Title: Basic and effective reproduction numbers of COVID-19 cases in South Korea excluding Sincheonji cases

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Abstract

In February and March 2020, COVID-19 epidemic in South Korea met a large black swan effect by a Sincheonji cult mass infection in Daegu-Gyeongbuk area. The black swan made it difficult to evaluate that the current policies for infection prevention including social distancing, closing schools, hand washing, and wearing masks good enough or not. Therefore, in this study, we evaluated basic reproduction number (R_0) and time-dependent reproduction number (R_t) of confirmed cases based on various kinds of populations, including total, Daegu-Geyoengbuk, except-Daegu-Gyeongbuk, Sincheonji, and except-Sincheonji. In total, it seems the infection is going to be under control, but this is never true because in the except-Sincheonji and except-Daegu-Geyongbuk cases, R_0 is still above 1.0, and R_t is drifting around 1.0. This study could be used to determine government policies in the near future.

Keywords: COVID-19

Text

South Korea currently has 9,241 cumulated confirmed COVID-19 cases as of March 26th, 2020. There was a large “black swan” event called the Sincheonji cult mass infection incidence that lead to an exponential increase of confirmed cases. Since then, a great effort has been made to defend the public from virus, and to some extent, these efforts have suppressed the spread.

The basic and time-dependent effective reproduction number R_0 and R_t are two of the most representative characteristics for the dynamics of the infectious virus. To observe the basic features of the COVID-19 outbreak in South Korea without the black swan effect, we collected the daily counts of confirmed cases. The Korean Centers for Disease Control and Prevention (KCDC) has investigated, summarized, and released daily updates on the cumulated counts of confirmed cases, which are available online[1]. The cumulated counts have been provided in total, according to the administrative provinces (Gwangyeok-Si and Do in the South Korean administrative system), and several mass infection cases have occurred. We collected counts of daily confirmed cases from the Sincheonji cult, which was named after a church with a COVID-19 outbreak, and subtracted them from the total counts to comprise the “except Sincheonji” cases. Additionally, we collected the case counts from Daegu-si and Gyeongsangbuk-do province, which surrounds Daegu-si, because the initial outbreak in the Sincheonji cult took place in those areas. We summed up the counts from the two provinces and subtracted them from the total counts to total the “except Daegu-Gyeonbuk” cases. The Sincheonji cult cases and Daegu-Gyeongbuk cases are not mutually inclusive nor exclusive. Because it took days to identify a confirmed case belonging to the Sincheonji cult, the time frames of the Sincheonji cases could have been confounded.

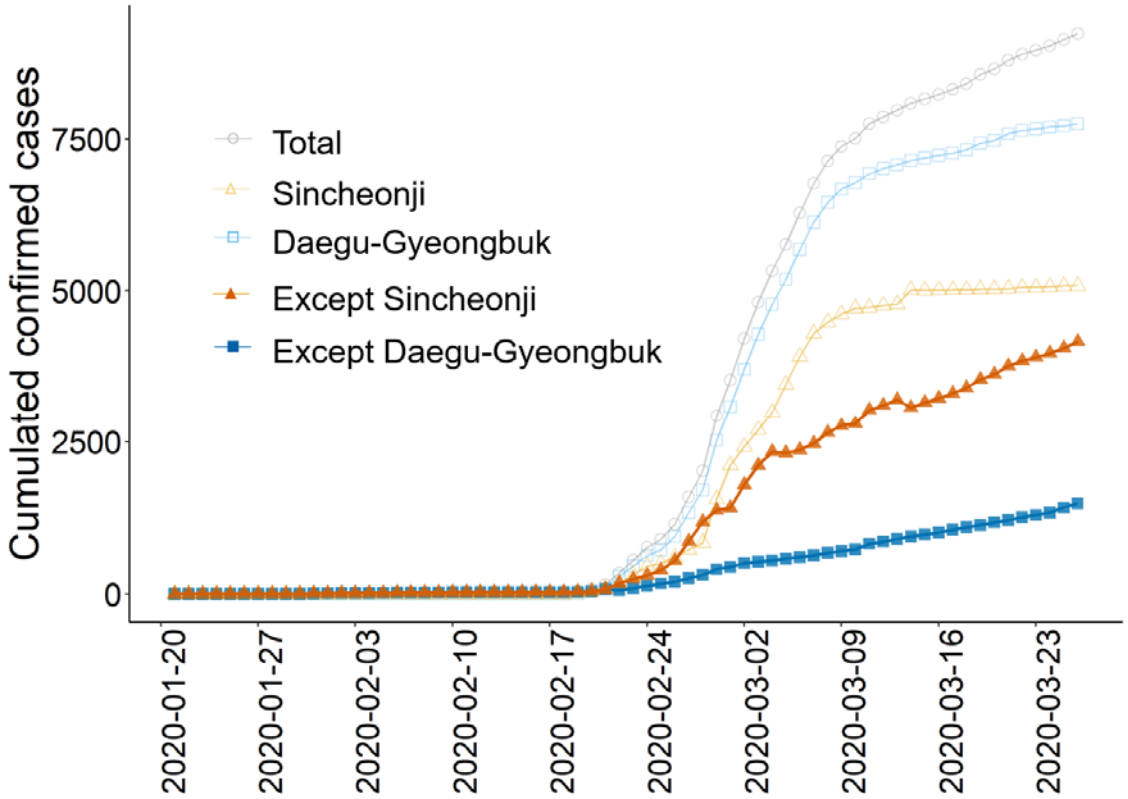
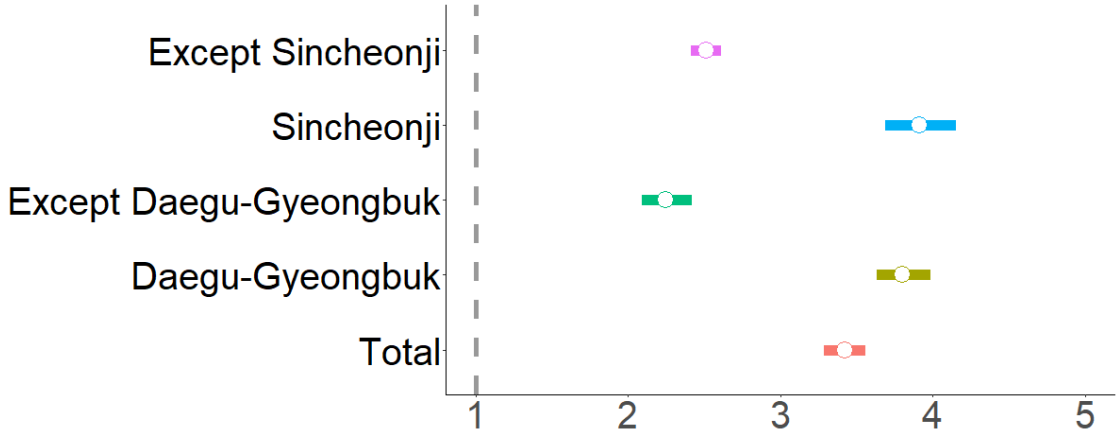


Figure 1. Cumulated counts of confirmed cases of the subgroups, including the total, Daegu-Geyoengbuk, except-Daegu-Gyeongbuk, Sincheonji, and except-Sincheonji cases.

The cumulated counts from January 21st, 2020 (the first confirmed case of COVID-19 in South Korea) to March 26th, 2020 are shown in Figure 1. The first Sincheonji cult case appeared on February 18th, 2020, and it was the first case in the Daegu-Gyeongbuk area. Qualitatively, the cumulated counts curves for Daegu-Gyeongbuk and Sincheonji looks like they are reaching for a plateau, but the curves for the except-Sincheonji and except-Daegu-Gyeongbuk cases do not.

R statistics software version 3.6.3 (R Foundation for Statistical Computing, Vienna, Austria) and the R0 package[2] was used. For the estimation of the subgroups' R_0 values, we fitted an exponential growth model[3]. Sensitivity analysis of the exponential growth period was

77 performed. The generation time distribution should be obtained from the time lag between all
78 infector–infectee pairs[4], which is called a serial interval, but it is currently unavailable.
79 Instead, we assumed that the serial interval had a gamma distribution with mean ± standard
80 deviation of 2.0 ± 1.0, 3.0 ± 1.5, 4.0 ± 2.0, 5.0 ± 2.5, and 6.0 ± 3.0 days. The serial interval
81 could be approximated by referring to the estimated incubation time of COVID-19. Recent
82 research by Guan et al.[5] suggested that the virus has an incubation period of four days with
83 an interquartile range two to seven days. Some studies have estimated a wider range for the
84 incubation period; data for human infection with other coronaviruses (e.g. MERS-CoV,
85 SARS-CoV) suggested that the incubation period may range from two to 14 days[6].
86 Sensitivity tests for the generation time assumptions were performed (Figure S1).



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88 **Figure 2.** R_0 with 95% confidence intervals in the subgroups, including the total, Daegu-
89 Gyeongbuk, except Deagu-Gyeongbuk, Sincheonji, and except Sincheonji groups.

90

91 Figure 2 shows the estimated R0 for each study subgroup and their 95% confidence
92 intervals (by simulation) with an assumption of 4.0 ± 2.0 (mean ± standard deviation). In the
93 sensitivity test, the R_0 values were sensitive to the generation time assumptions; therefore,
94 the numbers themselves are not reliable in the current study. On the contrary, the relative
95 scales among the R_0 values were robust to the generation time assumptions.

96 The Daegu-Gyeongbuk cases showed significantly higher R_0 than the except-Daegu-
97 Gyeongbuk cases, and the Sincheonji cases showed significantly higher R_0 than the except-
98 Sincheonji cases. In all subgroups, R_0 was larger than 1.0. R_0 is an initial-stage
99 characteristic before the health authorities take action or social awareness rises. Since the
100 Sincheonji cult mass infection incidence was noticed, health authority actions including
101 COVID-19 tests, isolation, active surveillance, and school closures, were executed
102 immediately. In addition, social awareness of COVID-19 soared, and South Korean residents
103 began to more actively follow hygiene recommendations, including wearing masks, washing
104 hands frequently, and practicing social distancing in everyday life, throughout the nation.

105 Adding to such efforts to fight the disease, we measured the time dependent reproduction
106 rate R_t[7] for each subgroup. We again assumed the generation time to gamma distribution
107 with a 4.0 ± 2.0 mean ± standard deviation.

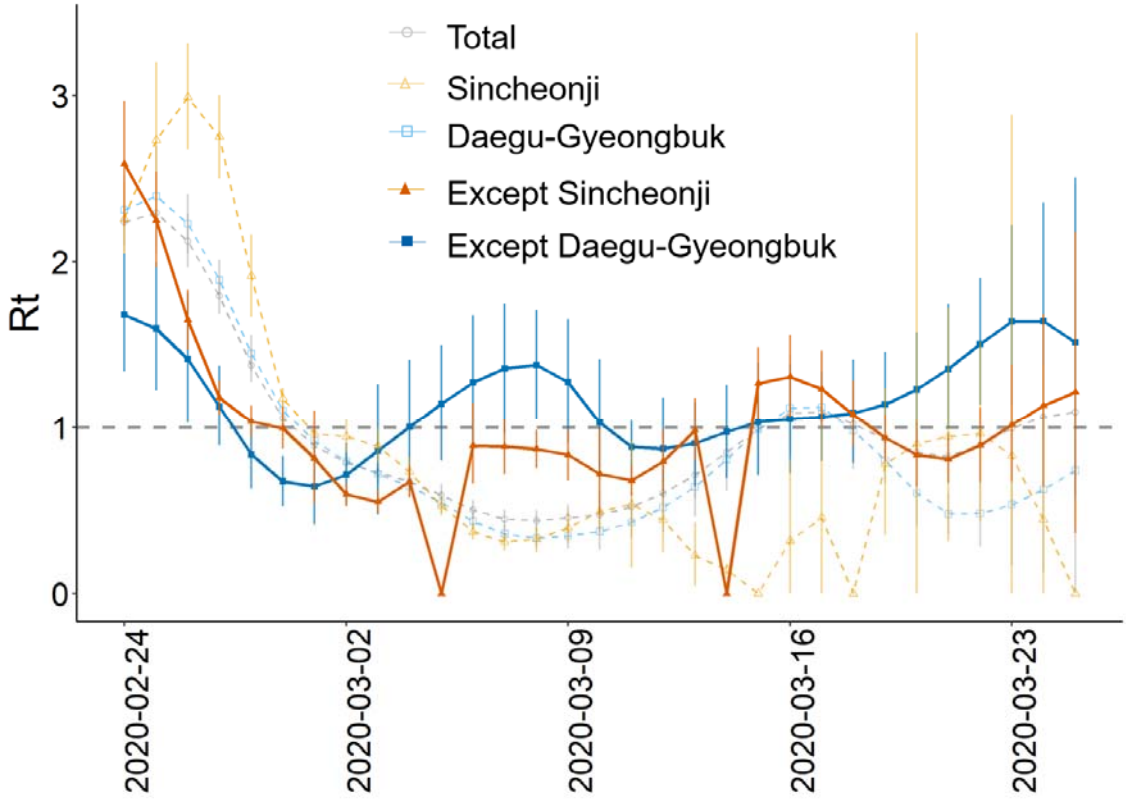

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Figure 3. Changes of R_t with 95% confidence intervals of subgroups, including the total, Sincheonji, except-Sincheonji, Daegu-Gyeongbuk, and except-Daegu-Gyeongbuk groups. A week after the first Sinceonji cult mass infection case (February 24th, 2020), R_t for all subgroups decreased for a couple of days. In the following weeks (around March 2nd, 2020 and after) Sincheonji and Daegu-Gyeongbuk cases fell under the R_t = 1.0 horizon, but R_t for the except-Sincheonji and except-Daegu-Gyeongbuk cases were drifting around the 1.0 horizon.

In Figure 3, R_t with 95% confidence intervals in the subgroups, including the total, Sincheonji, except-Sincheonji, Daegu-Gyeongbuk, and except-Daegu-Gyeongbuk subgroups, are shown. In all subgroups, R_t gradually decreased until the end of February. R_t for the Sincheonji and Daegu-Gyeongbuk cases are staying under R_t = 1.0 horizon, but in the except-Sincheonji and except-Daegu-Gyeongbuk cases, R_t is drifting around the R_t = 1.0 horizon currently (as of March 26th, 2020).

Although the analysis in Figure 3 is preliminary, and thus, we should be very cautious about its interpretations, we see a great uncertainty that South Korea is still in danger of COVID-19. Another instance of the mass infection case could happen if we lose the current momentum in social distancing and preventive action, even if no black swan comes. Assessing only the total counts may blind our sense of danger. Therefore, analyzing the except-Sincheonji and except-Daegu-Gyeongbuk cases separately from the total cases would be recommended. We are releasing the R_t estimates' daily updates for various regional subgroups of South Korea online; http://covid19.mi2rl.co/

Our current analysis has substantial limitations. Because we collected the daily press releases from the KCDC, there could be re-classified cases not reflected in our analysis. There could also be misclassification, because a Sincheonji cult may deny his or her beliefs

in the KCDC investigations. Imported cases were not accounted for in the current analysis, though the cumulated imported cases until March 17th, 2020 was 54, according to KCDC press release. Another source of confounding is that we are not aware of the true number of cases. In a recent study in China, Li et al.[8] estimated that only 14% of infected cases have been confirmed by the authorities. Nevertheless, qualitative interpretations may stay robust to under-reporting if they are constant. Delays in confirmation and in classification are another source of error. The uncertainty in the generation time is also an issue, but it could be overcome by performing sensitivity analysis. If more detailed data on infector–infectee interactions becomes available, more reliable analysis could be achieved.

To conclude, in total, it seems that the virus is going to be under control, but this is never true because if we analyze the except-Sincheonji and except-Daegu-Geyongbuk cases, the basic reproduction rate is still above 1.0, and the effective reproduction rate Rt is still higher than 1.0. The current efforts to suppress the COVID-19 outbreak should at least be maintained.

Disclosure

All authors have no potential conflicts of interest to disclose.

Author Contributions

Conceptualization: Hwang J, Kim S, Jung J, Kim N. Methodology: Hwang J, Kim N. Formal analysis: Hwang J, Kim N. Data curation: Par H, Software: Hwang J, Kim N. Investigation: Jung J, Kim S, Kim N. Writing – original draft preparation: Hwang J, Park H. Writing – review and editing: Jung J, Kim S, Kim N. Approval of final manuscript: all authors.

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165 **REFERENCES**

166 1. KCDC. Korean Centers for Disease Control and Prevention http://cdc.go.kr2020.

167 2. Obadia T, Haneef R, Boelle PY. The R0 package: a toolbox to estimate reproduction
168 numbers for epidemic outbreaks. Bmc Medical Informatics and Decision Making 2012;12.

169 3. Wallinga J, Lipsitch M. How generation intervals shape the relationship between
170 growth rates and reproductive numbers. Proceedings of the Royal Society B-Biological
171 Sciences 2007;274(1609):599-604.

172 4. Svensson A. A note on generation times in epidemic models. Mathematical
173 Biosciences 2007;208(1):300-11.

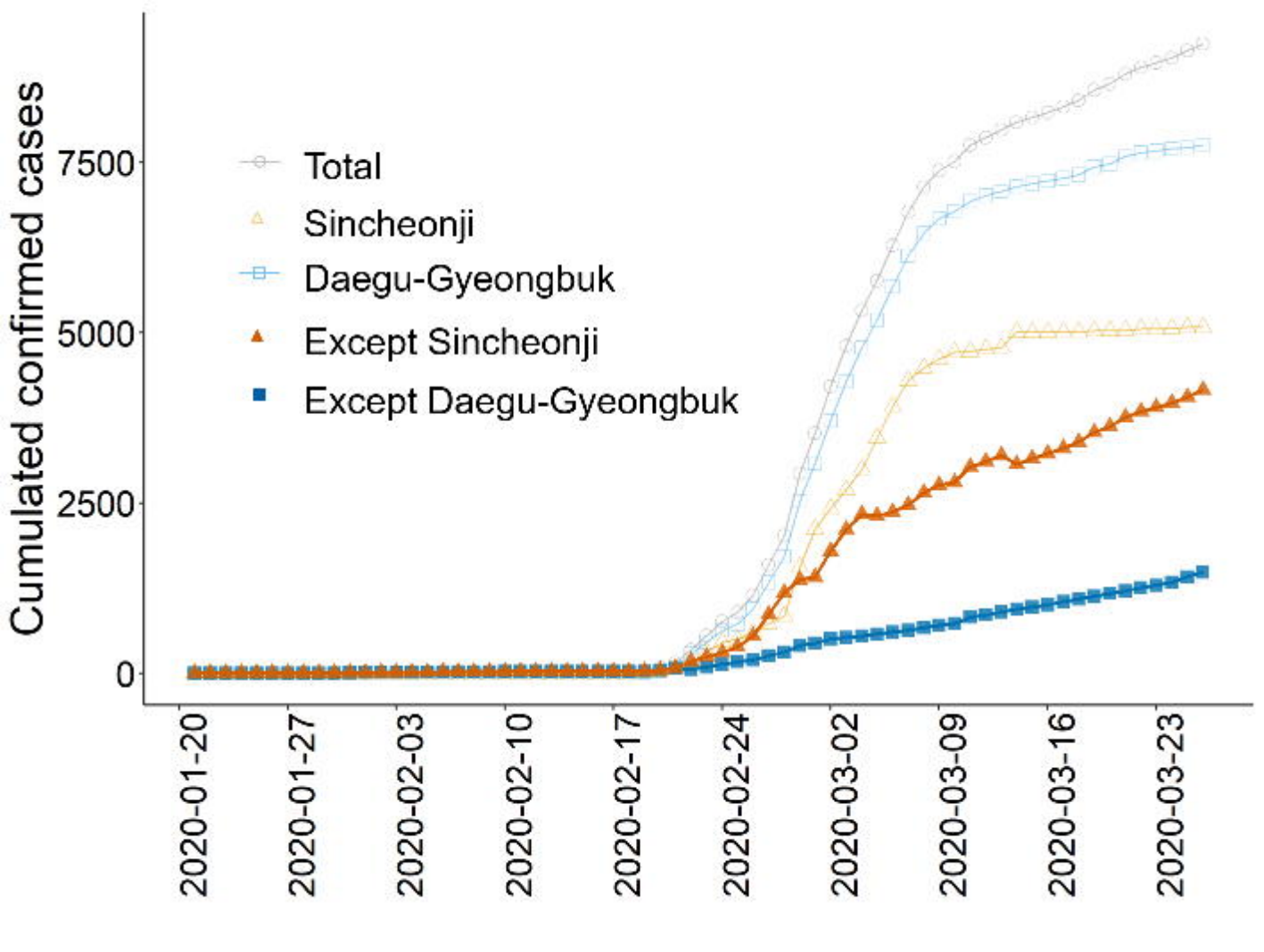
174 5. Guan WJ, Ni ZY, Hu Y, Liang WH, Ou CQ, He JX, et al. Clinical Characteristics of
175 Coronavirus Disease 2019 in China. N Engl J Med 2020.

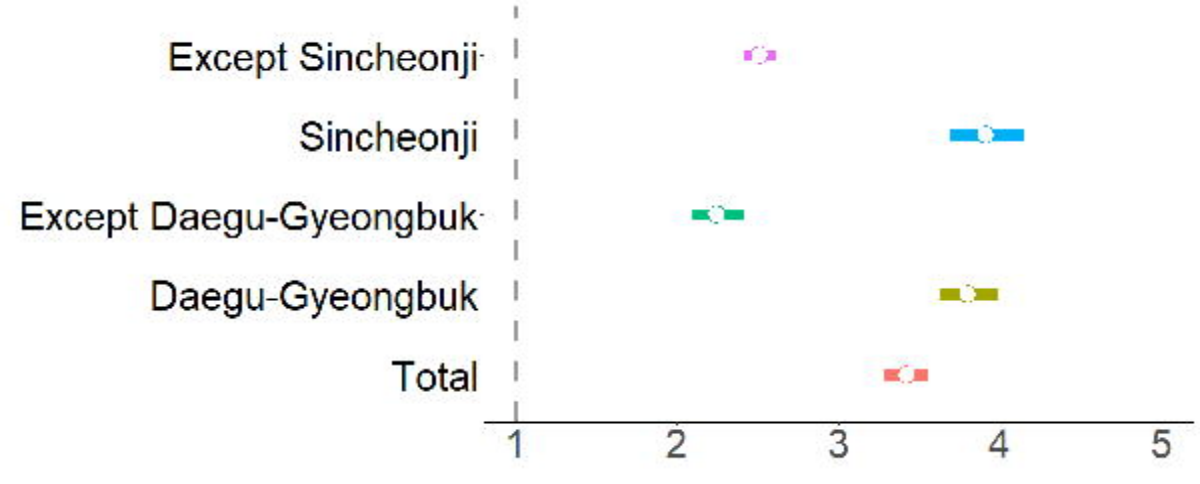
176 6. CDC. Interim Clinical Guidance for Management of Patients with Confirmed
177 Coronavirus Disease (COVID-19). https://www.cdc.gov/coronavirus/2019-ncov/hcp/clinical-
178 guidance-management-patients.html. Updated March 7, 20202020.

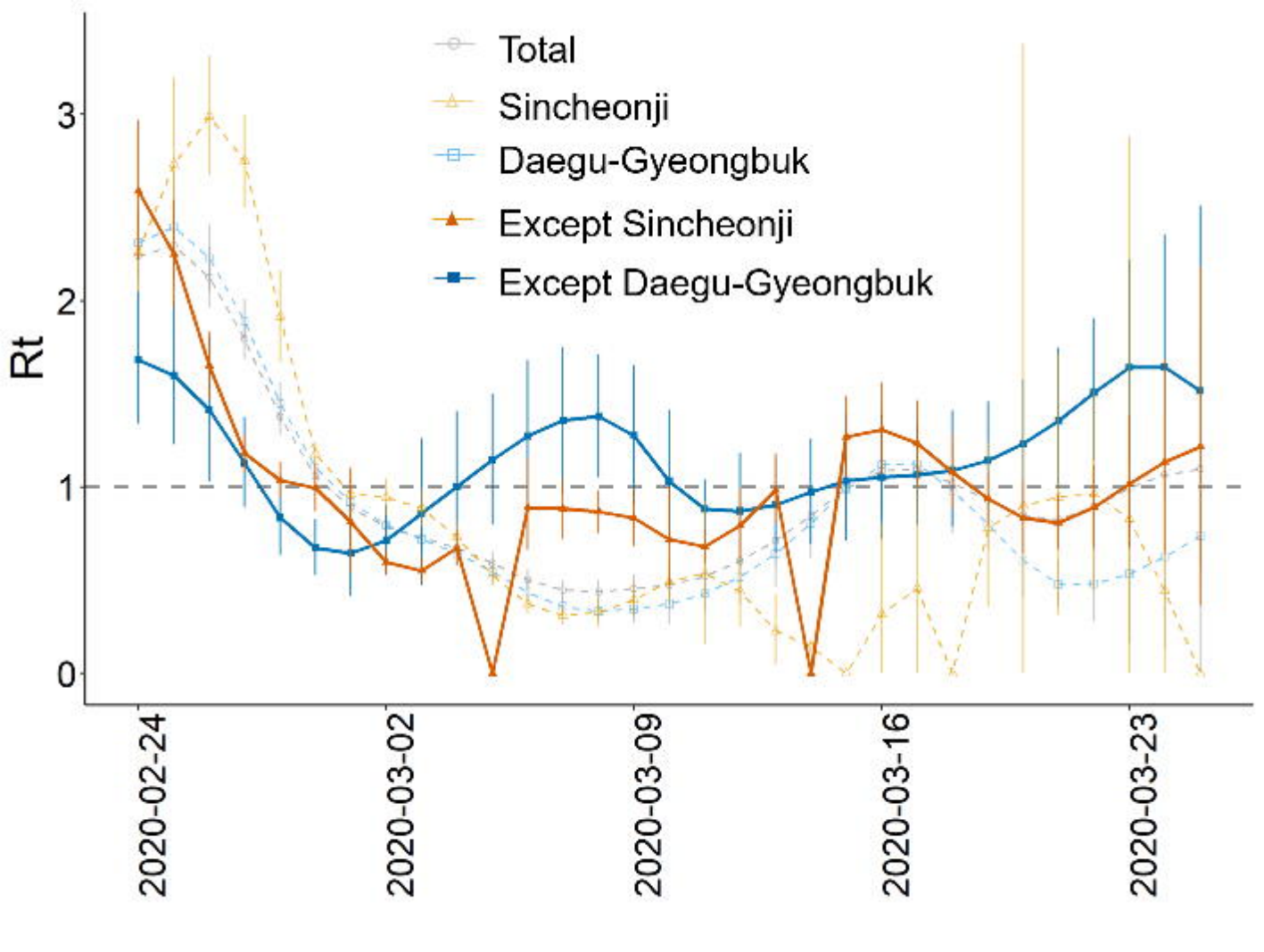
179 7. Wallinga J, Teunis P. Different epidemic curves for severe acute respiratory
180 syndrome reveal similar impacts of control measures. American Journal of Epidemiology

2004;160(6):509-16.

8. Li R, Pei S, Chen B, Song Y, Zhang T, Yang W, et al. Substantial undocumented infection facilitates the rapid dissemination of novel coronavirus (SARS-CoV2). Science 2020.


Cumulated confirmed cases
7500
5000
2500
0
Total
Sincheonji
Daegu-Gyeongbuk
Except Sincheonji
Except Daegu-Gyeongbuk
2020-01-20
2020-01-27
2020-02-03
2020-02-10
2020-02-17
2020-02-24
2020-03-02
2020-03-09
2020-03-16
2020-03-23


Except Sincheonji
Sincheonji
Except Daegu-Gyeongbuk
Daegu-Gyeongbuk
Total
1
2
3
4
5


Total
Sincheonji
Daegu-Gyeongbuk
Except Sincheonji
Except Daegu-Gyeongbuk
Rt
3
2
1
0
2020-02-24
2020-03-02
2020-03-09
2020-03-16
2020-03-23