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Research Article

Analysing the Propagation of the Coronavirus Epidemic: The Case of Wuhan in Hubei Province, China

Mihir Dash

Alliance University, Bangalore, India.
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E-mail Id:
mihirda@rediffmail.com
Orcid Id:
https://orcid.org/0000-0002-9790-1117
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ABSTRACT

The ongoing coronavirus epidemic, Covid-19, has spread across the world in matter of weeks, and has led to a global pandemic. The current study examines the propagation of Covid-19 in Wuhan, the epicentre of the outbreak, and Hubei Province in China, across which the spread was initially the fastest. The logistic model was used to analyse the propagation of the epidemic.

The results of the study suggest that the logistic model is an adequate model for explaining the propagation of the epidemic. The model gives projections for the limiting cumulative number of cases, cured/ discharged, and deaths. A more integrated approach is proposed for further studies, which would consider the number cured and number of deaths as subprocesses of the number of infected cases at any point of time, as a coupled system of differential equations.

Keywords: Covid-19 Epidemic, Propagation, Logistic Model

Introduction

The ongoing coronavirus, Covid-19 epidemic, , has spread across the world within few weeks, and has led to a global pandemic. As of 20th March, 2020, globally, it had infected 234,073 people and had resulted in 9840 deaths. China, where the outbreak had begun, has successfully managed to contain the spread of the epidemic through stringent lock-down measures. The current study examines the propagation of Covid-19 in Wuhan, the epicentre of the outbreak, and Hubei Province in China, across which the spread was initially the fastest.

The first case of Covid-19 has been traced back to a 55-year-old person from Wuhan, Hubei province on November 17, 2019, according to Chinese government data.[1] It is not clear exactly when doctors identified Covid-19 as a new coronavirus. A study by Chinese doctors from Jinyintan Hospital in Wuhan published in *The Lancet* puts the date of the first known case at December 1, 2019. Another report, however, suggested that the first officially-confirmed case was recorded on December 8, 2019. Initially, up to five new cases were reported each day and by December 15, 2019, the cumulative number of cases was 27. On December 17, 2019, the number of new cases reached double digits, and by December 20, 2019, the cumulative number of cases reached 60. On December 27, 2019, Dr. Zhang Jixian from Hubei Provincial Hospital of Integrated Chinese and Western Medicine told China's health authorities that the disease was caused by a new coronavirus, but by that time more than 180 people had already been infected. By December 31, 2019, the cumulative number of cases had risen to 266, and the next day, January 1, 2020, it shot up to 381.

[1]Josephine Ma, "Coronavirus: China's first confirmed Covid-19 case traced back to November 17," South China Morning Post, March 13, 2020.

The initial reaction of the Chinese government was to suppress information about the new disease from the public. They reportedly ignored and silenced initial warnings by some doctors of the impending epidemic. However, as the epidemic started to spread faster, the Chinese National Health Commission reported the matter to the World Health Organisation (WHO) on December 31, 2019. When it was clear that the situation was getting out of control, a state of lock-down was imposed in Wuhan and other cities in Hubei Province on January 23, 2020 in an effort to quarantine the Covid-19 outbreak. All citizens were directed to stay at home. All transport services were suspended, and citizens were not allowed to leave the city. All shops except those selling food or medicines were ordered to shut down. Initially, citizens were allowed to leave their homes once every two/three days, but even this was restricted by mid-February. In addition to the lock-down, health workers started door-to-door health checks, and anyone found to be ill was immediately isolated. Most importantly, the community was educated of the importance of wearing masks and constantly washing hands to prevent further spread.

The Chinese were also quick to adopt high tech in their efforts to control the epidemic.[2] Robots were deployed in hospitals for delivery of medication and meals to patients to avoid human contact. Robots and drones were also deployed for delivery of essential goods to quarantined households and to disinfect roads and open spaces. Online diagnostic and monitoring systems were installed so that doctors could check on patients via video screens. Further, governments at all levels, tech companies, and local communities joined together to fight the epidemic by upgrading the technological aspects of control and prevention work. Big data analytics was used to monitor the development of the epidemic, and temperature-screening technology and artificial intelligence were used for detecting and analysing possible risks. Social media, online platforms and apps were used by citizens to track the latest developments of the epidemic, and to search their travel history to see if they were in proximity with any confirmed cases as having the coronavirus, and to receive a remote diagnosis. Another app, the *Alipay Health Code*, indicated a citizen's health status, based on their recent travel history, close contacts, temperature, and related symptoms, which was then used to suggest self-quarantine for those who needed it.

The WHO initially termed the Wuhan lock-down as unprecedented, stressing that they had not recommended such a measure. But as it became clearer that the strategy was working, they praised the Chinese efforts.[3] The WHO Director-General Tedros Adhanom Ghebreyesus stated, "The Chinese government is to be congratulated for the extraordinary measures it has taken to contain the outbreak, despite the severe social and economic impact those measures are having on the Chinese people." Dr. Gauden Galea, the WHO representative in China, also commended the Chinese efforts in containing the spread of Covid-19.[4] He argued that the Chinese have demonstrated that the course of the outbreak can be altered. "It is an epidemic that has been nipped as it was growing and stopped in its tracks… So that's a big lesson: that the natural course of the outbreak does not need to be a very high peak that overwhelms health services. This lesson in containment, therefore, is a lesson that other countries can learn from and adapt for their own circumstances."

Data and Methodology

The objective of the study is to measure the propagation rate of the Covid-19 epidemic under conditions of containment. The case study of Wuhan, Hubei Province, was considered, as it was the first successful case of containment of the epidemic. The data for the study consisted of the official daily status reports, obtained from the official website of the Hubei Province.[5] The study period considered was January 29, 2020 to March 20, 2020, due to data unavailability prior to this date. The variables available are (daily) the number of new cases, the cumulative number of cases, the number of deaths, the cumulative number of deaths, the number of cured/discharged, and the cumulative number of cured/discharged. These variables were considered for Wuhan city as well as for Hubei Province as a whole.

There were several errors in the official data. Most of these errors were small, in ones or twos, but there was one major error. On February 1, 2020, the number of new cases reported for Wuhan city was 1894, so that the cumulative number of cases should have been 5109, not 4109 as reported. Correcting for these errors, the cumulative number of cases for Wuhan becomes 51,861, not 50,005 as reported, and for Hubei Province as a whole 68,479, not 67,800 as reported; similarly, the cumulative number of deaths for Wuhan becomes 2612, not 2504 as reported, and for Hubei Province as a whole 3246, not 3139, as reported. There were also major discrepancies in the cumulative number of cured/discharged for both Wuhan city and Hubei Province as a whole, so it is difficult to be certain of its reliability.

[2] Zhao Yimeng, "Robots, drones, AI, big data bring modern touch to disease control," China Daily, March 12, 2020
[3] https://time.com/5796425/china-coronavirus-lockdown/
[4] "China shows COVID-19 Coronavirus can be 'stopped in its tracks'," Health, March 16, 2020, available at: https://news.un.org/en/story/2020/03/1059502
[5] http://en.hubei.gov.cn/special/coronavirus_2019/update_2019ncov/index.shtml

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There was also a major anomaly/outlier. On February 12, 2020, the number of new cases reported was 13,436 for Wuhan city and 14,840 for Hubei Province as a whole. As this data point can completely alter the nature of the results, it had to be omitted from the analysis. Thus, the effective study period was February 13, 2020 to March 20, 2020.

The focus variables for the study were the cumulative number of cases, the cumulative number of deaths, and the cumulative number of cured/discharged. The model used for analysing the propagation rate was the logistic model, one of the oldest models of population growth.[6] This model was selected because of the initial slow rate of spread, and the gradual tapering off of the rate of spread (Gambhir et al, 2015; Ma et al, 2016; Aarthee and Ezhilmaran, 2017; Büyüktahtakın et al, 2018; Brown et al, 2018; Batista, 2020; Jia et al, 2020; Wu et al, 2020).

The logistic model is given by the following differential equation , which implies that, as the value of y gets closer to both the upper bound M and the lower bound 0, the rate of growth decreases accordingly. Solving the differential equation yields the time-dependent functional form of the model: This was estimated by performing a quadratic regression of dy/dt on y. This yield estimates for the propagation rate r and the upper bound M.

Findings and Analysis

The model estimates are presented in the table below.

		Logistic Model parameters		
		r	M	R^2
cases	Wuhan city	1.56%	51,486.23	88.67%
	Hubei Province	1.61%	67,993.08	89.09%
cured/ discharged	Wuhan city	0.87%	43,601.17	94.20%
	Hubei Province	0.64%	60,687.63	96.53%
deaths	Wuhan city	0.79%	2597.42	93.19%
	Hubei Province	0.68%	3230.50	94.85%

The logistic model was found to have adequate model fit (with R^2 in excess of 85.0%). The limiting cumulative number of cases was found to be less than 51,776.75 and 68,298.39, with 95% confidence, respectively, for Wuhan city and Hubei province. The limiting cumulative number cured/discharged was found to be less than 44,920.38 and 61,807.65, with 95% confidence, respectively, for Wuhan city and Hubei province. The limiting cumulative number of deaths was found to be less than 2625.50 and 3259.76, with 95% confidence, respectively, for Wuhan city and Hubei province.

In order to get a better understanding of the lagged effects of the spread of the epidemic on the deaths and the cured/ discharged, these variables were regressed on the lagged number of new cases. The optimal lag structure was found to be eleven lags. The regression results are presented in the tables below.

	Coeff	Std Err	t Stat	p-value
Intercept	8.5704	1.4728	5.8192	0.0000
new cases(-1)	0.0027	0.0005	5.3344	0.0000
new cases(-2)	0.0037	0.0005	7.1139	0.0000
new cases(-3)	0.0032	0.0005	6.0279	0.0000
new cases(-4)	0.0007	0.0005	1.2650	0.2180
new cases(-5)	0.0011	0.0005	2.0137	0.0554
new cases(-6)	0.0045	0.0005	8.4705	0.0000
new cases(-7)	0.0017	0.0005	3.2359	0.0035
new cases(-8)	0.0029	0.0005	5.6017	0.0000
new cases(-9)	0.0025	0.0005	4.8372	0.0001
new cases(-10)	0.0024	0.0005	4.6188	0.0001
new cases(-11)	0.0063	0.0005	12.2698	0.0000
Dependent Variable: deaths R^2=98.11%, F Stat=113.001, p=0.0000				

The regression results for deaths found significant impact of the first eleven lags of new cases on deaths, except for lags four and five. Also, there were no significant lags beyond eleven. Thus, the first eleven days after detection/ diagnosis is the critical period in which patients are most likely to succumb to the virus. The overall mortality rate was estimated by adding the coefficients of the first eleven lags, and was found to be 3.16%.

	Coeff	Std Err	t Stat	p-value
Intercept	1,294.65	113.29	11.43	0.0000
new cases (-1)	-0.0470	0.0391	-1.2048	0.2400
new cases (-2)	-0.0275	0.0402	-0.6833	0.5010
new cases (-3)	-0.0355	0.0403	-0.8813	0.3869
new cases (-4)	-0.0265	0.0404	-0.6545	0.5190
new cases (-5)	-0.0120	0.0405	-0.2967	0.7693

[6] https://www.sciencedirect.com/topics/medicine-and-dentistry/epidemic-model

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new cases (-6)	-0.0226	0.0406	-0.5561	0.5833
new cases (-7)	-0.0284	0.0405	-0.7021	0.4894
new cases (-8)	-0.0088	0.0404	-0.2165	0.8304
new cases (-9)	0.0100	0.0403	0.2493	0.8053
new cases (-10)	0.0023	0.0403	0.0582	0.9541
new cases (-11)	-0.0008	0.0393	-0.0216	0.9829
Dependent Variable: cured/ discharged R2=31.48%, F Stat=1.002, p=0.4730				

The regression results for deaths found significant impact of the first eleven lags of new cases on deaths, except for lags four and five. Also, there were no significant lags beyond eleven. Thus, the first eleven days after detection/diagnosis is the critical period in which patients are most likely to succumb to the virus. The overall mortality rate was estimated by adding the coefficients of the first eleven lags, and was found to be 3.16%.

The regression results for cured/discharged found no significant impact of the first eleven lags of new cases on cured/discharged. Thus, the recovery period for patients with the disease is expected to be more than fourteen days after detection/diagnosis.

Discussion

The results of the study suggest that the logistic model is an adequate model for explaining the propagation of the Covid-19 epidemic. The projections for the limiting cumulative number of cases from the model are close to the stabilised cumulative number of cases, at 51,861 and 68,479 for Wuhan city and Hubei Province, respectively. The logistic model can thus provide a projection of the limiting cumulative number of cases which can help governments plan their medical infrastructure accordingly. This complements the results of Wu et al. (2020) and Jia et al. (2020).

The results of the study suggest that the logistic model also fit well for the number of cured/discharged and the number of deaths. Jia et al (2020) had also used the logistic model for the cumulative number of number of deaths, and their projection for the limiting cumulative number of deaths is similar to the result obtained in the present study. However, there is no theoretical justification for the logistic model for the number of cured/discharged and the number of deaths, other than that they are closely related with the spread of the epidemic. Also, the recovery/mortality rate depends on several other factors including the patient demographics and medical history. Thus, the logistic model may be too superficial to capture the dynamics of recovery/death by the epidemic. A more integrated approach would consider the number cured and number of deaths as subprocesses of the number of infected cases at any point of time, perhaps as a coupled system of differential equations.

The results of the study also suggest that the first eleven days after detection/diagnosis is the critical period in which patients are most likely to succumb to the virus, while the recovery period for patients with the disease is expected to be more than fourteen days after detection/diagnosis. These may again vary with patient demographics and medical history, and would need to be studied in more detail.

There are several limitations inherent in the study. The study period considered is quite short, but adequately captures the effect of the lockdown. Another limitation is the data quality; even after correction of errors, it is not sure whether the data are reliable and valid. Another shortcoming is that the early data of the outbreak and initial propagation were not available, so that the effect of the lockdown could not be assessed in terms of its impact on the propagation rate and limiting cumulative number of cases.

The study can be extended by examining the propagation of Covid-19 in Europe and USA, where the situation appears to be peaking at present (as on March 24, 2020). The study can also be readily extended using generalised logistic models, as suggested by Wu et al. (2020).

Conflicts of Interest: None

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