

1 **Title Page**

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3 **Forecasting the Cumulative Number of COVID-19 Deaths in China: a**  
4 **Boltzmann Function-based Modeling Study**

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## 24 Abstract

25 **The COVID-19 outbreak is on-going in China. Here we estimated the potential total**  
26 **numbers of COVID-19 deaths in China, outside Hubei (in China), Hubei Province, Wuhan**  
27 **City and outside Wuhan (in Hubei) by Boltzmann function-based analyses, which are 3342**  
28 **(95% CI, 3214, 3527), 111 (109, 114), 3245 (3100, 3423), 2613 (2498, 2767) and 627 (603, 654),**  
29 **respectively. The results may help to evaluate the severity of COVID-19 outbreaks and**  
30 **facilitate timely mental service for the families of passed patients.**

31  
32 An outbreak of 2019 novel coronavirus diseases (COVID-19) caused by SARS-CoV-2 is on-  
33 going in China and has spread worldwide <sup>[1, 2]</sup>. As of Feb 13, 2020, there have been over 80000  
34 confirmed COVID-19 patients and over 3000 deaths in China, most of which are in the epicenter  
35 of the outbreak, Wuhan city and related regions in Hubei province. Although the number of new  
36 confirmed cases has substantially decreased since Feb 13, 2020 and the outbreak appears to  
37 approach the late phase in China, people have raised grave concerns about the severity of the  
38 outbreak, especially questioning how many patients will die eventually. Here we estimated the  
39 potential total number of COVID-19 deaths by applying Boltzmann function-based regression  
40 analysis, an approach we recently developed for estimating the potential total numbers of  
41 confirmed cases for both the ongoing SARS-CoV-2 outbreak and the gone 2003 SARS epidemic  
42 <sup>[3]</sup>.

43  
44 We collected data for analysis on the officially released cumulative numbers of deaths in mainland  
45 China, other provinces than Hubei, Hubei Province, Wuhan City, and other cities in Hubei (from  
46 Jan 21 to Feb 29, 2020). We first verified that the cumulative numbers of confirmed cases with  
47 respect to each region were all well fitted to the Boltzmann function ( $R^2$  all being close to 0.999);  
48 **Fig. 1A**), consistent with our earlier report using the data from Jan 21 to Feb 14, 2020 <sup>[3]</sup>.  
49 Assuming that the number of deaths is proportional to the number of confirmed cases for the

50 outbreak under specific circumstances, we speculated that the cumulative number of COVID-19  
51 deaths would also obey the Boltzmann function. In support of this speculation, the cumulative  
52 numbers of COVID-19 deaths in the above regions were all well-fitted to the Boltzmann function  
53 ( $R^2$  all being close to 0.999; **Figs. 1B, 1C** and **Table 1**), with the potential total numbers of deaths  
54 being estimated as  $3200 \pm 40$ ,  $108 \pm 1$ ,  $3100 \pm 40$ ,  $2500 \pm 40$  and  $604 \pm 6$  respectively (**Table 1**). This  
55 result, in conjunction with our earlier observation that the cumulative numbers of confirmed cases  
56 of 2003 SARS in mainland China and worldwide were well fitted with the Boltzmann function,  
57 prompted us to analyze the cumulative numbers of 2003 SARS deaths in the same way.  
58 Consistently, we observed that the cumulative numbers of 2003 SARS deaths in mainland China,  
59 Hong Kong and worldwide were all well fitted to the Boltzmann function (**Fig. 1D**), strongly  
60 suggesting that the Boltzmann function is suitable to simulate the course of deaths associated with  
61 coronavirus-caused diseases.

62  
63 One issue regarding our analyses is that some COVID-19 deaths might be miss-reported such that  
64 the reported death numbers represent a lower limit. For instance, 134 new deaths were suddenly  
65 counted from more than 13000 clinically diagnosed patients in Hubei Province on Feb 12, 2020  
66 (as clearly indicated by a sudden jump of deaths in **Fig. 1B**). Another uncertainty might result  
67 from those unidentified COVID-19 deaths at the early phase of the outbreak. We applied the  
68 Monte Carlo method (for detail, refer to the Methods section in SI file) to estimate such  
69 uncertainty assuming that the relative uncertainty of the reported numbers of deaths follows a  
70 single-sided normal distribution with a mean of 1.0 and a standard deviation of 2.5%. The  
71 potential total numbers of COVID-19 deaths in the above regions were estimated to be 3260 (95%  
72 CI 3187, 3394), 110 (109, 112), 3174 (3095, 3270), 2550 (2494, 2621) and 617 (607, 632),  
73 respectively (**Figs. 1E** and **S1**), which are slightly higher than those estimated without uncertainty  
74 (refer to **Table 1**).

75

76 To verify our Boltzmann function-based estimations, we calculated the potential total numbers of  
77 deaths in the above regions by applying Richards function-based regression analyses, which had  
78 been explored to simulate the cumulative numbers of confirmed cases of 2003 SARS in different  
79 regions <sup>[4,5]</sup>. The potential total numbers of COVID-19 deaths in mainland China, other provinces,  
80 Hubei Province, Wuhan City and other cities were estimated to be 3342 (3214, 3527), 111 (109,  
81 114), 3245 (3100, 3423), 2613 (2498, 2767) and 627 (603, 654), respectively (**Fig. S2**), which are  
82 close to what are estimated by the Boltzmann function-based analyses (**Table 1**). In addition, we  
83 found that the established Boltzmann function was able to predict the death course in a short  
84 period such that the released cumulative numbers of deaths from Mar 1 to 5 Mar 5 are close to  
85 the estimated numbers, as exemplified in Wuhan (**Fig. 1F** and **Table S1**). If the data from Jan 21  
86 to different closing dates were arbitrarily analyzed, we found that the course of COVID-19 deaths  
87 could be largely simulated based on the data as of Feb 14 (**Fig. 1F**), implicating that the  
88 Boltzmann function-based analysis could predict the trend ahead of approximate three weeks.  
89  
90 Collectively, we observed that all sets of data from both the COVID-19 deaths and the 2003  
91 SARS deaths were well fitted to the Boltzmann function. We propose that the Boltzmann function  
92 is suitable for analyzing not only the cumulative number of confirmed COVID-19 cases, as  
93 reported by us recently <sup>[3]</sup> (also refer to **Fig. 1A**), but also those of deaths as reported here. We  
94 noticed that modeling studies on the COVID-19 outbreak have been performed <sup>[6]</sup> and COVID-  
95 19 deaths have been estimated by other groups using different models. For instance, Li et al  
96 recently showed <sup>[7]</sup> by data driven analysis that a total of deaths in Hubei would be 2250, a number  
97 much lower than the observed (2761 as of Feb 29). Using the Susceptible-Infected-Recovered-  
98 Dead model Anastassopoulou et al forecasted that the total death might exceed 7000 by Feb 29  
99 <sup>[8]</sup>, a number apparently much higher.  
100  
101 Since case fatality ratio in the epicenter of the outbreak is still much higher than that in other

102 provinces of mainland China <sup>[1, 2]</sup>, there is a great potential for government to optimize  
103 preparedness and medical resource supplies therein, by which hundreds of lives of COVID-19  
104 patients, particularly those severe and critically ill patients <sup>[2, 9]</sup>, might be saved. In addition, our  
105 estimates on the course of COVID-19 deaths (refer to **Table S2**) may benefit the mental health  
106 service that needs to be timely provided to the families of passed patients <sup>[10]</sup>.

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111 **Declaration of interest statement:** All authors declare no conflicts of interests.

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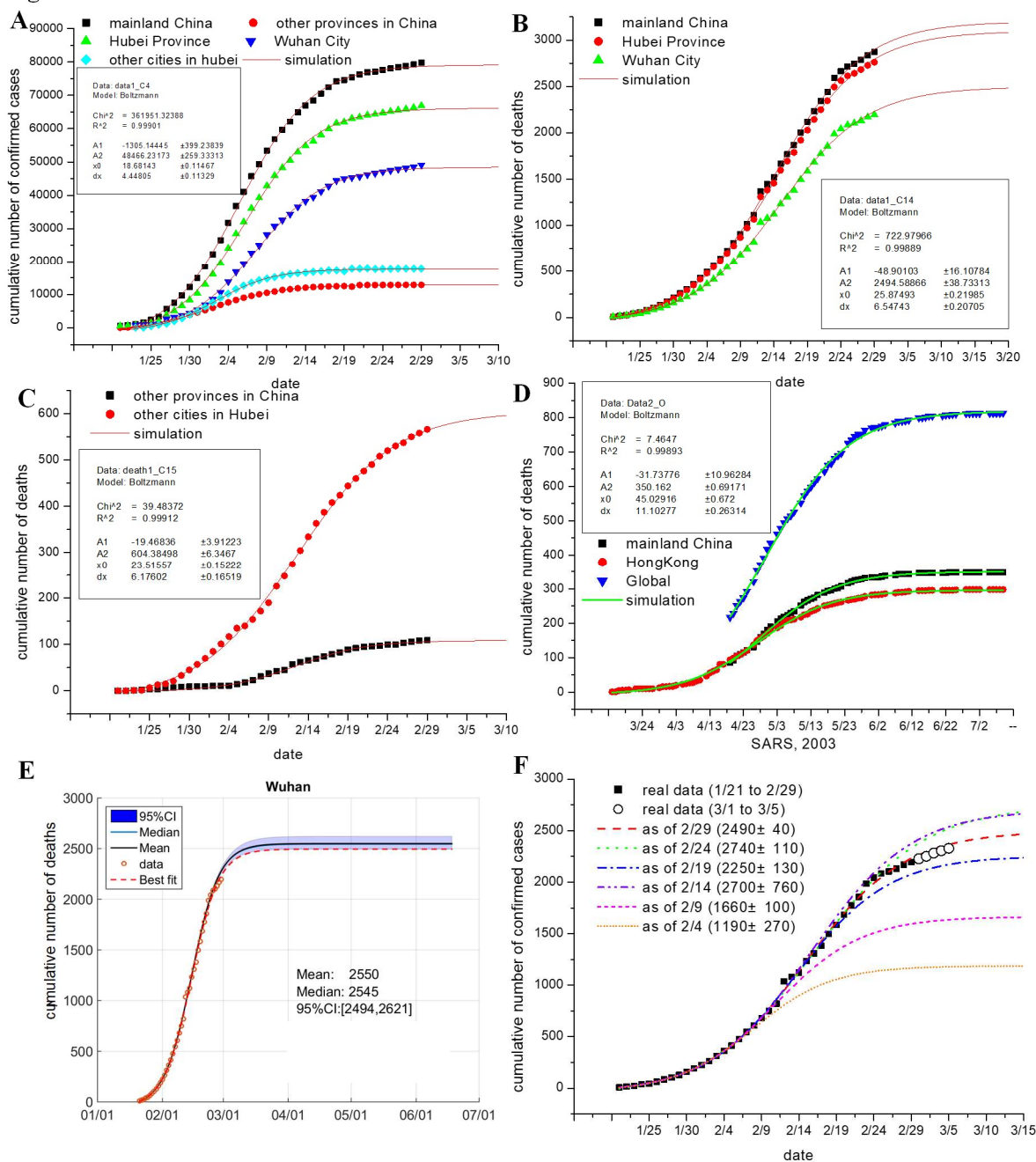
149 **Table 1 Summary of the estimated total numbers of COVID-19 deaths in China**

Regions	Boltzmann <sup>a</sup>		Boltzmann <sup>a</sup>	Richards <sup>a</sup>
	Mean±SD	R <sup>2</sup>	(mean, 95% CI)	(mean, 95% CI)
mainland China	3200±40	0.999	3260 (3187, 3394)	3342 (3214, 3527)
other provinces	108±1	0.996	110 (109, 112)	111 (109, 114)
Hubei Province	3100±40	0.999	3174 (3095, 3270)	3245 (3100, 3423)
Wuhan City	2490±40	0.998	2550 (2494, 2621)	2613 (2498, 2767)
other cities in Hubei	604±6	0.999	617 (607, 632)	627 (603, 654)

150 <sup>a</sup> Boltzmann function-based regression analysis results assuming the reported cumulative number of deaths are  
151 precise and have uncertainty (a standard deviation of 2.5%), respectively (for detail, refer to the Methods section  
152 in the supporting information file and **Figs. 1E, S1**). The same uncertainty was set for Richards function-based  
153 regression analysis (for detail, refer to the Methods section and **Fig. S2**)

154  
155

**Figure 1**



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157 **Figure 1. Fitting the cumulative number of COVID-19 deaths to Boltzmann function**

158 (A, B, C) Boltzmann function-based regressions analysis results on the cumulative numbers of confirmed  
 159 COVID-19 cases (panel A) and deaths (panels B and C) in the indicated geographic regions. Parameters  
 160 of the established functions for Wuhan City (panels A and B) and for other cities in Hubei (panel C) are  
 161 shown in insets. Note: the reported cumulative number of confirmed cases of Hubei Province and Wuhan  
 162 City were re-adjusted for data fitting due to the suddenly added cases determined using clinical features  
 163 (for details, refer to **Table S1**).

164 of 2003 SARS deaths in the indicated regions. Parameters of the established function for mainland China  
165 are shown in insets. (E). Regressions analysis results on COVID-19 deaths in Wuhan City by the  
166 Boltzmann functions assuming that the relative uncertainty of the data follows a single-sided normal  
167 distribution with a mean of 1.0 and a standard deviation of 2.5%. Original data are shown as circles;  
168 simulated results are presented as colored lines as indicated. Inserts show key statistics. Results for other  
169 regions are presented in **Figs. S1**. (F). Prediction of COVID deaths in Wuhan City by Boltzmann function-  
170 based analyses. The real data from Jan 21 to different ending dates were arbitrarily analyzed (colored lines),  
171 with the potential total numbers of deaths under these analyses being shown in insets.