

## Report 25: Response to COVID-19 in South Korea and implications for lifting stringent interventions

Amy Dighe<sup>1\*</sup>, Lorenzo Cattarino<sup>1\*</sup>, Gina Cuomo-Dannenburg<sup>1\*</sup>, Janetta Skarp<sup>1\*</sup>, Natsuko Imai<sup>1\*</sup>, Sangeeta Bhatia<sup>1</sup>, Katy A. M. Gaythorpe<sup>1</sup>, Kylie E. C. Ainslie<sup>1</sup>, Marc Baguelin<sup>1</sup>, Samir Bhatt<sup>1</sup>, Adhiratha Boonyasiri<sup>2</sup>, Olivia Boyd<sup>1</sup>, Nicholas F. Brazeau<sup>1</sup>, Giovanni Charles<sup>1</sup>, Laura V. Cooper<sup>1</sup>, Helen Coupland<sup>1</sup>, Zulma Cucunuba<sup>1</sup>, Bimandra A. Djaafara<sup>1</sup>, Ilaria Dorigatti<sup>1</sup>, Oliver D. Eales<sup>1</sup>, Jeff Eaton<sup>1</sup>, Sabine L. van Elsland<sup>1</sup>, Fabricia Ferreira Do Nascimento<sup>1</sup>, Richard G. FitzJohn<sup>1</sup>, Seth Flaxman<sup>3</sup>, Lily Geidelberg<sup>1</sup>, William D. Green<sup>1</sup>, Timothy Hallet<sup>1</sup>, Arran Hamlet<sup>1</sup>, Katharina Hauck<sup>1</sup>, David Haw<sup>1</sup>, Wes Hinsley<sup>1</sup>, Ben Jeffery<sup>1</sup>, Edward Knock<sup>1</sup>, Daniel J Laydon<sup>1</sup>, John A. Lees<sup>1</sup>, Thomas Mellan<sup>1</sup>, Swapnil Mishra<sup>1</sup>, Gemma Nedjati-Gilani<sup>1</sup>, Pierre Nouvellet<sup>1,4</sup>, Lucy C. Okell<sup>1</sup>, Kris V. Parag<sup>1</sup>, Margarita Pons-Salort<sup>1</sup>, Manon Ragonnet-Cronin<sup>1</sup>, Hayley A. Thompson<sup>1</sup>, H. Juliette T. Unwin<sup>1</sup>, Robert Verity<sup>1</sup>, Michaela A. C. Vollmer<sup>1</sup>, Erik Volz<sup>1</sup>, Patrick G. T. Walker<sup>1</sup>, Caroline E. Walters<sup>1</sup>, Oliver J. Watson<sup>5, 1</sup>, Charles Whittaker<sup>1</sup>, Lilith K. Whittles<sup>1</sup>, Xiaoyue Xi<sup>3</sup>, Azra C. Ghani<sup>1</sup>, Christl A. Donnelly<sup>1,6</sup>, Neil M. Ferguson<sup>1</sup>, Steven Riley<sup>1</sup>.

1. WHO Collaborating Centre for Infectious Disease Modelling  
MRC Centre for Global Infectious Disease Analysis  
Abdul Latif Jameel Institute for Disease and Emergency Analytics (J-IDEA)  
Imperial College London, London, UK
2. NIHR Health Protection Research Unit in Healthcare Associated Infections and Antimicrobial Resistance, Imperial College London, UK
3. Department of Mathematics, Imperial College London, London, UK
4. School of Life Sciences, University of Sussex, Brighton, UK
5. Department of Laboratory Medicine and Pathology, Brown University, Providence, RI, USA
6. Department of Statistics, University of Oxford, Oxford, UK

*\*contributed equally*

Correspondence: [s.riley@imperial.ac.uk](mailto:s.riley@imperial.ac.uk); [neil.ferguson@imperial.ac.uk](mailto:neil.ferguson@imperial.ac.uk)

### SUGGESTED CITATION

Amy Dighe, Lorenzo Cattarino, Gina Cuomo-Dannenburg *et al.* Response to COVID-19 in South Korea and implications for lifting stringent interventions. Imperial College London (29-05-2020). doi: <https://doi.org/10.25561/79388>.



This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.

## Summary

While South Korea experienced a sharp growth in COVID-19 cases early in the global pandemic, it has since rapidly reduced rates of infection and now maintains low numbers of daily new cases. Despite using less stringent “lockdown” measures than other affected countries, strong social distancing measures have been advised in high incidence areas and a 38% national decrease in movement occurred voluntarily between February 24<sup>th</sup> - March 1<sup>st</sup>. Suspected and confirmed cases were isolated quickly even during the rapid expansion of the epidemic and identification of the Shincheonji cluster. South Korea swiftly scaled up testing capacity and was able to maintain case-based interventions throughout. However, individual case-based contact tracing, not associated with a specific cluster, was a relatively minor aspect of their control program, with cluster investigations accounting for a far higher proportion of cases: the underlying epidemic was driven by a series of linked clusters, with 48% of all cases in the Shincheonji cluster and 20% in other clusters. Case-based contacts currently account for only 11% of total cases. The high volume of testing and low number of deaths suggests that South Korea experienced a small epidemic of infections relative to other countries. Therefore, caution is needed in attempting to duplicate the South Korean response in settings with larger more generalized epidemics. Finding, testing and isolating cases that are linked to clusters may be more difficult in such settings.

## 1. Introduction

Coronavirus disease 2019 (COVID-19) has become a major global pandemic with 5,656,615 cases and 355,355 deaths reported as of May 28<sup>th</sup> 2020 [1]. One of the first countries to be affected by the COVID-19 pandemic was South Korea, where the first confirmed case was reported on January 20<sup>th</sup> 2020, detected at Incheon international airport [2]. Sporadic cases were reported up to February 20<sup>th</sup>, all with travel histories to mainland China, in line with the testing protocol during that period. After the identification of the Shincheonji cluster of local transmission in Daegu on February 18<sup>th</sup>, testing was expanded to all suspected cases including individuals with no travel history [3]. Case incidence peaked on February 29<sup>th</sup>, shortly after Daegu was placed in a two-week quarantine [4] (Figure 1A and Table S1). Daily incidence has since generally been declining, with the decline starting approximately three weeks before stricter social distancing measures (including stay-at-home recommendations and restriction of non-essential retail) were implemented nationally [5]. As of May 11<sup>th</sup>, South Korea has reported a total of 10,909 cases with 35 new cases in the last day. The pattern of COVID-19 deaths in South Korea has not followed the same clear epidemic pattern as cases (Figure 1B), with a total of only 256 deaths up to and including May 11<sup>th</sup>, distributed throughout the period since February 20<sup>th</sup> with a peak, by date of report, of only 9 deaths per day.

Despite a rapid growth of cases early in the global timescale, South Korea has brought the transmission of SARS-CoV-2 under control with less stringent national social distancing policies relative to countries such as Italy, France, and the UK [6]. This has led to substantial interest in their “test, trace, isolate” strategy, as other countries plan to, or have started to relax their “lockdowns” and transition to more sustainable packages of interventions. However, it is important to understand the epidemiological peculiarities of the South Korea outbreak and characterise their effective response package before trying to apply these measures to other settings. For instance, it is unclear how much the “test, trace, isolate” strategy on its own was responsible for successfully controlling the outbreak relative to other measures such as social distancing and regional quarantine.

We conducted a quantitative review of South Korea's interventions in response to the COVID-19 epidemic to draw insights into the different components of the response. We characterized temporal trends in i) transmission, by estimating the time-varying reproduction number  $R$ ; ii) testing capacity; iii) case origins and how they were identified and iv) case isolation. We then discuss possible implications for other countries' strategies for lifting stringent social distancing interventions. As of May 28<sup>th</sup>, a total of 11,344 cases have been reported with 79 new confirmed cases in the last 24 hours resulting in implementation of localised measures in Seoul [7]. This recent increase in cases is not considered in our analysis here.

## 2. Results

### *Transmission*

Our estimates of SARS-CoV-2 transmissibility in South Korea vary substantially over time (Figure 2). We estimated the time-varying reproduction number  $R$  for cases, using previously published methods [8]. Using a 7-day sliding window and confirmed cases by date of report, we estimated that  $R$  initially dropped below 1 as travel-related cases were only imported sporadically [9]. Estimates of  $R$  increased significantly after the identification of the large Shincheonji cluster and the changes in testing protocol on February 18<sup>th</sup> and 20<sup>th</sup> 2020, respectively [10,11]. Following this substantial increase in testing and local transmission we estimated a very high  $R$  of 27.3 (95% Cri; 24.4 - 30.4 with prior distributions on  $R$  with mean = 1, standard deviation = 10). However, this estimate is biased upwards as the method assumes constant reporting over time, and the relative contributions to  $R$  from increased testing and increased transmission cannot be disentangled. Following the changes in testing, estimates are likely reliable again from the beginning of March. Despite consistently high levels of testing from this point (Figure 3),  $R$  was still estimated to be above 3. However, it dropped to a low of 0.4 in mid-March before increasing to 1 at the start of April. During April, the estimate of  $R$  continued to decline to  $\sim 0.5$  until the recent cluster of cases from the Itaewon nightclubs which has pushed it back above 1 (Figure 2).

### *Social distancing*

Unlike other countries affected by COVID-19, South Korea has not implemented a national "lockdown". However, a localised lockdown of Daegu occurred after the large cluster of cases associated with Shincheonji religious group was reported [12] (Figure 1A). Movement in Daegu decreased by 80% during this period as compared to the same time in 2019, and decreased nationally by 38% during February 24<sup>th</sup> - March 1<sup>st</sup> as compared to January 9<sup>th</sup> - 22<sup>nd</sup> before the first case had been detected in South Korea [13,14]. Schools have remained closed since the February 23<sup>rd</sup> nationally, and the country has transitioned to remote learning [15]. On March 22<sup>nd</sup>, in response to the ongoing emergence of local small clusters, imported cases, and an increase in population movement up to 28% below baseline [13], the Korean government implemented a stronger social distancing campaign nationally (Figure 1A). People were asked to leave their houses only for daily necessities, healthcare and commuting to work, and many community spaces were asked to close [16]. On April 19<sup>th</sup> low-contact outdoor facilities and churches were allowed to reopen. From May 6<sup>th</sup> South Korea has transitioned again with the intention of establishing long-term routine distancing with exact details to be decided by individual departments [17,18]. Sustaining the routine distancing policy depends on low daily case numbers, very low incidence of detecting apparently sporadic cases and >80% of new cases being detected in

individuals who are already in self-quarantine. These conditions were being met until the recent increase in cases reported on May 28<sup>th</sup> [7]. Social distancing measures are re-evaluated every two weeks [16].

### **Testing**

South Korea has a population of 51 million [20]. By licensing private companies and clinics to conduct tests early in the epidemic South Korea rapidly expanded testing capacity from 3000/day on February 7<sup>th</sup> [5] to 15,000 - 20,000/day with a turnaround time of 6 – 24 hours by the end of March (Figure 3). As of March 25<sup>th</sup>, there were 118 institutions capable of conducting tests for COVID-19 including: Korea Centers for Disease Control and Prevention (KCDC), 4 National Quarantine Stations, 18 Research Institutes of Public Health and Environment (RIPHEs), and 95 private medical laboratories and hospitals [3]. Initially, only individuals who were symptomatic and had a history of travelling in areas with known infections or had been in contact with confirmed cases were tested (Table S2) [21]. However, testing policy changed on February 20<sup>th</sup> to test anyone exhibiting symptoms, regardless of travel history, and to all close contacts of confirmed cases [22]. This coincided with the Shincheonji cluster and explosive growth in cases, reducing the average number of tests conducted per case. Mass testing has also been used in high-risk facilities such as hospitals, care homes, and other social care institutions in high incidence areas since March 18<sup>th</sup>. In Daegu, a total of 33,610 high-risk individuals have been tested with 322 testing positive as of April 4<sup>th</sup> [17]. As case numbers decreased, the average tests per case increased again until the mid-May increase in cases, which resulted in another reduction in the number of average tests per case (Figure 4). We are unable to infer the delay from symptom onset to testing from our data set collated from the KCDC daily press releases. A study of the first 28 patients (identified from January 20<sup>th</sup> to February 10<sup>th</sup>) estimated the mean delay from symptom onset to diagnosis to be 5.2 days (range: 0-16 days) [23]. We did not find data on delays to testing later in the outbreak.

### **Clusters and contact tracing**

A high proportion of cases have been epidemiologically linked throughout the outbreak. Case-based contact tracing in South Korea can be separated into: i) cluster investigation which utilises targeted mass testing of hospitals and communities; and ii) identification and follow-up of individual cases and their contacts (see Supplementary Material for more detailed protocol) [24–26]. Clusters now account for 68% of South Korea's COVID-19 cumulative cases nationally, while individual case-based contacts account for only 11% (Figure 5A). The large cluster associated with the Shincheonji religious group, accounts for 48% of all cases nationally. Although most cases were in Daegu, the cluster extended to group members in Gyeongbuk, Gyeongnam, Gangwon, Ulsan and Gwangju provinces (see Figure S1 for a regional breakdown of case type by epidemiological link or origin). Other smaller clusters mainly in workplaces, hospitals and churches, make up the further 20% of cases (ranging in size from 2-196 people). Most clusters of >100 cases occurred in hospitals, where mass testing protocols were in place. For example, 2,368 caregivers from 61 hospital-grade healthcare institutions were tested in Daegu in mid-March [27]. Later in the epidemic, between March 25<sup>th</sup> and May 11<sup>th</sup>, the Shincheonji cluster contributed very few new cases. During that period the relative contribution of local transmission to new cases steadily decreased until 82% of new cases in the two weeks prior to the May 8<sup>th</sup> were imported, however the Itaewon nightclub cluster [28] brought the relative contribution of local clusters back up to 40% of new cases reported in the fortnight ending on the 11<sup>th</sup> of May (Figure 5B).

### **Isolation**

Isolation of cases and self-quarantine of contacts has been a consistent feature of the South Korean response. As of May 11<sup>th</sup>, there were 1,021 confirmed cases currently isolated (Figure 6). Although we were not able to identify openly accessible data sources that reported the number of contacts isolated over the course of the outbreak, media outlets reported that approximately 30,000 people were in self-quarantine on March 6<sup>th</sup> [29], 27,000 on April 2<sup>nd</sup> [30] and 46,000 on April 7<sup>th</sup> [31]. Based on severity and risk factors, confirmed cases were either isolated in a hospital (1 room per patient or cohort isolation), at home, or in a Residential Treatment Centre (RTC). Cases were isolated in hospital in their own rooms or cohorted (grouping patients with the same characteristics in the same ward) depending on the clinical characteristics of the confirmed case, and the characteristics of the available isolation space such as ventilation and structural barriers between patients. Cases were isolated in RTCs when symptoms were too severe for home isolation, but did not require hospitalisation, when home isolation was not possible because no individual room was available or because they live with a high-risk person in the household [32]. Medical staff in RTCs and public health managers (for home isolation) monitored and recorded the patient's symptoms twice per day and, if necessary, transferred them to medical facilities. Close contacts of confirmed cases were asked to self-quarantine for 14 days and were monitored every day.

We were unable to estimate the delay to isolation of a confirmed case from the KCDC press release data. Another study, which fitted gamma distributions to case data of 211 confirmed cases, estimated the mean delay from symptom onset to isolation of cases as 4.3 days, before the red alert warning on February 23<sup>rd</sup> and 3.3 days after [33]. The same study estimated the mean delay from exposure to isolation as 7.2 days before the red alert, and 6.5 days after.

Confirmed cases were required to test negative twice in 24 hours before release from isolation [32]. Close contacts with no symptoms in the 14 days following contact were released from home quarantine after testing negative at the end of the quarantine period.

## **3. Discussion**

This analysis of South Korea's response to COVID-19 highlights how, despite South Korea experiencing a sharp growth in cases early in the global pandemic, transmission was rapidly controlled, resulting in a relatively small epidemic made up of large linked clusters. As of May 11<sup>th</sup>, a total 10,909 cases and 256 deaths have been reported since the first case on January 20<sup>th</sup> [2]. South Korea's epidemic is characterised by large clusters of cases, particularly the Shincheonji religious group which accounted for 48% of cases. The rapid expansion of test capacity, early localised lockdown of Daegu, voluntary social distancing, and continued case-based contact tracing across the large clusters have all likely contributed to help contain South Korea's epidemic.

South Korea have not implemented a national lockdown during their COVID-19 outbreak, Instead their comprehensive approach ranges from case-based testing and isolation, investigation of large clusters of confirmed cases, and targeted lockdowns in the most heavily affected provinces. Early identification and management of cases, clusters, and contacts has been a key strategy of the South Korea response. Combined with the expanded testing capacity and the use of pooled or mass testing in high-risk

facilities and clusters has allowed the majority of new cases to be traced back to existing clusters (Figure 5), such as the Shincheonji religious group, the Seoul/Guro Gu call centre, hospital/healthcare institutions in Daegu, and the Itaewon nightclub.

There are several limitations to this analysis. South Korea's response was characterized by multiple measures including rapid large-scale testing, and social distancing measures, and we did not find enough evidence to attribute the success in controlling the COVID-19 outbreak to one particular aspect of their response. When estimating time-varying  $R$ , we assumed constant reporting, which does not hold for the South Korea dataset. A dynamic transmission model could help disentangle the relative contribution of different measures and account for changes in reporting. Through a non-systematic review of the published literature and a systematic review of governmental sources (KCDC, Ministry of Health and Welfare and Ministry of Education), we were able to identify important data gaps. The national-level dataset we collated did not contain information on how many contacts each individual case had (and the proportion who tested positive), though data on the total number of contacts per confirmed case were available for some municipalities [33,34]. Furthermore, we could not estimate a delay from confirmation of test result to isolation of cases or their contacts from our dataset, as only the number of confirmed cases per day were available. There is a need for reliable up-to-date information on the number of contacts isolated at any one time.

As is the case for other countries looking at exiting their lockdowns, the South Korea exit strategy involves a mix of social distancing policies, behavioural interventions, and testing. South Korea has moved to a phase of partially relaxed social distancing since May 6<sup>th</sup> [35]. This includes allowing activities in low-risk venues, such as recreation parks and forests and closed-door sporting events, while maintaining partial restrictions on the use of high-risk facilities (e.g. religious facilities, fitness venues) and non-essential public gatherings which are all subject to strict infection prevention and control guidelines [36]. Additionally, although schools have moved to online teaching, a growing number of companies have eased their "smart-working" policies. Consultations between government, industry and community-based bodies have been conducted to increase preparedness, reduce conflicts and maximize uptake of long-term "every day" social distancing [37].

It is important to emphasize some key aspects particular to the South Korea outbreak, which are relevant when attempting to apply lessons from the outbreak in South Korea to other settings. The number of SARS-CoV-2 infections in South Korea has been far smaller than the US or most European countries. Over two-thirds of cases were linked to a few major clusters, which were promptly identified and tested en-masse. South Korea has implemented effective strategies for detecting and quarantining imported cases, reducing the risk of secondary transmission. All these measures have contributed to the outbreak remaining geographically localised. However, cluster-based management will be more difficult in settings with much more widespread transmission across the country. Finally, the South Korean response was facilitated by structures and processes such as additional legal powers for quarantine, surveillance systems, and digital technologies introduced after the 2015 MERS outbreak [38] which may be lacking in other countries. These key aspects may limit the extent to which the testing and contact-tracing strategies adopted by South Korea can be translated to other settings.

## 4. Methods

### **Data**

We systematically extracted numbers of tests conducted, PCR-confirmed cases, deaths and recoveries, and numbers of confirmed cases in isolation from surveillance data from and as defined by the KCDC for the period January 20<sup>th</sup> to May 11<sup>th</sup> 2020 [39,40]. Where available (from March 25<sup>th</sup> onwards), we also extracted data on the numbers of confirmed cases with an identified epidemiological link and/or origin to assess the efficacy of contact tracing and identification of transmission clusters.

### **Time-varying reproduction number, $R$**

We use an approach similar to those previously described [8,41] to quantify transmissibility over a 7-day sliding window, from the incidence time series, assuming a certain distribution for the serial interval (the time between symptom onset in a case and symptom onset in their infector). We assumed that transmissibility was constant over that 7-day window, and measured it through the reproduction number,  $R$ , defined as the average number of secondary cases infected by an infected individual. Our method assumes that the daily incidence can be approximated by a Poisson process using the so-called renewal equation:

$$I_t \sim \text{Poisson}(R_t \sum_{s=1}^t I_{t-s} w_s),$$

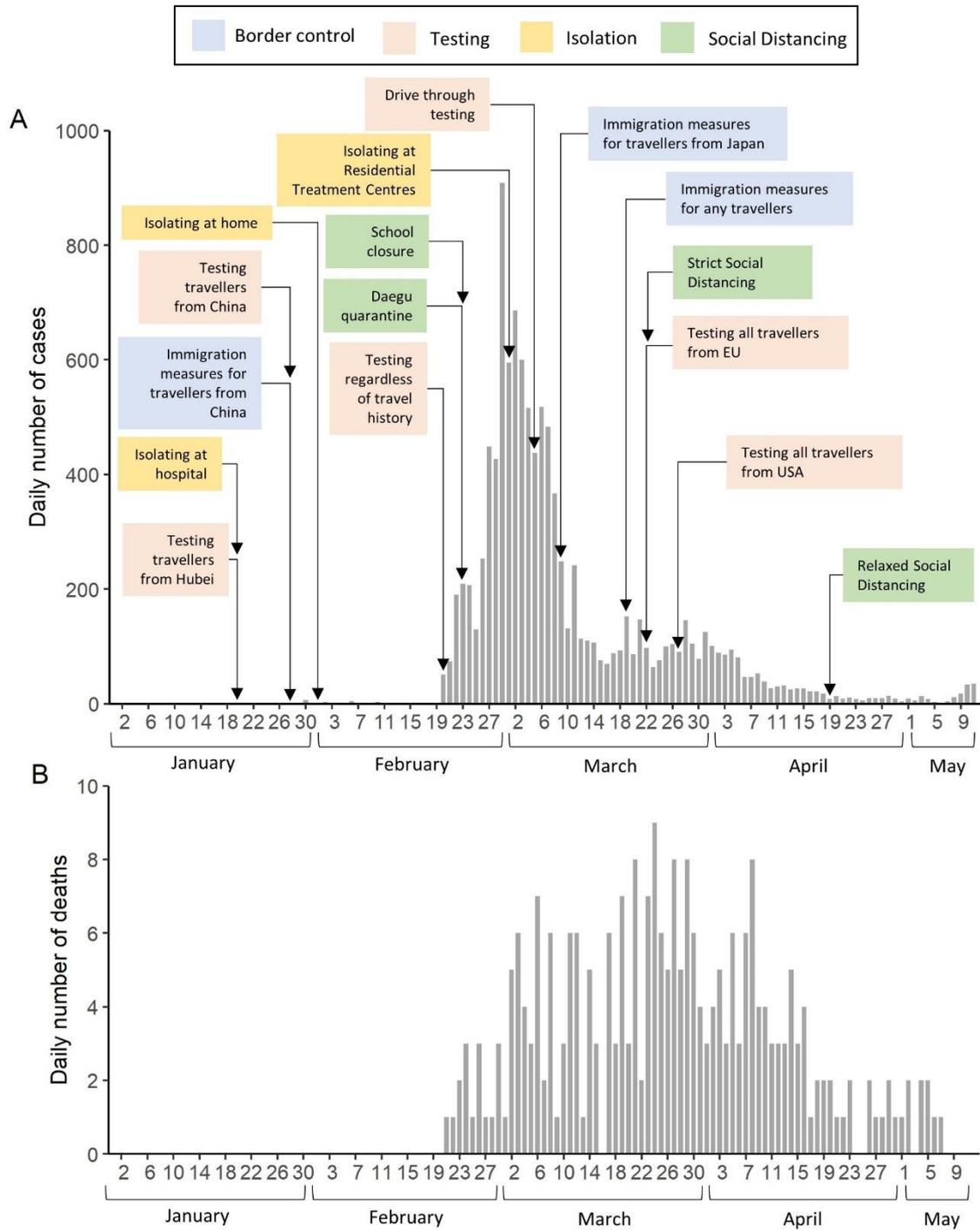
where  $I_t$  is the “true” incidence on day  $t$ ,  $R_t$  is the reproduction number on day  $t$ , and  $w$  is the probability mass function of the serial interval. We assumed a gamma distributed serial interval with mean 6.48 days and standard deviation 3.83 days [42] and uninformative prior distributions on  $R$  (mean 1 and standard deviation 10). As onset dates were not available for all cases,  $R$  was estimated based on cases by date of report using data from KCDC using the R packages *EpiEstim* and *orderly*. All analyses were done with R software (Version 3.6.3) [8,43–45]. To assess sensitivity of the  $R$  estimates to the assumed prior distribution, we ran our analysis with a range of prior distributions (Table S3) and found that our conclusions were consistent.

*EpiEstim* is robust to under-reporting but assumes that this reporting rate remains constant. This was not the case in South Korea due to changes in the case definition and testing criteria to include local transmission from February 20<sup>th</sup>, 2020 (as indicated by the vertical line, Figure 2). This causes bias in the  $R$  estimate. To explore how long these estimates were biased for, we truncated the dataset from 3 days following the change in testing until the end of the study period (May 11<sup>th</sup>) and re-estimated time-varying  $R$ . We found that the estimates of  $R$  were consistent from March 6<sup>th</sup>, 2020 onward between the full and truncated data and therefore estimates from this point are unaffected by the scale up in testing.

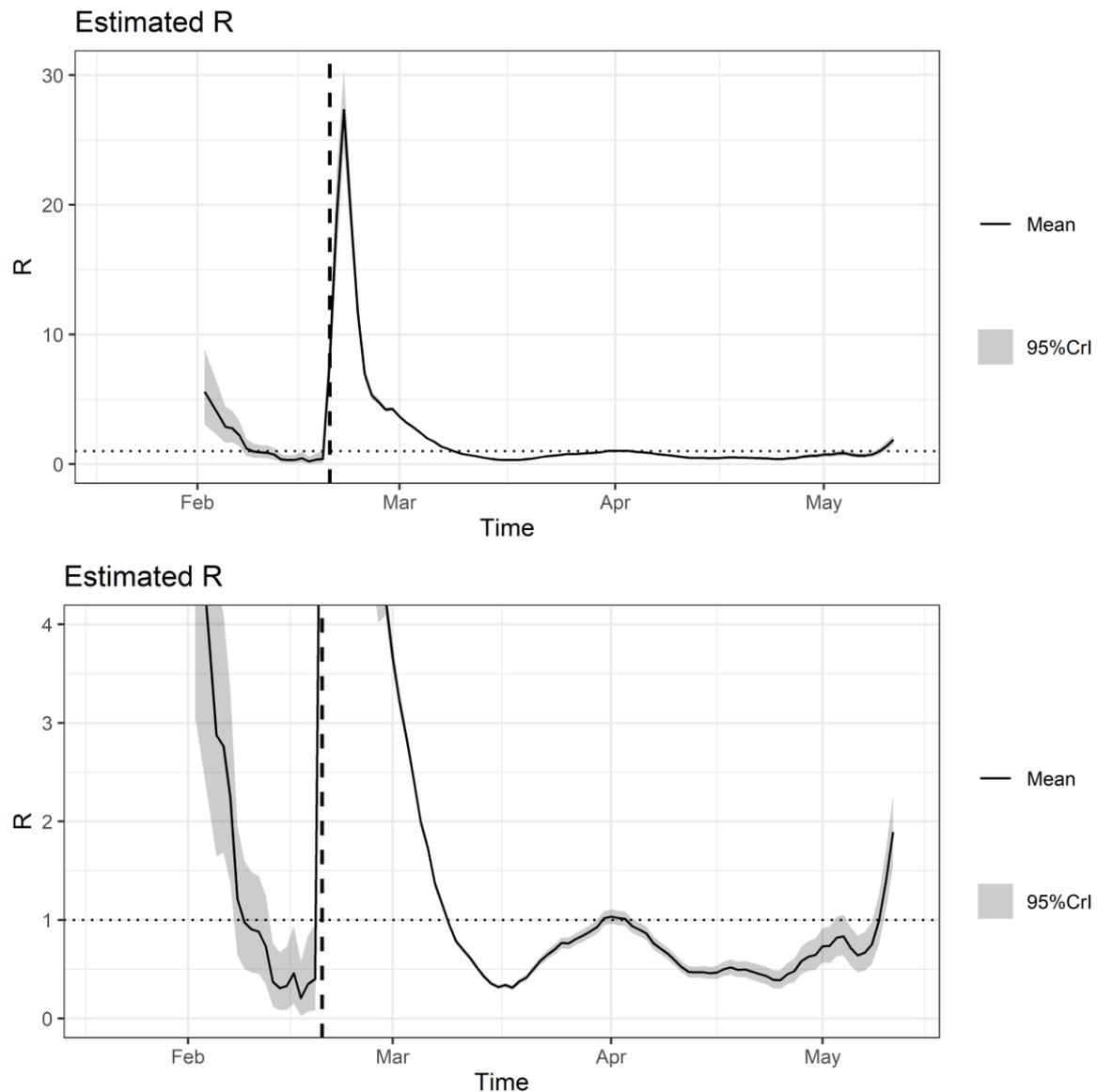
### **Tests per positive case**

To calculate the rolling 7-day average of tests per case, we first calculated the right-aligned 7-day rolling average of cases and tests separately using the *roll\_mean* function from the R package *RcppRoll* [46]. We then divided the average tests by the average cases for each day to obtain an estimate for average tests per case.

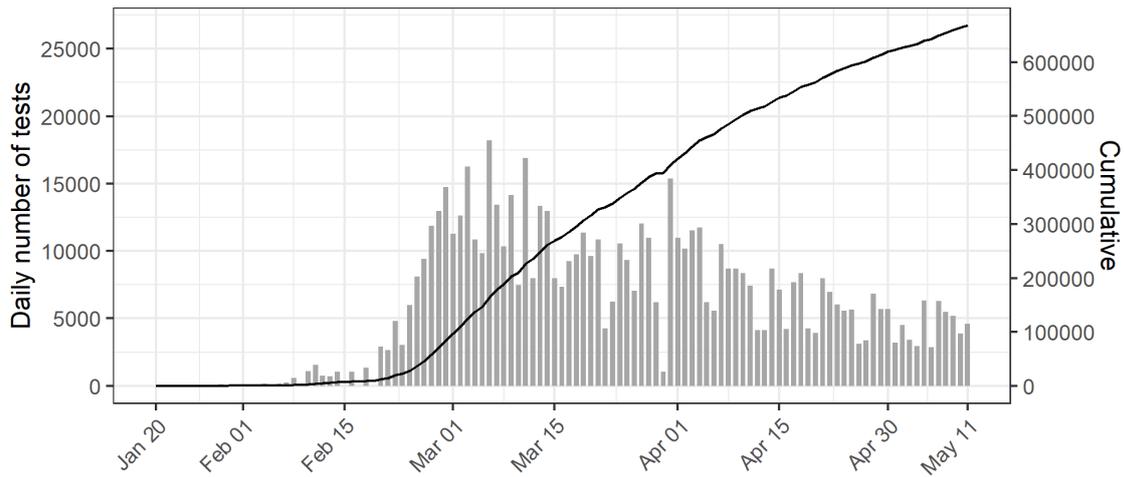
### 5. Figures



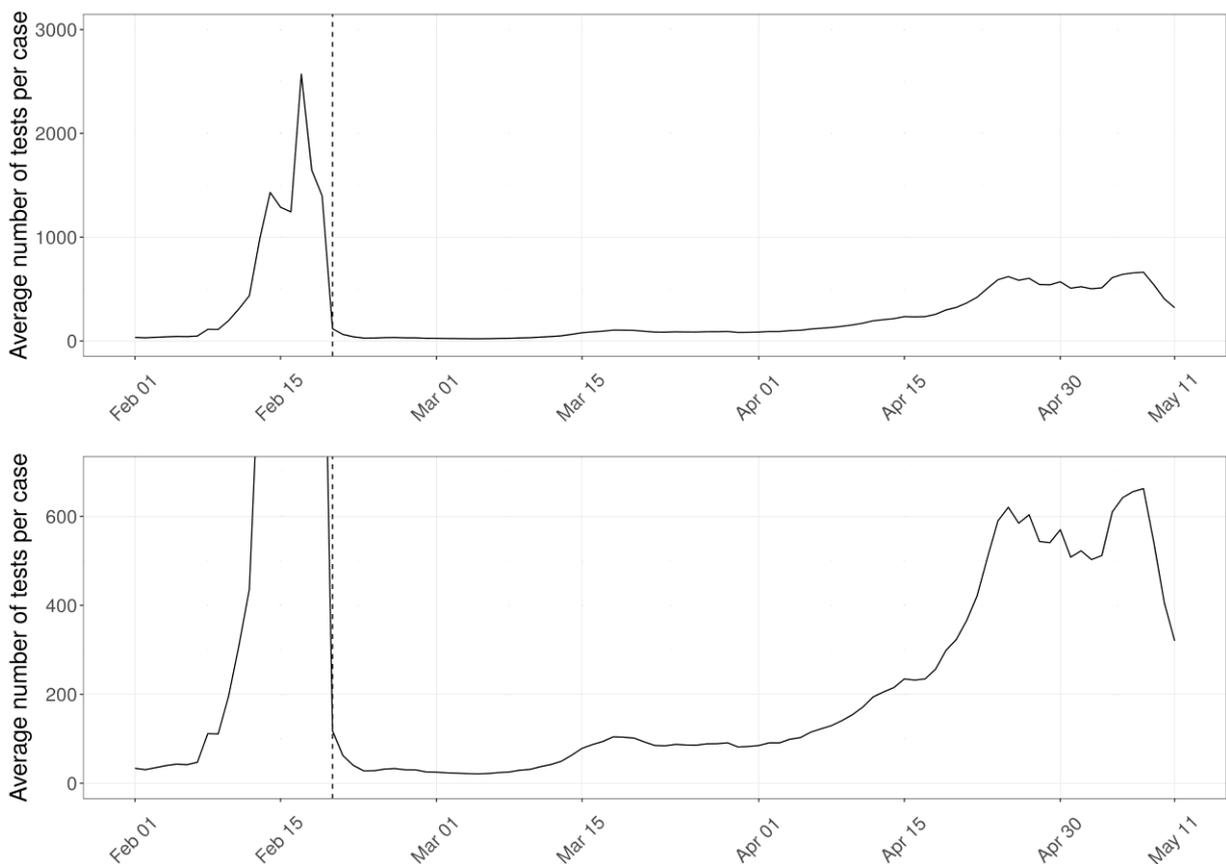
**Figure 1.** Incidence of confirmed cases by date of report from daily KCDC press releases with key intervention timings (A), and deaths (B). Interventions are separated into border control, testing, isolation and social distancing. Sources of interventions: KCDC press releases, Ministry of Health and Welfare, and Ministry of Education.



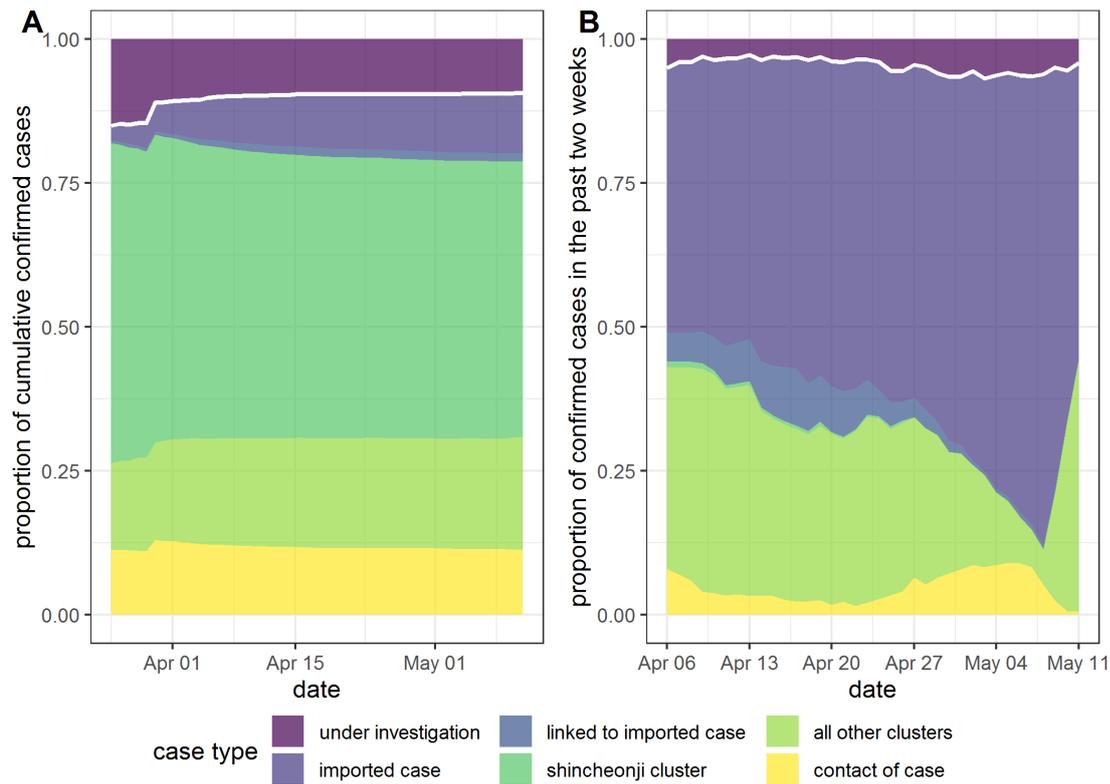
**Figure 2.** Estimates of time-varying effective reproductive number  $R$  based on confirmed cases by date of report.  $R$  is estimated using a sliding window of 7 days and an uninformative prior distribution with mean 1 and standard deviation 10. The black line represents the posterior median value of  $R$  and the shaded region shows the 95% credible interval (CrI). The dotted horizontal line shows  $R = 1$ . The top panel shows the full range of  $R$  values, with the bottom panel zoomed in to  $R$  between 0 and 4. Vertical dotted line indicates the time at which the testing protocol was changed (February 20<sup>th</sup>).



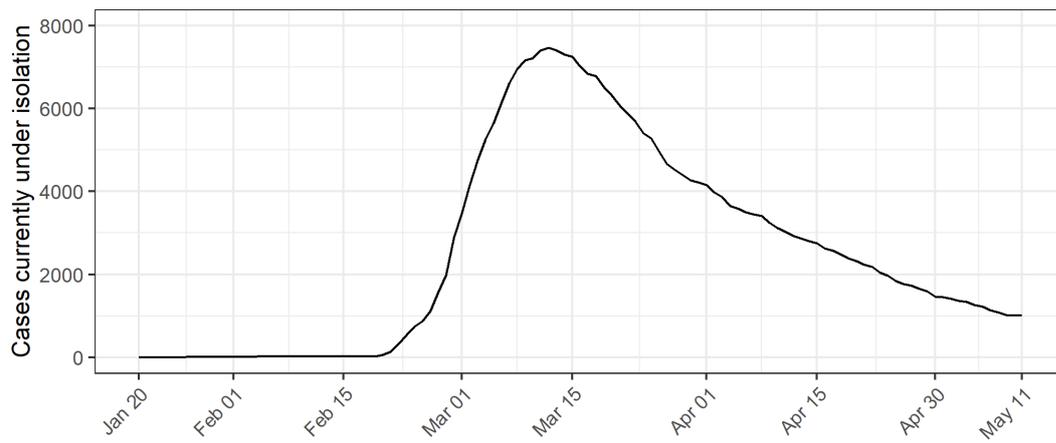
**Figure 3.** New and cumulative numbers of people being tested in South Korea from the beginning of the COVID-19 outbreak on January 20<sup>th</sup> until May 11<sup>th</sup>, 2020. Grey bars represent daily number of tests by date of report and black line shows the cumulative number of tests conducted over time. Source: KCDC press releases.



**Figure 4.** Rolling 7-day average of the number of people tested per case until May 11<sup>th</sup>, 2020. The dashed vertical line indicates the date on which South Korea changed its testing protocol from testing suspected cases with contact with a case or travel history to a country with infections to testing all suspected cases (February 20<sup>th</sup>). Bottom panel zooms in to show region of 0 – 650 tests per case. Source: KCDC press releases.



**Figure 5. A.** Cumulative proportion of confirmed cases by epidemiological link and/or origin from March 25<sup>th</sup> to May 11<sup>th</sup>. The proportion of cumulative confirmed cases that are linked to existing cases or imported (white line) as opposed to “under investigation” (which includes apparent sporadic cases). Linked cases are broken down into whether they are connected to an imported case, part of the Shincheonji cluster, a smaller cluster or a non-cluster contact of a confirmed case. **B.** Non-cumulative proportion of new cases reported during the two weeks prior to the date on the x axis, by type of case. Source: KCDC press releases.



**Figure 6.** Isolation dynamics in South Korea. Number of confirmed cases currently in isolation per day. Source: KCDC press releases.

## 6. References

1. European Centre for Disease Prevention and Control. COVID-19 situation update worldwide, as of 21 May 2020. 2020 [cited 21 May 2020]. Available: <https://www.ecdc.europa.eu/en/geographical-distribution-2019-ncov-cases>
2. Korea Centers for Disease Control and Prevention. The first imported case of the novel coronavirus (2019-nCoV) in Korea | Press Release | News Room : KCDC. [cited 21 Jan 2020]. Available: [https://www.cdc.go.kr/board/board.es?mid=a30402000000&bid=0030&act=view&list\\_no=365797&tag=&nPage=1](https://www.cdc.go.kr/board/board.es?mid=a30402000000&bid=0030&act=view&list_no=365797&tag=&nPage=1)
3. The Government of the Republic of Korea. Tackling COVID-19 The Government of the Republic of Korea. 2020. Available: <https://ecck.eu/wp-content/uploads/2020/03/Tackling-COVID-19-Health-Quarantine-and-Economic-Measures-of-South-Korea.pdf>
4. Korea Centers for Disease Control and Prevention. The Updates of COVID-19 in Republic of Korea as of 24 February 2020. 24 Feb 2020 [cited 2 May 2020]. Available: [https://is.cdc.go.kr/upload\\_comm/syview/doc.html?fn=158253439203200.pdf&rs=/upload\\_comm/docu/0030/](https://is.cdc.go.kr/upload_comm/syview/doc.html?fn=158253439203200.pdf&rs=/upload_comm/docu/0030/)
5. Lee SK, Chun T-M. Episode #1 COVID-19 Case Study: The use of ICT & AI to flatten the curve in the Republic of Korea 27 March 2020 Webinar - AI for Good Global Summit. 27 Mar 2020 [cited 18 Apr 2020]. Available: <https://aiforgood.itu.int/webinar/>
6. World Health Organization. WHO Public Health and Social Measures Database. 2020 [cited 8 May 2020]. Available: <https://www.who.int/emergencies/diseases/novel-coronavirus-2019/phsm>
7. Korea Centers for Disease Control and Prevention. Updates on COVID-19 in Republic of Korea, 28 May 2020. 28 May 2020 [cited 28 May 2020]. Available: [https://is.cdc.go.kr/upload\\_comm/syview/doc.html?fn=159065340015200.pdf&rs=/upload\\_comm/docu/0030/](https://is.cdc.go.kr/upload_comm/syview/doc.html?fn=159065340015200.pdf&rs=/upload_comm/docu/0030/)
8. Cori A, Ferguson NM, Fraser C, Cauchemez S. A New Framework and Software to Estimate Time-Varying Reproduction Numbers During Epidemics. *Am J Epidemiol*. 2013;178: 1505–1512. doi:10.1093/aje/kwt133
9. Bhatia S, Imai N, Cuomo-Dannenburg G, Baguelin M, Boonyasiri A, Cori A, et al. Report 6: Relative sensitivity of international surveillance. 2020. doi:10.25561/77168
10. Korea Centers for Disease Control and Prevention. The updates of COVID-19 in Republic of Korea as of 19 February 2020 문서뷰어. 2020 [cited 2 May 2020]. Available: [https://is.cdc.go.kr/upload\\_comm/syview/doc.html?fn=158207688673200.pdf&rs=/upload\\_comm/docu/0030/](https://is.cdc.go.kr/upload_comm/syview/doc.html?fn=158207688673200.pdf&rs=/upload_comm/docu/0030/)
11. Korea Centers for Disease Control and Prevention. The 15 new cases of COVID-19 have been confirmed in Korea | Press Release | News Room : KCDC. 2020 [cited 2 May 2020]. Available: [https://www.cdc.go.kr/board/board.es?mid=a30402000000&bid=0030&act=view&list\\_no=366239&tag=&nPage=16](https://www.cdc.go.kr/board/board.es?mid=a30402000000&bid=0030&act=view&list_no=366239&tag=&nPage=16)
12. Korea Ministry of Health and Welfare. Ministry of Health & Welfare : Briefing on the pan-governmental meeting for COVID-19 2020-02-23. [cited 2 May 2020]. Available: [https://www.mohw.go.kr/eng/nw/nw0101vw.jsp?PAR\\_MENU\\_ID=1007&MENU\\_ID=100701&page=1&CONT\\_SEQ=353124](https://www.mohw.go.kr/eng/nw/nw0101vw.jsp?PAR_MENU_ID=1007&MENU_ID=100701&page=1&CONT_SEQ=353124)
13. Korea Ministry of Health and Welfare. Ministry of Health & Welfare : Extending Intensive “Social Distancing” for Another 2 Weeks 2020-04-07. 2020 [cited 2 May 2020]. Available: [https://www.mohw.go.kr/eng/nw/nw0101vw.jsp?PAR\\_MENU\\_ID=1007&MENU\\_ID=100701&page=1&CONT\\_SEQ=353953](https://www.mohw.go.kr/eng/nw/nw0101vw.jsp?PAR_MENU_ID=1007&MENU_ID=100701&page=1&CONT_SEQ=353953)

14. Park SW, Sun K, Viboud C, Grenfell BT, Dushoff J. Potential roles of social distancing in mitigating the spread of coronavirus disease 2019 (COVID-19) in South Korea. medRxiv. 2020; 2020.03.27.20045815. doi:10.1101/2020.03.27.20045815
15. Ministry of Education. The New School Year Begins with Online Classes. 13 Apr 2020 [cited 8 May 2020]. Available: <http://english.moe.go.kr/boardCnts/view.do?boardID=265&boardSeq=80297&lev=0&searchType=null&statusYN=W&page=1&s=english&m=0301&opType=N>
16. Korea Centers for Disease Control and Prevention. Coronavirus Infectious Diseases-19 Regular Disaster Prevention Headquarters Regular Briefing (April 19). 19 Apr 2020 [cited 2 May 2020]. Available: [http://www.mohw.go.kr/react/al/sal0301vw.jsp?PAR\\_MENU\\_ID=04&MENU\\_ID=0403&page=2&CONT\\_SEQ=354112](http://www.mohw.go.kr/react/al/sal0301vw.jsp?PAR_MENU_ID=04&MENU_ID=0403&page=2&CONT_SEQ=354112)
17. Korea Centers for Disease Control and Prevention. Coronavirus Infectious Diseases-19 Regular Disaster Safety Headquarters Regular Briefing (April 27). 27 Apr 2020 [cited 2 May 2020]. Available: [http://www.mohw.go.kr/react/al/sal0301vw.jsp?PAR\\_MENU\\_ID=04&MENU\\_ID=0403&page=2&CONT\\_SEQ=354231](http://www.mohw.go.kr/react/al/sal0301vw.jsp?PAR_MENU_ID=04&MENU_ID=0403&page=2&CONT_SEQ=354231)
18. Korea Centers for Disease Control and Prevention. Updates on COVID-19 in Republic of Korea (Press Release: 6 May 2020). 6 May 2020 [cited 14 May 2020]. doi:10.1017/CBO9781107415324.004
19. Korean Centers for Disease Control and Prevention. Coronavirus Infectious Diseases-19 Regular Disaster Prevention Headquarters Regular Briefing (May 3). 3 May 2020 [cited 3 May 2020]. Available: [http://www.mohw.go.kr/react/al/sal0301vw.jsp?PAR\\_MENU\\_ID=04&MENU\\_ID=0403&page=1&CONT\\_SEQ=354337](http://www.mohw.go.kr/react/al/sal0301vw.jsp?PAR_MENU_ID=04&MENU_ID=0403&page=1&CONT_SEQ=354337)
20. Korean Statistical Information Service. Statistical Database | KOSIS KOREAN Statistical Information Service. [cited 9 May 2020]. Available: [http://kosis.kr/eng/statisticsList/statisticsListIndex.do?menuId=M\\_01\\_01&vwcd=MT\\_ETITLE&parmTabId=M\\_01\\_01&statId=1962001&themald=#SelectStatsBoxDiv](http://kosis.kr/eng/statisticsList/statisticsListIndex.do?menuId=M_01_01&vwcd=MT_ETITLE&parmTabId=M_01_01&statId=1962001&themald=#SelectStatsBoxDiv)
21. Korea Centers for Disease Control and Prevention. The case definition of 2019 novel coronavirus will be expanded. 2020 [cited 2 May 2020]. Available: [https://is.cdc.go.kr/upload\\_comm/syview/doc.html?fn=158003243029400.pdf&rs=/upload\\_comm/docu/0030/](https://is.cdc.go.kr/upload_comm/syview/doc.html?fn=158003243029400.pdf&rs=/upload_comm/docu/0030/)
22. Korea Centers for Disease Control and Prevention. The Updates of COVID-19 in Republic of Korea 19 February 2020. 19 Feb 2020 [cited 2 May 2020]. Available: [https://is.cdc.go.kr/upload\\_comm/syview/doc.html?fn=158209860015800.pdf&rs=/upload\\_comm/docu/0030/](https://is.cdc.go.kr/upload_comm/syview/doc.html?fn=158209860015800.pdf&rs=/upload_comm/docu/0030/)
23. Ki M. Epidemiologic characteristics of early cases with 2019 novel coronavirus (2019-nCoV) disease in Korea. Epidemiol Health. 2020;42: e2020007. doi:10.4178/epih.e2020007
24. Korea Centers for Disease Control and Prevention. The updates of COVID-19 in Republic of Korea 22 February, 2020. 2020 [cited 8 May 2020]. Available: [https://is.cdc.go.kr/upload\\_comm/syview/doc.html?fn=158235699555200.pdf&rs=/upload\\_comm/docu/0030/](https://is.cdc.go.kr/upload_comm/syview/doc.html?fn=158235699555200.pdf&rs=/upload_comm/docu/0030/)
25. Park SY, Kim Y-M, Yi S, Lee S, Na B-J, Kim CB, et al. Coronavirus Disease Outbreak in Call Center, South Korea. Emerg Infect Dis. 2020;26. doi:10.3201/eid2608.201274
26. Naver blog. Coronal virus infection 19 regular briefing on response. 2020 [cited 8 May 2020]. Available: [https://blog.naver.com/daegu\\_news/221846363885](https://blog.naver.com/daegu_news/221846363885)
27. Korea Centers for Disease Control and Prevention. The updates on COVID-19 in Korea as of 31 March. 31 Mar 2020 [cited 8 May 2020]. Available: [https://is.cdc.go.kr/upload\\_comm/syview/doc.html?fn=158565093755500.pdf&rs=/upload\\_comm/doc](https://is.cdc.go.kr/upload_comm/syview/doc.html?fn=158565093755500.pdf&rs=/upload_comm/doc)

u/0030/

28. Korea Centers for Disease Control and Prevention. Updates on COVID-19 in Republic of Korea 11 May 2020. 11 May 2020 [cited 14 May 2020]. Available: [https://is.cdc.go.kr/upload\\_comm/syview/doc.html?fn=158919530461600.pdf&rs=/upload\\_comm/docu/0030/](https://is.cdc.go.kr/upload_comm/syview/doc.html?fn=158919530461600.pdf&rs=/upload_comm/docu/0030/)
29. Technology Review. South Korea is watching quarantined citizens with a smartphone app | MIT Technology Review. 2020 [cited 3 May 2020]. Available: <https://www.technologyreview.com/2020/03/06/905459/coronavirus-south-korea-smartphone-app-quarantine/>
30. 620WTMJ Wisconsin. The Latest: South Korea says over 27,000 self-quarantined - WTMJ. [cited 3 May 2020]. Available: <https://wtmj.com/national/2020/04/02/the-latest-south-korea-says-over-27000-self-quarantined/>
31. CNN. More than 46,000 people are in self-quarantine in South Korea April 7 coronavirus news - CNN. [cited 3 May 2020]. Available: [https://edition.cnn.com/world/live-news/coronavirus-pandemic-04-07-20/h\\_8968f40eb281f76ce2df52373887b6b5](https://edition.cnn.com/world/live-news/coronavirus-pandemic-04-07-20/h_8968f40eb281f76ce2df52373887b6b5)
32. Korea Centers for Disease Control and Prevention. Coronavirus Disease 2019 Response Guidelines (For Local Governments). 15 Mar 2020 [cited 2 May 2020]. Available: [https://covidtranslate.org/CovidPlaybook\\_EN\\_v1.0.pdf](https://covidtranslate.org/CovidPlaybook_EN_v1.0.pdf)
33. Busan Metropolitan City. Northeast Asia Ocean Capital Busan Metropolitan City. [cited 14 May 2020]. Available: <http://www.busan.go.kr/corona19/index>
34. Gwangju Metropolitan City. Corona 19 Gwangju Metropolitan City. [cited 14 May 2020]. Available: <https://www.gwangju.go.kr/c19/c19/contentsView.do?pagelD=coronagj2>
35. Korea Centers for Disease Control and Prevention. Updates on COVID-19 in Republic of Korea 6 May 2020. 2020 [cited 9 May 2020]. Available: [https://is.cdc.go.kr/upload\\_comm/syview/doc.html?fn=158875528510800.pdf&rs=/upload\\_comm/docu/0030/](https://is.cdc.go.kr/upload_comm/syview/doc.html?fn=158875528510800.pdf&rs=/upload_comm/docu/0030/)
36. Korea Centers for Disease Control and Prevention. Updates on COVID-19 in Republic of Korea 20 April 2020. 2020 [cited 9 May 2020]. Available: [https://is.cdc.go.kr/upload\\_comm/syview/doc.html?fn=158738192856000.pdf&rs=/upload\\_comm/docu/0030/](https://is.cdc.go.kr/upload_comm/syview/doc.html?fn=158738192856000.pdf&rs=/upload_comm/docu/0030/)
37. Korean Ministry of Health and Welfare. Regular Briefing of Central Disaster and Safety Countermeasure Headquarters on COVID-19 April 27. 27 Apr 2020 [cited 9 May 2020]. Available: [https://www.mohw.go.kr/eng/nw/nw0101vw.jsp?PAR\\_MENU\\_ID=1007&MENU\\_ID=100701&page=1&CONT\\_SEQ=354431](https://www.mohw.go.kr/eng/nw/nw0101vw.jsp?PAR_MENU_ID=1007&MENU_ID=100701&page=1&CONT_SEQ=354431)
38. Cowling BJ, Park M, Fang VJ, Wu P, Leung GM, Wu JT. Preliminary epidemiological assessment of MERS-CoV outbreak in South Korea, May to June 2015. *EUROSURVEILLANCE*. 2015;20: 7–13. doi:10.2807/1560-7917.ES2015.20.25.21163
39. Korea Centers for Disease Control and Prevention. List | Press Release | News Room : KCDC. [cited 21 May 2020]. Available: <https://www.cdc.go.kr/board/board.es?mid=a30402000000&bid=0030>
40. Korean Centers for Disease Control. Frequently Asked Questions for KCDC on COVID-19 (as of 30 March) | Press Release | News Room : KCDC. [cited 11 Apr 2020]. Available: [https://www.cdc.go.kr/board/board.es?mid=a30402000000&bid=0030&act=view&list\\_no=366764&nPage=1](https://www.cdc.go.kr/board/board.es?mid=a30402000000&bid=0030&act=view&list_no=366764&nPage=1)
41. WHO Ebola Response Team. West African Ebola Epidemic after One Year — Slowing but Not Yet under Control. *N Engl J Med*. 2015;372: 584–587. doi:10.1056/NEJMc1414992

42. Imperial College London COVID-19 Response Team. Report 9 - Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand | Faculty of Medicine | Imperial College London. [cited 21 May 2020]. Available: <https://www.imperial.ac.uk/mrc-global-infectious-disease-analysis/covid-19/report-9-impact-of-npis-on-covid-19/>
43. R Core Team. R: A Language and Environment for Statistical Computing. Vienna, Austria; 2020. doi:10.1007/978-3-540-74686-7
44. FitzJohn R, Ashton R, Hill A, Eden M, Hinsley H, Russell E, et al. orderly: Lightweight Reproducible Reporting. R package version 1.1.29. 2020. Available: <https://github.com/vimc/orderly>
45. Cori A. EpiEstim: Estimate Time Varying Reproduction Numbers from Epidemic Curves. R package version 2.2-1. 2019. Available: <https://cran.r-project.org/package=EpiEstim>
46. Ushey K. RcppRoll: Efficient Rolling / Windowed Operations. 2018. Available: <https://cran.r-project.org/package=RcppRoll>