of better calculating R0

Instead, the measurement of R0 presented in this section addresses these caveats by dynamically learning, from the data, the contagion growth corrected for these "local shocks". We have used "auto-regressive models", which allow integrating real-time evolutions in the epidemic evolution[3].

In the five most affected European countries, namely Spain, Italy, France, Germany, and the UK, overall, the reproduction rate has trended downwards to converge and fluctuate around 1 (Figure14).

Recently, Germany and Spain recorded a small bounce-back with an R0 moving up to 1.17 for Germany and 1.25 for Spain (See Table 1). Figure 14 indicates that these moves appeared as of the 14th of April, at which point Spain had decided to gradually resume activities in "non-essential" economic sectors. Italy then followed a similar path, with a R0 above 1. Table 1-bis shows that Italy, France, Germany have lately brought their reproduction rate below 1 though France experienced a rebound. The recent resurgence of the R0 value in some countries could be due to the incremental steps taken or planned towards lifting the lockdowns.

By contrast to Germany, it seems that the UK have succeeded in smoothly compressing its initially high reproduction rate over the past period. However, while Germany reached an end-point where the R0 is somehow controlled, this is not yet the case for the UK, for which the R0 is still around 1 (See Table 1-bis).

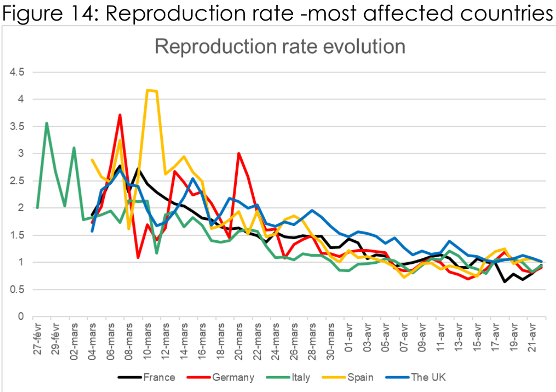
Table 1: R0 – value by 17th April

	France	Germany	Italy	Spain	the UK
R0 - latest value	0.68	1.17	1.04	1.25	1.06

Table 1-bis: R0 –value by 22nd April

France	Germany	Italy	Spain	UK
0.94	0.91	0.94	1.01	1.01

Figure 14: Reproduction rate -most affected countries

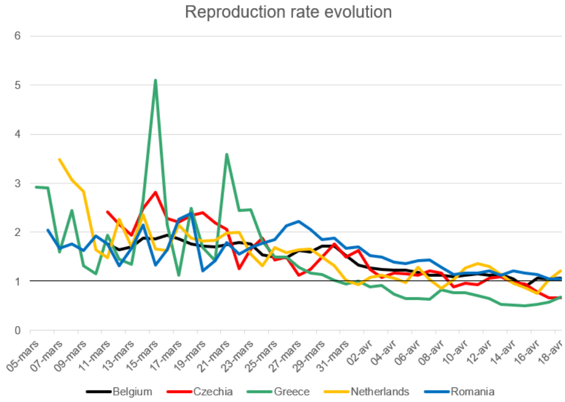


In the other five countries under investigation, both the evolution of the reproduction rate (Figure 15) and its latest calculated values (Table 2) were showing since the mid of April clear differences amongst the different countries so we below distinguish between medium-affected countries, namely Romania, The Netherlands and Belgium (Figure 16 and Table 2-bis) and least-affected countries, namely Greece and Czechia (Figure 17 and Table 2-ter).

Table 2: R0 – latest value (17th April) (Czechia: 15th April)

	Belgium	Czechia	Greece	The Nethelands	Romania
R0 - latest value	1.06	0.66	0.68	1.22	1.05

Figure 15: Reproduction rate-less affected countries



First and foremost, after experiencing a small rebound in R0, the Netherlands now exhibits a similar trend as Germany. It is worth noting that, until very recently, the Czech Republic featured a similar trend. Second, it seems that Belgium and Romania have, in the last few days, firmly levelled off their reproduction rate at around 1 and are now showing difficulties in bringing this rate below 1.

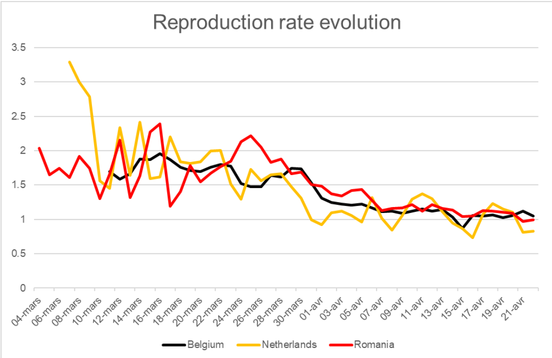
Table 2-bis: R0 value by 22nd April

Belgium	Netherlands	Romania
1.05	0.83	0.99

[2] Subsequent results derive from a Poisson auto-regression model of the daily new cases. https://www.ceps.eu/wp-content/uploads/2020/03/Monitoring_Covid_19_contagion_growth_in_Europe.pdf

[3] A simple linear regression is a modelling of the relationship between a variable one wants to explain and one or more independent explanatory variables. An autoregressive model is a regression model in which a time series is explained by its past values rather than by other, independent, variables.

Figure 16: Reproduction rate-medium affected countries



Finally, Greece, for the last three weeks has appeared to be the best performing country in containing the contagion of the virus, with an R0 of 0.68, by mid of April joined at this level by the Czech Republic, but with a later rebound (see Figure 17 and Table 2-ter).

Figure 17: Reproduction rate-least affected countries

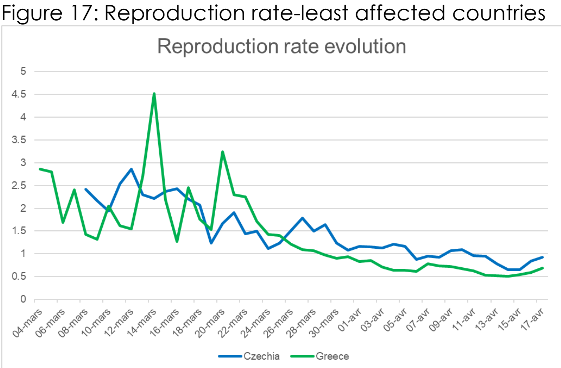


Table 2-ter: R0 latest value displayed (17th April)

Czechia	Greece
0.93	0.68

Differences with government assumptions

While the R0 value is very useful as a basis for designing and monitoring policies, it bears recalling that this epidemiologic metric is not set in stone. The R0 value of a given pathogen varies not only in time and space, but also as a function of "local shocks", due to containment measures and changes in testing and reporting. The "traditional" epidemiological model of R0 being referred to in national debates only accounts for variations in the total number of observed infected individuals and, therefore, is subject to a high measurement error.

Instead, the R0 measure presented in this paper, based on the autoregressive model proposed by Agosto and Giudici (2020) takes local shocks into account and, therefore, yields more accurate values, thus providing a more suitable basis to support policymakers in their policy strategies, and a basis which can evolve over time, to support continuous monitoring.

STATISTICAL MODELS AS POLICY TOOLS FOR LIFTING LOCKDOWNs

The comparative advantage of advanced statistics over conventional epidemiologic methods in monitoring the evolution of the COVID-19 contagion is that they can adjust to policy making decisions (for example, aimed at introducing social distancing, or other restrictions to mobility) and can therefore be employed to understand the impacts and effectiveness of government policies.

Differences between our and 'official' R0s

Several R0 models presently being used by governments presume that "implementation and adherence to social containment measures are complete."[4] But total adherence doesn't reflect behaviour in many countries, where enforcement (and citizen's acceptance of the lockdown) is varying a great deal.

Table 3 shows the official R0 used for some countries in our study[5]. Several countries are non-transparent and a few over-estimate their achievement. Notably in the UK, Germany and Spain we see large discrepancies that call for caution now that each are considering or planning to loosen their lockdowns.

Table 3

	Official R0	18th April Estimate	24th April Estimate
UK	0.7	1.06	1.01
Germany	0.9	1.17	0.91
Spain	1.03	1.25	1.01
Italy	Below 1	1.04	0.94
France	0.6	0.68	0.94
Belgium	NA	1.06	1.05
Czechia	Close to 1	0.66	0.93
Greece	Well below 1	0.68	NA[6]
Netherlands	Less than 1	1.22	0.83
Romania	NA	1.05	0.99

[4] As mentioned in the methodology section. Our auto-regressive modelling, draws from observed data and is thus more realistic.

[5] Government data, except for the UK (Imperial College study). They stand for dates varying 19th to 21st April, except for Czechia (April 8th). Netherlands data is a leaked scientific advice to the Guardian, saying it has been less than 1 since 15 March.

[6] Since April 16th, Greece has had so few reported cases that the R0 analysis was no longer scientifically valid (it produced a clear anomaly). As such, the figure for Greece has been omitted from this final round of reporting.

CONCLUSION – PERSISTENCE vs. EXTINCTION and LIFTING the LOCKDOWNs

Political leaders lack decision-supporting tools when an unknown virus crops up. With COVID-19, nations were rushed into making emergency decisions without full data on hand. Importantly, the countries that have been hit by the outbreak so far include some of the most advanced economies in the world, with a tradition of evidence-based policymaking.
To bridge the gap we analysed the evolution of the COVID-19 pandemic in the 10 largest European countries by population, representing a combined population of nearly four hundred million people. We measured the impact of early vs. delayed lockdowns on COVID-19 outbreaks and furthermore the ability to reduce the epidemics doubling time. As some countries now consider gradual lifting of lockdowns, our new estimates of the reproduction rate R0 allow some new recommendations.

We find a group of six countries whose COVID-19 outbreaks are substantially worse than their European neighbours: Italy, Spain, The Netherlands, France, Belgium and the UK. Their crises largely reflect a failure to react quickly and implement lockdowns. Germany has been performing better within this group, though with a patchy and partial lockdown. However the recent bounce-back of their R0 and a stubborn doubling rate calls for close monitoring by the authorities. Greece, followed by Czechia and Romania, is by far the best performing country in Europe in terms of doubling time control, thanks to its early and stringent lockdown. Going by the R0 parameter, the three best performing countries are Czechia, Greece, and France, which all share R0s within a small range of each other.

At a time when all countries are planning steps towards lifting lockdowns, the R0 should be closely and regularly monitored by policy makers, especially in countries with a very sizable number of confirmed cases. Indeed, a value above one –or high ***persistence***- in these countries with high numbers of cases is likely to cause a second significant wave of infections if no restrictive or protective measures are taken by the authorities -and if compliance decreases. A value lasting for a good time below 1, especially combined with a low number of cases, is conversely a sign of ***extinction***. Lastly, cases combining low persistence but still high contagion stock, or countries with lower contagion but sustained persistence are a matter of caution.

- In countries such as Greece, which has consistently showed a low persistence in contagion shocks, restrictive measures might become more relaxed, since there is a risk that social costs of lockdown may outweigh the benefits. The same could in time apply to Czechia and France, should they return to their recent encouraging R0 (after a deterioration in the past few days). France, additionally needs to monitor closely its doubling times.
- In countries with lower contagion, but high persistence and slowly increasing contagion (currently Germany), careful monitoring might be coupled with at least "mild" restrictions such as physical distancing or isolation of specific areas.
- Countries which experienced an explosive process such as Spain, The Netherlands, UK, combined with untamed persistence, require continued swift policy measures such as quarantine, diffuse testing and will need to consider a continued lockdown.
- Countries with a not completely contained process and R0 oscillating around 1, such as Italy, Belgium, equally need continued conservative policies.

Some geographic fine-tuning is worth exploring. This alternative method of calculating the R0 has can fit a country, but also a region, or a metropolitan area, depending on data availability. This allows truly granularized policy making. Our alternative way of calculating the R0 takes into account on a day-by-day basis how easing or implementing of lockdown immediately impacts R0s. The family of statistical models we present here is producing results that can and should be discussed by epidemiologists. Auto-regression models form a transparent statistical tool, easy to understand by policymakers, and offer much better transparency to citizens. They also pave the way for a more transparent government and democratic society after the first COVID-19 wave recedes. This will become all the more important as we prepare for a possible second wave.