Public health interventions to control the SARS-Cov2 outbreak in seven countries

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The Lancet

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--Manuscript Draft--

Manuscript Number:	THELANCET-D-20-10037
Article Type:	Article
Keywords:	COVID-19; Public health; Preparedness; containment measures
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Manuscript Region of Origin:	FRANCE
Abstract:	Background: To control the Covid-19 outbreak, national governments have implemented public health control measures (PHM) at different times and in differing order (lockdown, social distancing, etc.), which raises questions about the effectiveness of these interventions. The objective of this work is to study the impact of these measures and the timing of their implementation in the first few weeks of the outbreak in some countries (United Kingdom, France, Germany, South-Korea, the Netherlands, Spain, Italy). Methods: We first estimated case incidence, mortality per 100,000 population and case fatality rate based on data obtained from the European CDC website. We then created a model to estimate the impact of PHM on the outbreak using the results obtained in the first step of the analysis. Three indicators were calculated for each country: the slope reduction value (i.e., the reduction in the number of cases) 15 days and 25 days after measures were implemented and the exponential growth rate 40 days after the outbreak. Results: Case incidence in two countries (Germany and the Netherlands) remained under 10 cases/100,000. PHM were most effective in Korea, where the incidence always remained under 2 cases/100,000, with an estimated case reduction of 98% and a slope reduction of 84%. At the time of writing, the worst affected country in terms of the case fatality rate was France (151/1,000). Conclusions: Our results suggest that the rapidity of implementing PHM was more important than the nature of the intervention or the order in which they are implemented. Two PHM were decisive: general screening and self-quarantine of cases; these led to the flattening of the curve in Korea alone. This approach, coupled with the appropriate hospital response (use of resuscitation beds), appears to be have contributed to the low mortality observed in Germany and Korea. Funding: Agence Nationale pour la Recherche

Public health interventions to control the SARS-Cov2 outbreak in seven countries

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Abstract

Background: To control the Covid-19 outbreak, national governments have implemented public health control measures (PHM) at different times and in differing order (lockdown, social distancing, etc.), which raises questions about the effectiveness of these interventions. The objective of this work is to study the impact of these measures and the timing of their implementation in the first few weeks of the outbreak in some countries (United Kingdom, France, Germany, South-Korea, the Netherlands, Spain, Italy).

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Introduction

Since the first confirmed SARS-Cov 2 case in December 2019, unprecedented public health interventions have been implemented worldwide to control what appears to be the worst pandemic in the era of modern medicine.[1] The worldwide containment strategy involves roughly three billion people, resulting in a worrying slowdown of the world economy.

The pandemic shakes up certainties, challenges societal organization and will likely trigger profound changes in social and economic models. Previous outbreaks such as H1N1, Chikungunya, Zika, Ebola, West Nile, SARS Cov1, and MERS-Cov have had significant impacts on some populations (Zika in Brazil, Ebola in West Africa, etc.).[2,3] In contrast, Europe has remained mostly untouched by these epidemics; health care systems are therefore more focused on caring for non-transmittable diseases.[4,5] Most, if not all, European countries therefore lack the experience and organization required to face a lethal pandemic. In addition, national governments and the WHO have been slow in recognizing the pandemic nature of the SARS-Cov 2 threat.

Eventually, every country has had to implement public health measures to minimize the impact of the pandemic on populations by delaying or limiting the propagation of the virus. While these public health interventions were similar in many countries and mainly included lockdown, social distancing, and closure of schools, there were nevertheless many differences between countries in the timing and order of their implementation. In the present study, we compare the impact of containment measures taken by seven countries during the first weeks of the outbreak.[7]

Methods

Data Collection

We obtained COVID-19 data on France (Fr), Spain (Sp), Italy (It), United Kingdom (UK), the Netherlands (Ntl), Germany (Ger), and South Korea (SK) from the European Center for Diseases Control website. We selected these seven countries as they provided consistent daily health data and details of their containment strategies. The following data were collected from December 31, 2019 to April 13, 2020, for each country: number of new cases per day, number of deaths per day, and the actual population as of December 31, 2018.[8] We computed daily incidence of cases and case fatalities per 100,000 inhabitants (Figure 1).

Definitions

We considered the following interventions to be of interest: early detection of cases, social distancing, school closure and general lockdown, as these were the most frequent and representative measures across all seven countries.[7,9–16] We took into account the actual dates of implementation and not the official announcement dates (Figure 1).

Analysis

We charted the implementation of public health interventions in time and the time curves of cases/100,000 for each country. Each point on the graphs corresponded to one of the following four interventions—general screening, social distancing, school closure, and general lockdown. Thereafter, we plotted in logarithmic scale the cumulative number of COVID-19 cases per 100,000 inhabitants in each country from January 1, 2020 to April 13, 2020. We then computed the date of the onset of the outbreak, t_0, corresponding to the end of the plateau preceding the rapid increase of cases (Figure 2).

At point t_0, we defined three indicators of the effects of the public health interventions by country (Figure 4). In the descriptive analysis (first graph), the exponential growth rate of the outbreak (indicated by a red line) was computed from the date of implementing the last intervention (date t_1). The yellow line indicates the exponential growth rate of the epidemic 15 days later, at date t_2 (i.e., t_1+15). This means that at day t_1 (respectively t_2) the number of cases/100,000 increased approximately at the rate of: $C_1\exp(S_1*(t-t_1))$ (respectively $C_2\exp(S_2*(t-t_2))$). Moreover, the number of cases 10 days after t_2, at date t_3, is approximately equal to $C_2\exp(S_2*(t_3-t_2))$. The exponential growth rate, S_1, was determined using nonlinear least square regression at time t_1 based on the number of cases during the 10 previous days. Thus, if C_{-9}, …, C_{-1} and C_0 are the number of cases at time t_1-9, …, t_1-1 and t_1 (in days), and C_1 and S_1 indicate the minimum of the function *F* of variables *C* and *S*:

$$F(C,S) = \sum_{i=0}^{9}(Ce^{S((t1-i)-t1)} - C_{-i})^2$$

Due to the logarithmic nature of the evolution curve, the exponential growth rate at a given time almost coincides with the tangent slope at that point.

The three indicators estimated were as follows:

- the slope reduction value 15 days after measures are implemented; this was calculated for each country according to the formula below:

$$Slope\ reduction = 1 - S_2/S_1$$

- the reduction in the number of cases by country following the implementation of measures after 25 days; this is calculated according to the formula:

$$Reduction\ in\ case\ number\ after\ 25\ days = 1 - exp\ (10(S_2 - S_1))$$

This is the ratio of the expected number of cases after 25 days had no measures been taken (estimated by $C_{WO} = C_1\ exp\ (25\ S_1)$) to the approximate number of cases after 25 days following the implementation of the measures (estimated by $C_W = C_1\ exp\ (15\ S_1)\ exp\ (10\ S_2)$).

- The exponential growth rate (S_3) 40 days from the onset of the outbreak (i.e., at date $t_3 = t_0+40$).

All statistical analyses were conducted using MATLAB R2017A software (MathWorks, Natick, MA, USA).

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the article. The corresponding author (LJ) had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

According to our graphs, social distancing and school closure were the first measures taken by France, Italy, Spain, the Netherlands and United Kingdom. Italy implemented two out of the three public health interventions (social distancing, general lockdown) when case incidence rose to above 2/100,000 (Figs. 1–3). However, other countries initiated interventions when case incidence was lower. The first intervention undertaken by Germany and South Korea was large-scale early detection of cases, which these countries implemented earlier than other countries (Figs. 1–3).

The peak case incidence/100,000 inhabitants remained <2 cases for South Korea, <10 in Germany and The Netherlands, and >10 for France, Italy, Spain and the United Kingdom (Figure 1).

Outbreak profiles for France, Italy, The Netherlands, United Kingdom and Germany were comparable (Fig. 2). The outbreak profile for Spain showed an early acceleration in the number of cases from being the country with the lowest incidence, Spain rapidly reached Italy's highest incidence (Fig. 2). For South Korea, which implemented public health interventions before the

onset of the outbreak, the outbreak profile remained flat at the lowest among the seven countries studied (Fig. 2), (Figs. 1– 3).

The exponential growth rate in case incidence and evolution of the outbreak in the seven countries varied (Figs. 2, 4). For South Korea, the estimated reduction in the number of cases was 98% and the reduction slope was 84%. The reduction in the number of cases and the slope reduction for France, Germany and Italy were similar. The rate of reduction in the number of cases in Spain was 90% and the slope reduction was 58%. As United Kingdom was the last country to implement public health interventions (Fig. 3), the reduction in the number of cases was the least (67%, slope reduction 43%). In addition, at 40 days from the onset of the outbreak, exponential growth in case incidence in the United Kingdom continued to be markedly above that of any of the other country (Tab. 1). The Netherlands had implemented public health interventions without general lockdown much earlier than other European countries. This had a significant positive impact on the outbreak, resulting in a decrease of 80% in the number of cases (Fig. 4). Similarly, in South Korea and Germany, the nationwide containment strategy had considerable positive impact on COVID-19-related mortality. At the time of writing, France had the worst burden of COVID-19, with a case fatality rate of 151/1,000 (Table 1).

Discussion

Our study findings indicate that the rapidity, and not the order of implementation or the nature of the public health intervention was the key element in controlling the COVID-19 outbreak. Early interventions aimed at reducing physical contact between people reduce the dynamic of the epidemic and lessen the negative impacts on the population.[17]

From a public health perspective, these results highlight the importance of taking rapid action by policy makers. The example of South Korea is interesting in this regard. It is possible that South Korea has learned from its experience with the MERS-Cov outbreak in 2015, which may

have led to preparedness, and early and rapid responses to COVID-19.[18] The nationwide containment strategy was triggered as early as January before the onset of the outbreak. Interventions included the production of a significant number of tests for early detection of cases, organized mask distribution, and full compliance of the population with self-isolation measures for both cases and contacts.[19] South Korea also introduced the concept of "drive through" and "walk through" testing, thereby increasing its processing capacity and demonstrating an active administration.[20–23] South Korea remains the country most successful in controlling the COVID-19 threat, with the lowest cases fatalities. Germany has also been successful in limiting the burden of COVID-19, although its population is among the oldest in Europe. South-Korea and Germany have the highest number of hospital and intensive care unit (ICU) beds compared to the other five study countries.[24,25] In Germany, the number of ICU beds increased from 28,000 before the Covid-19 outbreak to 40,000.[25] Adequate number of ICU beds may have contributed partly to the lower mortality rates observed in South Korea and Germany. Digital tracking of case contacts has probably also helped in controlling the outbreak in South Korea.[26] Although digital tracking allows for early detection of cases and selective quarantining, the intervention remains controversial due to its potential impact on individual freedom. A democratic debate about the intervention is necessary; although this cannot be conducted during the pandemic, it should be arranged in the future. The current pandemic highlighted the insufficient preparedness of both public health authorities, as well as the general population in most countries, with the exception of South-Korea.

This study also highlighted the importance of the population's preparedness and willingness to comply with public health interventions that were restrictive of individual freedom. Human lifestyles (rapid international travel, pressure on the environment, climate change, etc.) may also have played a key role, suggesting the need for increased global awareness of the need to change our lifestyles and to anticipate future crises.[27] In the very short term, the specter of the

dreaded Covid-19 second wave should encourage us to take appropriate action, this time, without any delay.[28]

The study had several limitations. The data used were self-declared by the countries and data collection and reporting methods varied between countries. Nevertheless, as each country data were reported consistently over time, the trajectory and analyses of the dynamic evolution curves of the outbreak are valid. We selected only the most common or representative public health interventions. We cannot therefore rule out differences between countries due to differences in local or specific measures undertaken.

We analysed only Western European countries and South Korea as a reference model. Results to other European countries or to other continents should therefore be extrapolated with caution, and all research should be based on analyses of local conditions in each country.

In conclusion, regardless of the nature of nationwide containment measures or the order of their implementation, the rapidity with which they were implemented was the main determinant of the success of these measures in controlling the COVID-19 outbreak. It is possible that the rapidity of implementing public health measures was dependent on the country's preparedness in combating infection, such as the capacity for early case detection, educating the population in limiting inter-person contact, respect of social norms, and having the appropriate number of ICU beds.

Contributors

LJ, LD, and DA had the idea for and designed the study and had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. LJ, LD, and DA drafted the paper. LJ and DA decided to publish the paper. LD and LJ did the analysis, and all authors critically revised the manuscript for important intellectual content and gave final approval for the version to be published. All authors agree to be accountable for all aspects of the work.

Declaration of interests:

We declare no competing interests.

Acknowledgments

This work is part of FHU SEPSIS and RHU RECORDS, which are funded by the French government through the Agence Nationale pour la Recherche (Programme d'Investissements d'Avenir, project number ANR-18-RHUS60004).

Research in context

Evidence before this study

Since the first confirmed SARS-Cov 2 case in December 2019, the worldwide containment strategy involves roughly three billion people. Each nation launched its own containment.

While these public health interventions were similar and mainly included the same measures (lockdown, social distancing, and closure of schools...) there were nevertheless many differences between countries in the timing and order of their implementation. At the end strategies and impacts on populations were different. News from Korean and Germany reported a limited impact as Italian and Spanish outbreaks were dramatic. This pushed us to work for understanding a so huge difference. We first searched PubMed on March 20, 2020, for articles that documented the situation. We didn't find any interesting answer. Articles tried to predict the global impact or to estimate the R_0 but no one tried to explain the different impacts among countries. We searched with Google, in the days after, which strategies was used by nations (measures timing and order of their implementation). and all of them were different. We decided to try to understand such differences.

Added value of this study:

These findings indicate that the rapidity, and not the order of implementation or the nature of the public health intervention was the key element in controlling the COVID-19 outbreak. Early interventions aimed at reducing physical contact between people reduce the dynamic of the epidemic and lessen the negative impacts on the population.

Implications of all the available evidence:

The study highlighted the importance of the population’s preparedness and willingness to comply with public health interventions even restrictive of individual freedom. This results

implicate in the very short term, a Covid-19 second wave should encourage us to take appropriate actions, this time, without any delay. And in long term this results should push to modify our lifestyles (rapid international travel, pressure on the environment, climate change, etc.), because they have played a key role in this outbreak, and demonstrate the need for increased population preparedness to anticipate future crises, if nothing change.

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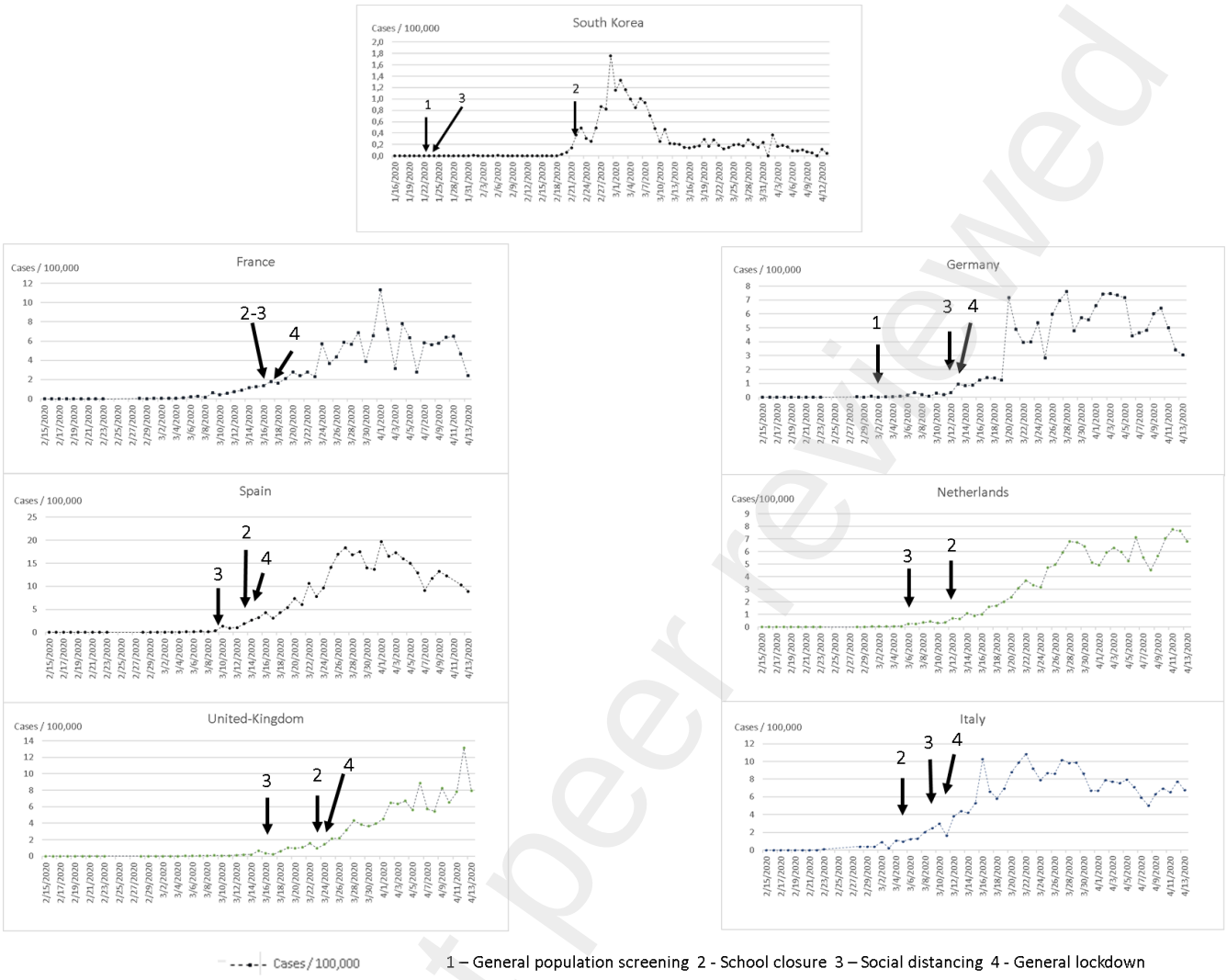

Figure 1 – Evolution of the Covid-19 outbreak in terms of the number of cases/100,000 in seven countries and dates of public health measures taken, January 16th –April 13th, 2020 (South Korea) and February 15th –April 13th, 2020 (other nations).

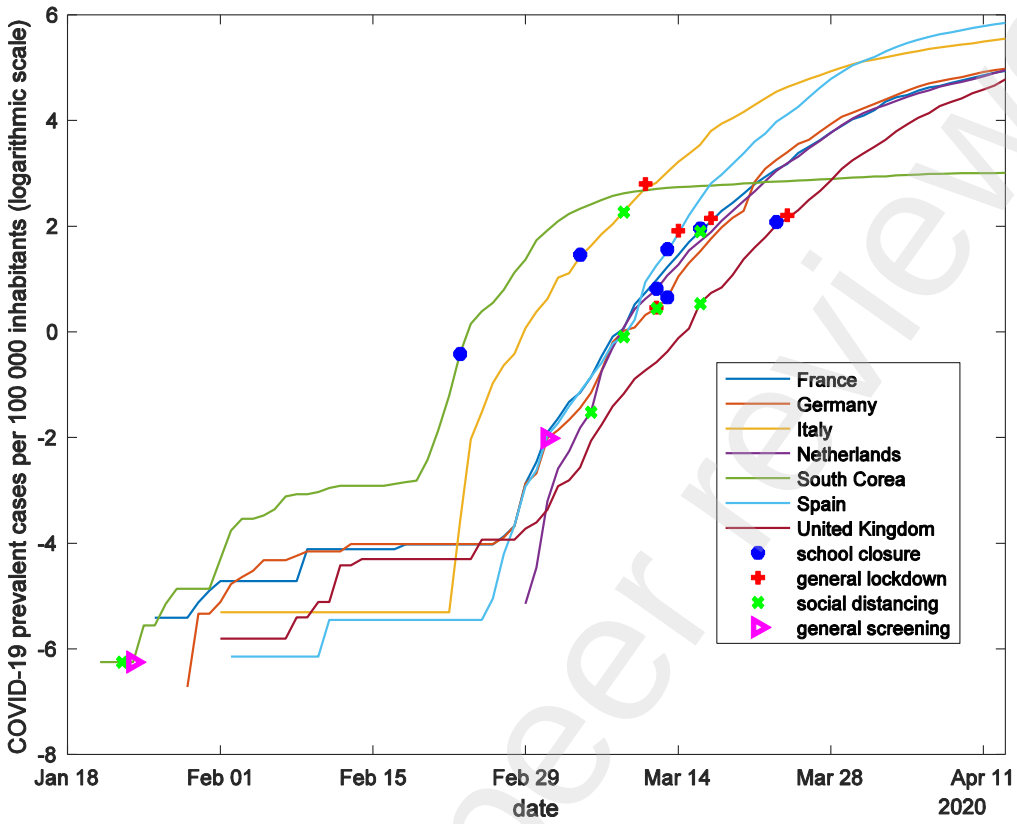

Figure 2 - Evolution of the outbreak in each country in terms of cumulative number of COVID-19 cases for 100,000 log scale, and measures taken, January 1st, 2020-April 13th, 2020.

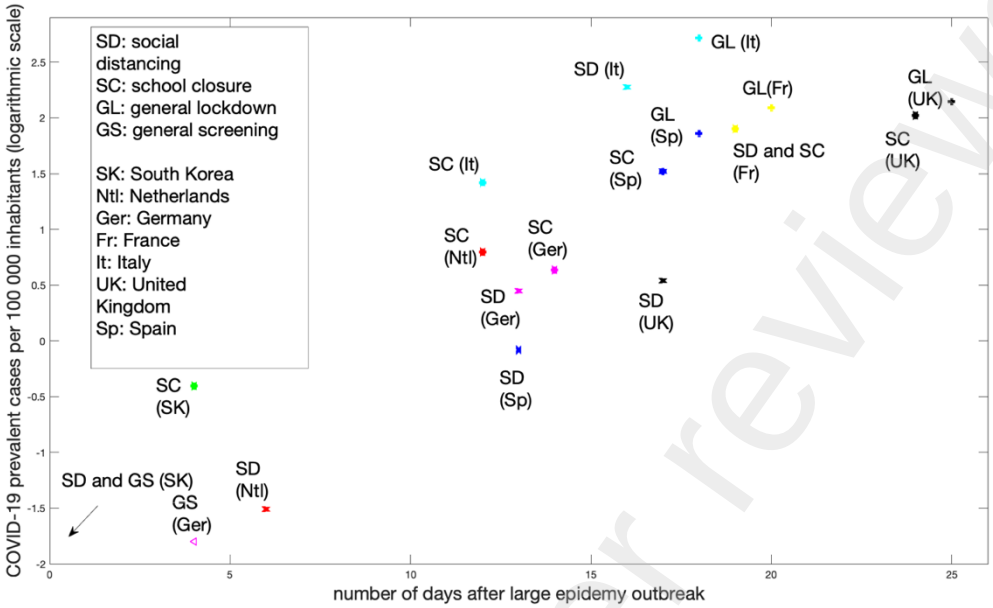

Figure 3 - Dates of public health measures after Covid-19 outbreak onset and the number for cases/100,000 in seven countries, January 1st, 2020–March 31st, 2020.

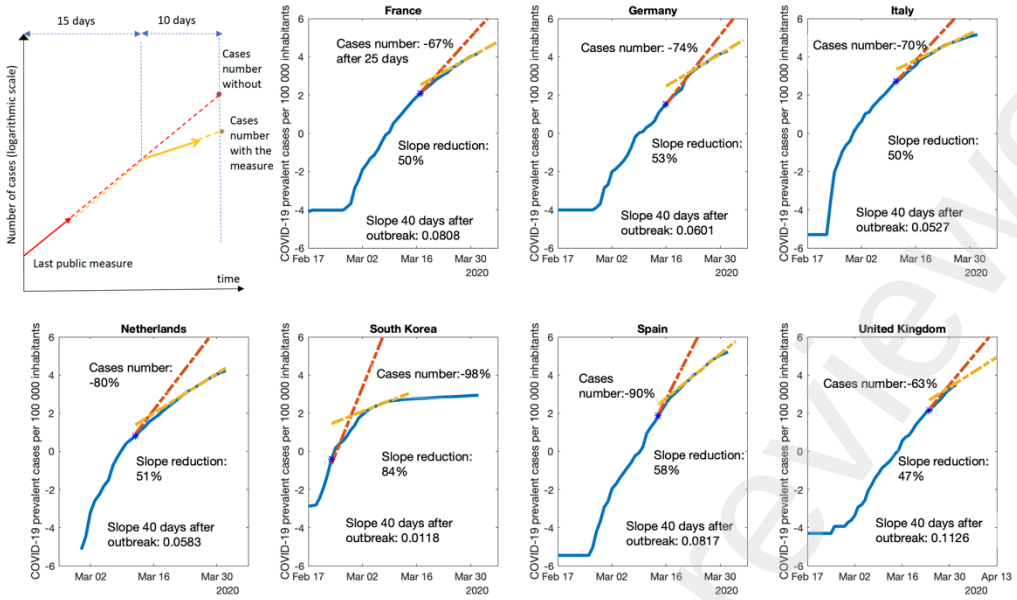

Figure 4 – Cumulative number of Covid-19 cases (seven countries, from January 1st, 2020–April 13th, 2020, log scale) and the three indicators*.

*Blue line: cumulative number of cases; red line: slope value at the last date measured; yellow line: slope value 15 days later.