Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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RESEARCH ARTICLE

Dynamics of the coronavirus disease 2019 (COVID-19) epidemic in Wuhan City, Hubei Province and China: a second derivative analysis of the cumulative daily diagnosed cases during the first 85 days

Bin Yu [a,b,*], Xinguang Chen [a], Shannan Rich [a], Qiqing Mo [a,c], Hong Yan [d,**]

[a] Department of Epidemiology, University of Florida, Gainesville, FL 32610, USA
[b] Department of Surgery, School of Medicine, Duke University, Durham, NC 27710, USA
[c] Department of Social Medicine and Health Promotion, School of Public Health, Guangxi Medical University, Nanning, Guangxi 530021, China
[d] Department of Preventive Medicine, School of Health Sciences, Wuhan University, Wuhan, Hubei 430072, China

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ABSTRACT

Background: Controlling the coronavirus disease 2019 (COVID-19) epidemic requires information beyond new and cumulative cases. This study aims to conduct an in-depth analysis by geographic strata: Wuhan City (hereafter referred to as Wuhan) only, Hubei Province (hereafter referred to as Hubei) excluding Wuhan, and China excluding Hubei.

Methods: Daily cumulative confirmed COVID-19 cases between December 8, 2019 (the date of symptom onset based on patients' recall during the investigation), and March 1, 2020, from official sources and published studies were analyzed. The second derivative model was used for information extraction. Data analysis was conducted separately for the three strata.

Results: A total of 80 026 diagnosed COVID-19 cases were reported during the first 85 days of the epidemic, with 49 315 cases from Wuhan, 17 788 from Hubei excluding Wuhan, and 12 923 from China excluding Hubei. Analytical results indicate that the COVID-19 epidemic consists of an Acceleration, a Deceleration, and a Stabilization Phase in all three geographic strata, plus a Silent Attack Phase for Wuhan only. Given the reported incubation period of 14 days, effects of the massive anti-epidemic actions were revealed by both the Acceleration and Deceleration Phases. The Acceleration Phase signaled the effect of the intervention to detect the infected; the Deceleration Phase signaled the declines in new infections after the infected were detected, treated and quarantined.

Conclusion: Findings of the study provide new evidence to better monitor the epidemic, evaluate its response to intervention, and predict the trend long. In addition to re-evaluating the control of the COVID-19 epidemic in China, this study provided a model for monitoring outbreaks of COVID-19 in different countries across the world.

1. Background

The control of the coronavirus disease 2019 (COVID-19) epidemic in China, caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2, previously provisionally named 2019 novel coronavirus or 2019-nCoV) has gained much attention across the globe.[1] The first COVID-19 case was reported on December 8, 2019 (the first date of symptom onset based on the patients' recall during the investigation), in Wuhan City (hereafter referred to as Wuhan),[2] the provincial capital of Hubei Province (hereafter referred to as Hubei) in Central China. As of March 1, 2020, there has been a total of 49 315 (61.6%) confirmed cases in Wuhan only,[3] plus 17 788 (22.2%) cases in Hubei excluding Wuhan, and 12 923 (16.1%) in China excluding Hubei, with a total of 80 026 cases in China.[4] Assessment of control and forecast future of the COVID-19 epidemic need further research to inform decision-makers, medical and public health professionals, and the general public.

China has taken a series of massive anti-epidemic actions to control the COVID-19 epidemic (see more details in Appendix Table A1). Typical examples include but are not limited to the declaration of human-to-human transmission and outbreak on January 20, the lockdown of

* Corresponding author: bin.yu@duke.edu.cn.
** Corresponding author: yanhmjxr@whu.edu.cn.

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Wuhan as a massive epidemic control measure on January 23, delivery of a large number of molecular testing kits on January 26, the Central Government Meeting on COVID-19 on January 25, the establishment of the National Anti-COVID-19 Leadership Group, and construction of two Emergency Hospitals, Huoshenshan and Leishenshan in days.[5-8] All these actions may potentially affect the epidemic dynamics of COVID-19 since the epidemic is nonlinear and chaotic in nature.[9]

We previously applied a new method, second derivative modeling that successfully characterized the dynamics of COVID-19 transmission in China as a whole in the first two months, evaluated the massive anti-epidemic measures, and predicted the trend of the epidemic pattern.[9] In this study, based on our previous study, we aim to investigate the COVID-19 epidemic by three different geographic strata, including Wuhan, Hubei excluding Wuhan, and China excluding Hubei.

2. Material and methods

2.1. Sources of data and data processing

The cumulative numbers of confirmed cases of COVID-19 on a daily basis were used. The data were derived from two sources: (1) Data from December 8 of 2019 (the first date of symptom onset based on patients' recall) to January 20 of 2020 were derived from a study by Li and colleagues.[2] This was the period before COVID-19 was officially declared as an outbreak. (2) Data from January 21 to March 1, 2020, were derived from the daily reported and officially finalized cases. Data for Wuhan City and Hubei Province were derived from the Wuhan Municipal Health Commission[8] and data for China were derived from the National Health Commission of P. R. China.[10]

To address the purposes of this study, we derived daily data: (1) for Wuhan only, (2) for Hubei excluding Wuhan by subtracting the daily cases of Wuhan from the provincial data, and (3) for China excluding Hubei by subtracting the cases in Hubei (including Wuhan) from the national data. Detailed data were included in Appendix Table A2.

2.2. Statistical analysis

To characterize the dynamics of the COVID-19 epidemic, identify evidence of massive anti-COVID-19 actions on dynamic changes in the epidemic, and predict future trends at the earliest time possible, we took the second derivative modeling approach.[9] Using this modeling approach, we first described the daily cumulative number of cases $F(x)$ as:

$$F(x) = \int_{i=1}^{t} x_i \approx \sum_{i=1}^{t} x_i, \tag{1}$$

where x_i represents new cases at day i ($i = 1, 2, 3, \ldots t$).

Taking the first derivative of $F(x)$, we obtain $F'(x)$:

$$F'(x) = \frac{dF(x)}{dt} = \int_{i=1}^{(t+1)} x_i - \int_{i=1}^{t} x_i \approx \sum_{i=1}^{t+1} x_i - \sum_{i=1}^{t} x_i, \tag{2}$$

where $F'(x)$ is equivalent to the daily new cases. It provides information regarding the speed of the epidemic on a daily basis. Although new cases are updated daily during the epidemic, this measure is sensitive to changes in disease diagnosis and is not informative to signal future trends. Therefore using $F'(x)$ alone is not adequate to monitor and make inferences about changes in epidemic dynamics, and inform decision-makers, medical and health professionals, as well as the general public about the epidemic.

To increase sensitivity to detect changes in the epidemic and to reduce potential impact from changes in diagnostic criteria, we took the derivative of $F'(x)$ to obtain the second derivative $F''(x)$:

$$F''(x) = \frac{dF'(x)}{dt'} \approx F'(x_{i+1}) - F'(x_i), \tag{3}$$

where $F''(x)$ measures the speed of changes in daily new cases or acceleration of $F(x)$.

Different from $F'(x)$, which mainly signals increase and decline in the epidemic, $F''(x)$ provides more information. (1) When $F''(x)$ is close or equal to 0, it indicates that the epidemic is stable over time. This can be: 1) consistent increase in $F'(x)$; 2) consistent decline in $F'(x)$; or 3) no new cases. (2) When $F''(x) > 0$, it indicates a daily acceleration in new cases. (3) When $F''(x) < 0$, it signals a daily deceleration in new cases.

Although we reported data for the whole study period of 85 days in the paper, *we, in fact, used the model on a daily basis to monitor the epidemic and to predict the trend in a real-time manner*. Data for Wuhan, Hubei excluding Wuhan, and China excluding Hubei were modeled separately using Eqs. (2) and Eqs. (3). Modeling results, including the estimated $F'(x)$ and $F''(x)$ were plotted. All statistical analyses and plotting were completed using a spreadsheet from Microsoft Excel (Microsoft Corporation, Redmond, WA, USA).

3. Results

3.1. The COVID-19 epidemic

The first COVID-19 case was reported in Wuhan on December 8, 2019 (the date of symptom onset based on patients' recall); the first case in the Hubei Province excluding Wuhan was reported on January 22; while the first case in China excluding Hubei was reported on January 21, 2020. Up to March 1 when this study was completed, we monitored the COVID-19 epidemic in China for 85 days with a total number of 49 315 diagnosed cases in Wuhan only, 17 788 in Hubei excluding Wuhan and 12 923 in the rest of China, yielding a total of 80 026 COVID-19 cases across China.

3.2. Recapture of daily new cases using $F'(x)$

Instead of reported daily cases, $F'(x)$, the first derivative of $F(x)$ for the three geographic strata is presented in Fig. 1. The $F'(x)$ for Wuhan (red line) indicates a long-term slow growth of the epidemic after the first case on December 8, 2019, until January 27 when a rapid increase forming a spike on the day after the massive number of testing kits was distributed to Wuhan on January 26. The $F'(x)$ reached a peak with a total of 13,436 new cases reported on February 12, the day when the diagnostic criteria were revised to include all patients with positive clinical symptoms regardless of laboratory confirmation. After the peak, the $F'(x)$ declined rapidly to below 400 on February 25 and left off at around 400 thereafter before declining again on February 29.

$F'(x)$ for Hubei excluding Wuhan (blue line) showed a very different pattern. After the first case on January 22, the $F'(x)$ increased steadily, surpassed the $F'(x)$ of Wuhan on January 28, and reached the peak on February 12, the same peak day of the $F'(x)$ for Wuhan. This was because the changes for COVID-19 diagnosis for Wuhan were also adapted by Hubei Province, not for the rest of China. After the peak, the $F'(x)$ for Hubei declined progressively with some fluctuations and reached to 3 on March 1.

$F'(x)$ for China excluding Hubei (black line) also had its distinct epidemic curve pattern. After the first case on January 21, 2020, the $F'(x)$ started to increase one day earlier than that of Hubei excluding Wuhan with slightly higher values until January 30 when the epidemic curves for Hubei excluding Wuhan and China excluding Hubei crossed. The $F'(x)$ peaked on February 3, followed by a progressive and quicker decline than that of Wuhan and Hubei excluding Wuhan. The epidemic curve for China excluding Hubei appears to be much flatter, indicating that the actions in Wuhan may result in the flattening of the epidemic curve for China.

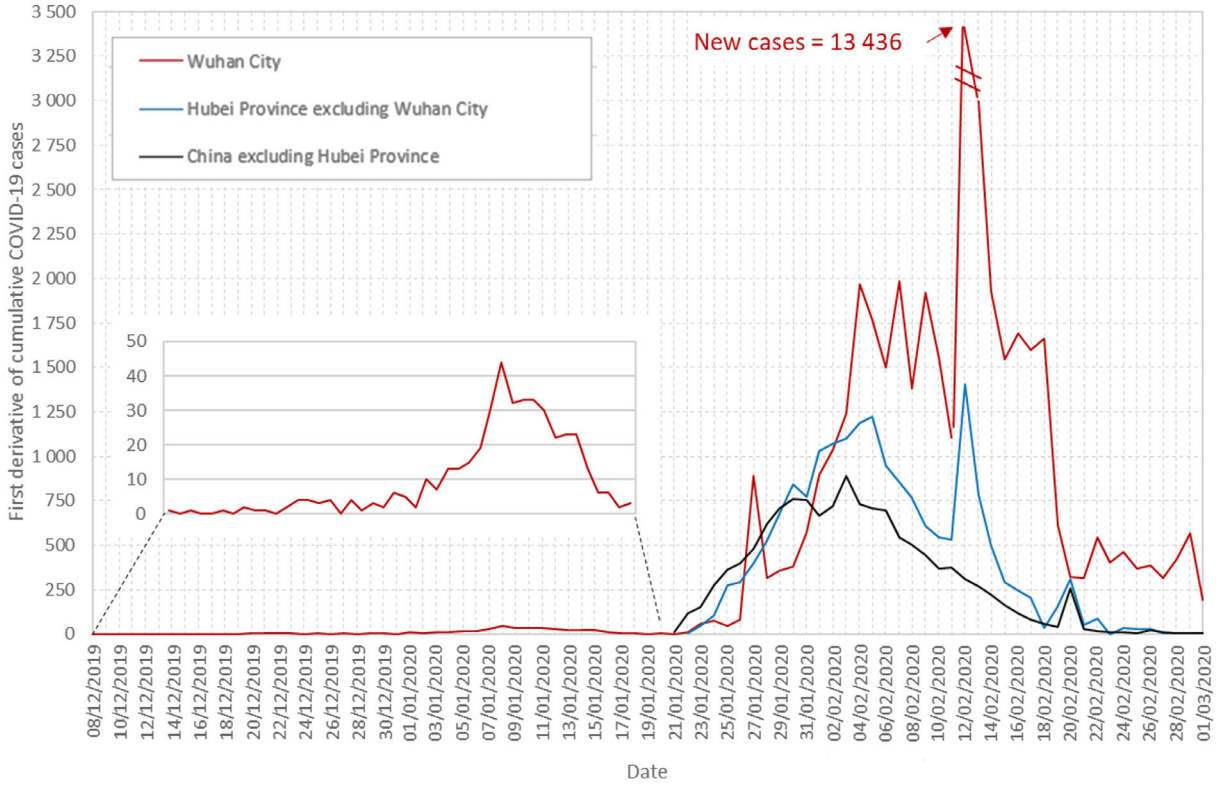

Fig. 1. Epidemic curve of the first derivative of cumulative COVID-19 cases by geographic strata from December 8 of 2019 to March 1 of 2020 in China. Data were derived from: (1) one published paper by Li and colleagues;[2] (2) Wuhan Municipal Health Commission;[8] (3) and the National Health Commission of the P. R. China.[10] December 8 to 26 of 2019 are the dates of symptom onset based on patients' recall during the investigation.

3.3. Second derivative of the COVID-19 epidemic

Fig. 2A depicts the $F''(x)$ for Wuhan that showing four distinct phases of COVID-19 epidemic dynamics that were essential for monitor the epidemic, assess the effect from massive anti-epidemic measures, and early prediction of future trends.

Silent Attack Phase (from December 8 of 2019 to January 20 of 2020): $F''(x)$ varied at a very low level during this period with no signal of the outbreak until the outbreak was officially declared on January 20. It was not supported by population-based evidence ($F''(x) > 0$), but individual-level data of confirmed person-to-person transmission.

Acceleration Phase (from January 21 to February 4 of 2020): $F''(x)$ started to fluctuate after a 4-day transition, forming a clear upward band between January 26 and February 4 (the dotted line). This result reflects the increases in detection of the infected cases from the massive anti-epidemic action initiated on January 21 that further intensified 4 days later. This was the earliest information provided by $F''(x)$ that the massive anti-epidemic actions had a positive impact on the epidemic mitigation.

Deceleration Phase (from February 5 to 19 of 2020): A downward trend, despite its high volatility, of $F''(x)$ was formed during this period. There were 15 days from the initiation of anti-epidemic action on January 21 to February 5 (the beginning of Phase 3), which was one day longer than the reported incubation period of 14 days for COVID-19. Three important pieces of information were revealed from the $F''(x)$ during this phase. (1) It provided evidence supporting the observations in Acceleration Phase that the massive anti-epidemic actions led to epidemic deceleration; (2) It signaled a possible future decline in the epidemic if most of the infected were detected and under treatment/quarantine. Although no such information could be found on the first several days since February 5, what needed was to monitor the $F''(x)$ on a daily basis from the beginning of this period to confirm the conclusion; (3) It signaled another wave of decline in the epidemic initiated on February 19 or 20, 14–15 days (another incubation period) after February 5 with the removal of most infected from the population.

Stabilization Phase (February 20 to March 1 of 2020): The $F''(x)$ stabilized at around zero following a 4-day transition in reductions of the deceleration from February 18 to 22 across Deceleration Phase and Stabilization Phase. Since the $F''(x)$ varied from negative to around zero, it suggests that the epidemic entered a very low level since February 20, and the epidemic in Wuhan is likely to be largely under control after another incubation period of 14–15 days on March 6 or 7.

The same $F''(x)$ for Hubei excluding Wuhan was presented in Fig. 2B. Since initial COVID-19 cases in Hubei excluding Wuhan were assumed to originate from Wuhan, $F''(x)$ contained no Silent Attack Phase, but it shared the other three phases with Wuhan (Acceleration, Deceleration, and Stabilization Phases). The differences included a shorter Acceleration Phase from January 22 to February 1; a deceleration with larger volatility from February 2 to 16; and a Stabilization Phase from February 17 to March 1. The shorter Acceleration Phase observed in Hubei excluding Wuhan did not correspond with the incubation period of 14–15 days for COVID-19. This discrepancy is probably due to two factors: (1) The initial cases of Hubei excluding Wuhan were those infected in Wuhan; (2) most of these infected persons were within the early period with no symptoms when they returned home from Wuhan and (3) the anti-epidemic action was stronger in Hubei excluding Wuhan than in Wuhan only as shown by more and larger fluctuations in the $F''(x)$ relative to that in Wuhan only.

Fig. 2C depicts the $F''(x)$ for China excluding Hubei. Three clear phases were observed in the figure, including the Acceleration Phase (January 21 to February 3 of 2020, 14 days), Deceleration Phase (February 4 to 13), and Stabilization Phases (February 14 to March 1). The Acceleration Phase ended one day ahead of Wuhan and 3 days later than

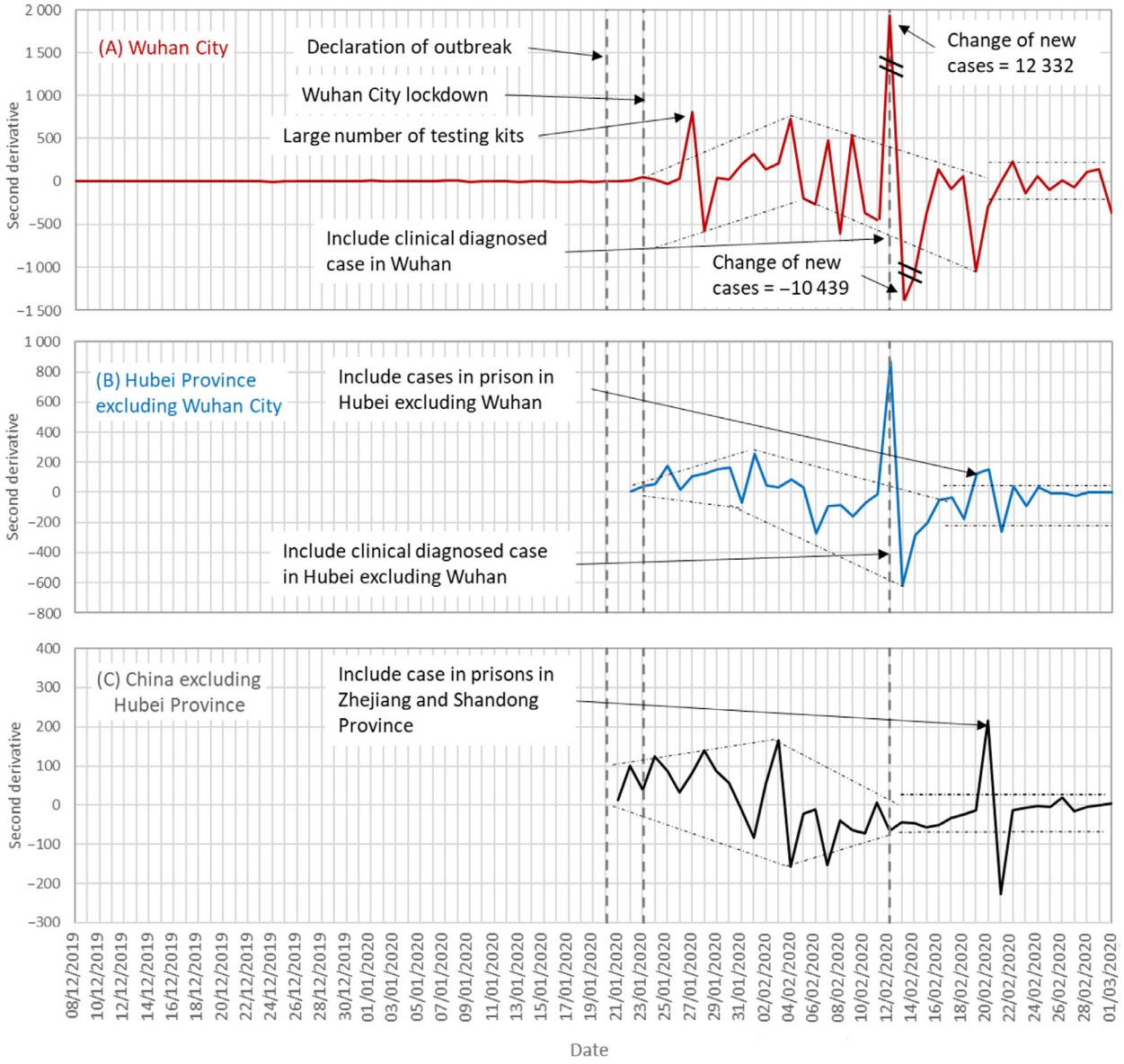

Fig. 2. Epidemic curve of the second derivative of COVID-19 cumulative cases by geographic strata from December 8 of 2019 to March 1 of 2020 in China. (A) Wuhan City; (B) Hubei Province excluding Wuhan City; (C) China excluding Hubei Province.
Data were derived from: (1) one published paper by Li and colleagues;[2] (2) Wuhan Municipal Health Commission;[8] and (3) the National Health Commission of the P. R. China.[10] December 8 to 26 of 2019 are the dates of symptom onset based on patients' recall during the investigation.

Hubei excluding Wuhan. The Stabilization Phase started 6 days earlier than Wuhan and 3 days earlier than Hubei excluding Wuhan.

4. Discussion

In this study, we presented the results from the second derivative modeling analysis of the cumulative cases of COVID-19 by geographic strata in China. It is difficult if not impossible to determine ahead of time when, where, and whom an outbreak of an epidemic like COVID-19 will attack. The best approach is to closely monitor and capture information at the earliest time possible to inform decision-makers, medical and health professionals, and the general public. Findings of the study provide new evidence without extra data but essential for us to better understand the outbreak and the current status of the COVID-19 epidemic as well as its future trend in a real-time manner. Findings of the study also add data supporting one of our previous studies that second derivative modeling can be used as a surveillance tool to monitor the outbreak of infectious disease epidemic and inform decision-makers for massive anti-epidemic actions, and evaluate the response of the epidemic to intervention and forecast the future based on current surveillance data not only in China but different countries across the world.[9]

4.1. Monitor the COVID-19 epidemic

In this study, we demonstrated that the second derivative model, built using data on daily cumulative cases that are widely available, can extract the hidden information to better inform us about the dynamics of COVID-19. Taking the epidemic in Wuhan as an example, information derived from cumulative daily cases can better inform us about the epidemic. For instance, the first spike on January 27 was at-

tributed to the distribution of a large number of testing kits on January 26, and the spikes on February 12 and 13 were attributed to the change of diagnostic criteria which were also observed in the first derivative results.

Further, the results of the second derivative model indicated a unique four-stage epidemic of COVID-19 in Wuhan which can be observed neither in cumulative cases nor in new cases. In addition to the Silent Attack Phase before the declaration of the outbreak, the 15-day Acceleration Phase from January 21 to February 4 was reflective of an increase in the epidemic from the day when the massive interventions were activated on January 21 to February 4, one incubation period after the intervention.[9] The 14-day Deceleration Phase from February 5 to 19 was reflective of another incubation period from February 5 when the massive anti-epidemic actions actually showed their effects. After the Deceleration Phase, the epidemic entered the Stabilization Phase when most infected cases were detected and treated/quarantined. This phase indicates that the epidemic was at a very low level, suggesting the success in controlling the COVID-19 epidemic in Wuhan.

4.2. Assess responses of COVID-19 to massive anti-epidemic actions

Similar to the situation in Wuhan, results of second derivative modeling for Hubei excluding Wuhan and China excluding Hubei also revealed responses of the COVID-19 epidemic to the massive anti-epidemic actions, as indicated by the spike in the second derivative on February 12 in Wuhan and Hubei, corresponding to the day when a large number of diagnosed cases with clinical symptoms but not confirmed with a blood test,[11] and the spikes on February 20 and 21 in China excluding Hubei, corresponding to the inclusion of diagnosed cases in prisons.[12-13]

In addition to these spikes, the second derivative results suggest three similar phases as Wuhan, including an Acceleration Phase, a Deceleration Phase, and a Stabilization Phase; but the duration of the three phases differed a bit across the three geographic strata. The two strata outside of Wuhan entered the Deceleration Phase and Stabilization Phase a few days earlier than Wuhan. This could be due to the effect of the massive anti-epidemic action of city lockdown. Despite much social, economic, and political influences, evidence from our analysis suggests that massive anti-epidemic action, like a citywide lockdown, would be the only option at the time when an epidemic has already reached its later stages. To avoid the challenging city lockdown strategy for future interventions, potential actions should be taken in the early stage, including, but not limited to, informing the public about social distancing, hygiene, and other common approaches of prevention in an earlier stage although the CDC and health professionals may not have adequate evidence of the disease at that moment, applying the data science and machine learning technique to actively collect social media information about outbreaks, infections and symptoms as a supplement to the official report from the hospitals and local CDCs, and building professional teams (including psychologists, psychiatrists, social workers, etc.) to take care of people's mental health issues (e.g., anxiety, depression, etc.) as well as other society and community-related problems.

4.3. Predict future trends

As in a previous study for China as a whole,[9] results from the second derivative of cumulative daily cases in this study can better inform us about future trends of the COVID-19 epidemic in Wuhan, Hubei excluding Wuhan and China excluding Hubei. For example, the second derivative in Wuhan entered the Stabilization Phase on February 20, with one incubation period, it is expected that on March 6 the epidemic may substantially decline. It is worth noting that the ability to predict future trends for a subpopulation is slightly weaker than the full population. For example, in our previous study with data for the whole of China, it was predicted that the epidemic would be under control by the end of February.[9] However, the method with 14–15 days of incubation period worked only for Wuhan, but not for Hubei excluding Wuhan and China excluding Hubei. One explanation for this could be due to the cross-boundary movement of the infected persons.

4.4. Conclusion

The control and prevention of the pandemic of COVID-19 require more knowledge about the epidemic and the effects of taken actions. Findings of the study indicated that the citywide lockdown of Wuhan successfully flattened the curve outside Wuhan, and the epidemic curve in the regions of China excluding Hubei Province and Hubei excluding Wuhan City entered the Stabilization Phase earlier than Wuhan. Findings of the study provide new evidence to better monitor the epidemic, evaluate its response to intervention, and predict the trend long. In addition to re-evaluating the control of the COVID-19 epidemic in China, this study provided a model for monitoring outbreaks of COVID-19 in different countries in the era of the COVID-19 pandemic.

4.5. Limitations

This study depends solely on reported data. Although the second derivative of an epidemic is not very sensitive to changes in diagnostic criteria, the method will work better without such change. More work is needed to inform decision-makers, medical and health professionals, and the general public to understand and use the method in controlling the COVID-19 and other similar epidemics in the future. Despite these limitations, the study provided important data and informative evidence to characterize the epidemic of COVID-19 by geographic strata in China.

4.6. Implications

Findings of the study regarding the Acceleration, Deceleration, and Stabilization Phases provide important information regarding the epidemic of COVID-19 for other regions or countries to take actions to control the epidemic. The second derivative model developed by us provides a useful and real-time approach for other countries across the world that are still undergoing the COVID-19 epidemic to: (1) closely monitor the progression of the epidemic earlier than the commonly used new cases; (2) evaluate the responses taken by the governments on the COVID-19 epidemic, and build confidence for the governments, CDC experts, health professionals, and the general public to control the epidemic; and (3) provide early signals of the success of the control of the epidemic, and encourage the governments to continue maintaining their actions in controlling the COVID-19.

CRediT author statement

Bin Yu: Conceptualization, Data curation, Formal analysis, Methodology, Writing—original draft. **Xinguang Chen**: Conceptualization, Methodology, Supervision, Writing—review & editing. **Shannan Rich**: Writing—review & editing. **Qiqing Mo**: Data curation, Writing—review & editing. **Hong Yan**: Writing—review & editing.

Availability of data and material

All data used in the study were publicly available. Data from December 8 of 2019 to January 20 of 2020 were derived from a study by Li and colleagues.[2] Data from January 21 to March 1, 2020, were derived from the daily reported and officially finalized cases. Data for Wuhan and Hubei were derived from the Wuhan Municipal Health Commission[8] and data for China were derived from the National Health Commission of P. R. China.[10]

Appendices

Table A1
Timeline of important events in preventing the epidemic of COVID-19 in China, 2020.

Date	Timeline
01/01	Close of the Huanan Seafood Wholesale Market in Wuhan City
01/20	Declaration of human-to-human transmission of COVID-19
	Declaration of the outbreak of COVID-19
	Formation of leading team by National Health Commission
01/21	Formation of collaborative leading team from multi-disciplinary in Wuhan City
	Hospitals assigned for the treatment of COVID-19
	WHO representative arrived at Wuhan City
01/22	Release of the Guidance for 2019-nCoV Pneumonia Prevention and Control Version II
01/23	Lock down of Wuhan City
	Initiation of the Huoshenshan Hospital project
	Three provinces initiated the Level I response to the Important Public Health Emergencies
	50 000 molecular testing kit delivered to Wuhan City
01/24	Hubei initiated the Level I response to the Important Public Health Emergencies
	Massive screening for the patients with fever
01/25	Special meeting at the Central Chinese Government
	Anti-2019-nCoV Group
	30 provinces initiated the Level I response to the Important Public Health Emergencies
	Four provincial medical teams arrived at Wuhan City for assistance
	National authorities conducted active case finding in all provinces
	Decision of building Leishenshan Hospital
01/26	25 medical teams arrived at Hubei Province for assistance
	Release of 300 million RMB to build Huoshenshan and Leishenshan Hospitals
	Four molecular testing kits were approved by the National Medical Products Administration
	Transportation lock down in Wuhan City
01/27	Premier Li Keqiang went to Wuhan City to guide the work
	Five provincial medical teams arrived at Hubei Province for assistance
01/28	Vice Premier Sun led the work in Hubei Province
	Multiple provincial medical teams arrived at Hubei for assistance
01/29	6 079 doctors and nurses arrived at Hubei for assistance
	All 31 provinces initiated the Level I response to the Important Public Health Emergencies
01/30	Strengthen the prevention of COVID-19 in the rural area by the National Health Commission
	The capacity of molecular testing increased from 200 per day to 4 000 per day in Hubei Province
02/03	Promotion of the “Internet + Medical Service” project
	Initiation of the three Square Cabin Hospitals
	Five provincial medical teams went to Hubei for assistance
02/04	Wuhan City Huoshenshan Hospital began the treatment of COVID-19
	10 national emergency medical teams arrived at Wuhan City for assistance
02/05	The first Square Cabin Hospital began the service
	Further strengthen the prevention and screening of COVID-19 in the rural area in Hubei Province
02/06	The capacity of molecular testing of Wuhan City increased from 6 000 per day to 8 000 per day
02/08	Leishenshan Hospital began the treatment of COVID-19
	Wuhan City started the community household screening

Table A2
The number of cumulative confirmed cases of COVID-19 in China, overall and by geographic strata, from December 8 of 2019 to March 1 of 2020.

Date*	Wuhan City	Hubei Province excluding Wuhan City#	China excluding Hubei Province	Total
12/08	1	0	0	1
12/09	1	0	0	1
12/10	2	0	0	2
12/11	2	0	0	2
12/12	2	0	0	2
12/13	3	0	0	3
12/14	3	0	0	3
12/15	5	0	0	5
12/16	6	0	0	6
12/17	7	0	0	7
12/18	7	0	0	7
12/19	9	0	0	9
12/20	13	0	0	13
12/21	17	0	0	17
12/22	20	0	0	20
12/23	24	0	0	24
12/24	24	0	0	24
12/25	28	0	0	28
12/26	29	0	0	29
12/27	32	0	0	32
12/28	34	0	0	34
12/29	40	0	0	40
12/30	45	0	0	45
12/31	47	0	0	47

(*continued on next page*)

Table A2 (*continued*)

Date*	Wuhan City	Hubei Province excluding Wuhan City#	China excluding Hubei Province	Total
01/01	57	0	0	57
01/02	64	0	0	64
01/03	77	0	0	77
01/04	90	0	0	90
01/05	105	0	0	105
01/06	124	0	0	124
01/07	155	0	0	155
01/08	199	0	0	199
01/09	231	0	0	231
01/10	264	0	0	264
01/11	297	0	0	297
01/12	327	0	0	327
01/13	349	0	0	349
01/14	372	0	0	372
01/15	395	0	0	395
01/16	408	0	0	408
01/17	414	0	0	414
01/18	420	0	0	420
01/19	422	0	0	422
01/20	425	0	0	425
01/21	427	0	13	440
01/22	437	7	127	571
01/23	495	54	281	830
01/24	572	157	558	1 287
01/25	618	434	923	1 975
01/26	698	725	1 321	2 744
01/27	1 590	1 124	1 801	4 515
01/28	1 905	1 649	2 420	5 974
01/29	2 261	2 325	3 125	7 711
01/30	2 639	3 167	3 886	9 692
01/31	3 215	3 938	4 638	11 791
02/01	4 109	4 965	5 306	14 380
02/02	5 142	6 035	6 028	17 205
02/03	6 384	7 138	6 916	20 438
02/04	8 351	8 327	7 646	24 324
02/05	10 117	9 548	8 353	28 018
02/06	11 618	10 494	9 049	31 161
02/07	13 603	11 350	9 593	34 546
02/08	14 982	12 118	10 098	37 198
02/09	16 902	12 729	10 540	40 171
02/10	18 454	13 274	10 910	42 638
02/11	19 558	13 808	11 287	44 653
02/12	32 994	15 212	11 598	59 804
02/13	35 991	15 995	11 865	63 851
02/14	37 914	16 492	12 086	66 492
02/15	39 462	16 787	12 251	68 500
02/16	41 152	17 030	12 366	70 548
02/17	42 752	17 237	12 447	72 436
02/18	44 412	17 270	12 503	74 185
02/19	45 027	17 430	12 545	75 002
02/20	45 346	17 742	12 803	75 891
02/21	45 660	17 794	12 834	76 288
02/22	46 201	17 883	12 852	76 936
02/23	46 607	17 680	12 863	77 150
02/24	47 071	17 715	12 872	77 658
02/25	47 441	17 746	12 877	78 064
02/26	47 824	17 772	12 901	78 497
02/27	48 137	17 777	12 910	78 824
02/28	48 557	17 780	12 914	79 251
02/29	49 122	17 785	12 917	79 824
03/01	49 315	17 788	12 923	80 026
Max	49 315	17 883	12 923	80 026
Min	1	0	0	1
M (Q_1, Q_3)	422 (40, 16 902)	0 (0, 12 729)	0 (0, 10 540)	422 (40, 40 171)

Data were derived from: (1) Li Q, Guan X, Wu P, et al. Early Transmission Dynamics in Wuhan, China, of Novel Coronavirus-Infected Pneumonia. *N Engl J Med.* 2020;382(13):1199–1207. doi:10.1056/NEJMoa2001316; (2) Wuhan Municipal Health Commission. Updates of the prevention and control of 2019-nCoV. http://wjw.wuhan.gov.cn/front/web/list3rd/no/804. Accessed February 11, 2020; (3) National Health Commission of the People's Republic of China. Updates of the COVID-19 epidemic. http://www.nhc.gov.cn/xcs/fkdt/202001/12ec9062d5d041f38e210e8b69b6d7ef.shtml. Accessed February 12, 2020. *December 8 to 26 of 2019 are the dates of symptom onset based on patients' recall during the investigation. #The number of cumulative cases of Hubei Province excluding Wuhan City was calculated as the cumulative cases in Hubei Province subtract the cases in Wuhan City. In theory, the number of cumulative cases should increase along with the date. However, there may exist some issues in the official reports during February 20 and 22 that the number of cumulative cases reduced on February 23. The second derivative method used in the study can diminish the influence of these issues when reporting the overall trend.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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