An Empirical Model to Estimate the Effect of Social Distance Levels on COVID-19 Outbreak

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Method Article

Keywords: COVID-19 outbreak, level of social distancing, weekly growth ratio, odds of exposing

Posted Date: October 20th, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-90435/v2>

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Abstract

The implementation of social distancing measures for controlling the outbreak of coronavirus disease 2019 (COVID-19) in different countries has not been at the same level due to differences in policies, economies, and cultures. Hence, the effect of this pandemic on different aspects of societies varies depending on several factors.

In this study, we found that the speed of disease transmission is directly related to the odds of being exposed to the disease in the society, that is directly related to the level of practicing social distancing measures. We introduced the weekly growth ratio (WGR) index and proposed an experimental rule model to monitor the current level of social distancing and predict the levels of intervention so as to reduce the WGR and control the sequential peaks. Our model showed that the minimum level of practicing social distancing in the community should be 80% to control the first peak of the disease; but after controlling the first peak, maintaining 50% of social distancing policies continuously keeps the number of cases/deaths constant and prevents the occurrence of a new peak.

Introduction

The outbreak of coronavirus disease 2019 (COVID-19) pandemic is still a serious public health problem worldwide in the 21st century. COVID-19 was firstly identified in Wuhan, China in late 2019 and the number of cases increased rapidly within a few weeks and the disease spread to the entire China. As the result, the Chinese government decided to shutdown Wuhan and 15 other cities in Hubei Province¹. At the time, perhaps no one imagined that they might one day be forced into lockdown in most countries to prevent the spread of the disease and the resulting deaths.

Hubei Province, and especially Wuhan City, was the first place to be affected by the COVID-19. Afterwards, the virus spread to other countries, including Iran, Italy, Germany, and France, and it became a global health crisis within several weeks. At first, most countries were initially reluctant to implement quarantine, but the rapid spread of the disease, hospitalization, and deaths forced governments to propose strict laws and enforce extended lockdown throughout their countries.

The implementation of quarantine in different countries was not at the same level due to differences in policies, economies, and cultures; as a result, the effects were not similar to each other in different countries². Perhaps the most severe levels of social distancing and compliance among the community were observed in China, New Zealand, and Australia.

Various studies have been conducted in the field of modeling intervention methods such as isolating patients and their contacts, personal protection (physical distancing, face masks, hand washing), and extensive or smart quarantine of cities to prevent COVID-19 and control outbreaks. But most of these models are complex and require many parameters²⁻⁷. In the present study, a simple experimental rule has

been introduced that can predict the time required to control the pandemic, the number of cases in consecutive weeks, and the total number of cases based on the level of intervention (social distancing).

Methods

Evaluating the current trend in cases of COVID-19 in different countries before and after the intervention, we found that the speed of the disease transmission is directly related to the odds of being exposed to the disease in the society. When any kind of intervention is done, such as raising awareness about personal protection, isolating patients, or launching quarantine, the odds of being exposed to the infection in the community are reduced, resulting in a slower spread of the disease. Also, by looking at the pattern in the chart of patients in different countries, a periodic pattern (seasonal trend) of 6 to 7 days can be seen, which is almost equal to half the incubation period of the disease.

In Wuhan, 900 patients were diagnosed on January 17-23, up from 15 a week earlier, a 60-fold increase in one week. In Italy, 868 patients were diagnosed on February 22-28, while in the previous week there were 17 patients; this means that the number of patients increased 50 times in one week. In New Zealand, the number of cases was 205 on March 18-24, while in the previous week it was 20, which is about 10 times more. This verifies the effectiveness of the measurements taken by people and governments to prevent the spread of the disease. However, this readiness was still insufficient, and governments were forced to order lockdowns.

Each intervention shows its effect on the growth rate of COVID-19 after a week. Hence, instead of monitoring patients daily, it is better to monitor the total number of new cases/deaths on a weekly basis. Based on this principle, the following index is introduced:

$$WGR_k = \left(\frac{\text{the number of new cases/death in week } k}{\text{the number of new cases/death in week } (k-1)} \right)^{\frac{1}{7}}$$

where WGR_k is the Weakly Growth Ratio of COVID-19 in a population at week k after observing the first local case.

Now, we can find an empirical rule to predict the WGR_k after intervention on social distancing at level p . It is directly related to the odds of being exposed to the disease in the community. The effect of intervention

on decreasing reproduction number increased during time with this empirical rule:

$$WGR_k = WGR_0 \times \left(\frac{1-p}{p} \right)^{\sqrt{k}} \quad (1)$$

where $K= 1, 2, 3, \dots$ is weeks after intervention, WGR_k is Weakly Growth Ratio after K weeks from intervention, WGR_0 is the Weekly Growth Ratio at the last week before intervention and p is the level of social distancing.

We supposed that for very extended lockdown, p is equal to 90% (such as Wuhan, New Zealand, etc.) because of the long-term incubation period of the disease and existence of carriers with no symptoms in the families.

Also, the weekly number of new cases/deaths could be estimated by:

$$N_k = N_{k-1} * WGR_k \quad (2)$$

where $k=1, 2, 3, \dots$ and is the total number of cases in weeks before intervention. Indeed, N_0 is the number of infected cases and WGR indicated the ratio of susceptible population each week.

This study made use of publicly available data from <https://github.com> . The codes for implementation of proposed model using R program, is available in the supplementary file.

Results

The results of this rule for different values of $WGR_0 = 10, 20, 30, 40$ and $p=0.6, 0.7, 0.75, 0.80, 0.85, 0.90$ are presented in tables 1-4. As shown in table 1, when $WGR_0 = 10$, if $p=0.7$ is the level of social distancing, after 8 weeks the weekly growth ratio fell to 1. If this percent is 80%, this occurred after week 4 and for 90% its reduction occurred after 2 weeks (such as New Zealand). Reaching zero new cases/deaths depends on the number of cases at the time of quarantine. In tables 2-4, this situation is done for $WGR_0 = 20, 30, 40$. As shown in this table, when WGR increased before intervention, controlling the outbreak in 8 weeks was feasible only with 90% level of social distancing (lockdown the cities), such as Hubei province in China.

We defined two situations to show the application of the proposed formula. First, the number of cases at time of intervention is 900 and $WGR_0=30$ (Figure1). As shown in this Figure, the outbreak reached to zero new cases/deaths at week 16, 11, 7 for $p= 0.80, 0.85, 0.90$, respectively. Also, the total number of cases are considerably different according to p . Second situation was run for the situation in the first scenario by initial cases of 150. The duration to achieve zero new cases/deaths is similar to the first scenario, but the total number of cases are very small (Figure 2).

Figure 3 shows the effect of each percent increasing in social distancing level from 85% to 90% on the cumulative number of cases according to equation (2) when the $N_0=1000$ and $WGR_0=40$ at time of intervention up to 8 weeks. It is clear that in a country with a population of 100 million 1% is equal to 1 million individuals being exposed to infection. Thus, the expected number of infected cases considerably increase per each percent decrease in social distancing level.

Figure 4 compares the prediction results with observed statistics for Hubei province that have 900 cases and weekly reproduction number 60 before lockdown (shutdown) on 24 January 2020.

Discussion

In such countries as China and Italy that first experienced the pandemic, WGR was very high before intervention. But other countries utilized the experience of these countries and this amount decreased; for example, it was around 10 in New Zealand before quarantine.

Lockdowns have been imposed to create social distancing in almost all countries, but the level has not been equal in different countries. Using the rule presented in this study, it was shown that a level of social distancing of less than 80% is not effective for controlling the first peak of the pandemic.

There is also a big difference between the required duration, the number of cases, and the resulting mortality at the levels of 80%, 85%, and 90% of the social distancing (Figures 1&2).

Also, according to the proposed rule, the level of social distancing less than 50% increases the WGR and the level of 50% keeps the WGR constant. Therefore, after the first lockdown, to prevent the second peak of the COVID-19, it is suggested that the level of social distancing be 50%.

In their study, Ibarra-Vega (2020) based on three different scenarios of lockdown showed that at the beginning of the outbreak lockdowns extended but people gradually started to have up to 40% of previous contacts. The current study supports this result, though contacts up to 50% could be agreed⁶.

M. Kennedy et al. also showed that at least 50% adherence to personal protection and creating lockdown every 80 days up to 2 years could be effective in preventing a second peak. According to the rule of the present study, if the level of social distancing after the initial control is less than 50%, WGR would be more than one, which indicates the need to increase the limit in the physical distancing. However, this limit would not be at the same level as the initial limit².

Cobb et al. showed that shelter-in-place (SIP) in the US counties was a good way to reduce the growth rate of COVID-19, but it is not sufficient to control the outbreak⁴.

The main advantage of the present study over similar studies is that it presents a simple rule with different applications for estimating the level of social distancing required, the duration of the restriction, and the expected number of patients based on the level of social distancing in the first or subsequent peaks.

This model works better for large cities or provinces or small and medium-sized countries with a uniform population distribution such as European countries; for such large countries as the United States, China, India, and Iran, it is better to use it for each state or province separately.

Conclusion

It might be concluded that in the initial attack phase of the virus, depending on the WGR and the number of infected cases at the time of intervention, a minimum level of 80% is required to control the pandemic. This rule could predict how long these restrictions will continue, depending on the number of patients and the capacity of the hospitals, as well as the economic and psychological resilience of the people and governments. Restrictions can be phased out when WGR falls down 1 and the number of patients is tolerable for the healthcare system. But if the restrictions, which include personal protection and prevention of communities, reach less than 50 percent, we will see the growth of WGR, which is the second peak alarm and the need to impose more restrictions.

Declarations

Competing Interests

There is no competing interest.

Ethical Approval

Ethical approval was not required as this study made use of publicly available data.

Funding

None.

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Tables

Table1. Weekly Growth Ratio after intervention by Level of social distance when $WGR_0=10$

WEEK	P					
	0.6	0.7	0.75	0.8	0.85	0.9
0	10.000	10.000	10.000	10.000	10.000	10.000
1	6.667	4.286	3.333	2.500	1.765	1.111
2	5.636	3.017	2.115	1.408	0.860	0.447
3	4.955	2.305	1.491	0.906	0.496	0.222
4	4.444	1.837	1.111	0.625	0.311	0.123
5	4.039	1.504	0.857	0.451	0.207	0.073
6	3.704	1.255	0.678	0.335	0.143	0.046
7	3.421	1.063	0.547	0.255	0.102	0.030
8	3.176	0.910	0.447	0.198	0.074	0.020
9	2.963	0.787	0.370	0.156	0.055	0.014
10	2.774	0.686	0.310	0.125	0.041	0.010
11	2.606	0.602	0.262	0.101	0.032	0.007
12	2.455	0.531	0.222	0.082	0.025	0.005

Table 2. Weekly Growth Ratio after intervention by Level of social distance when $WGR_0=20$

WEEK	P					
	0.6	0.7	0.75	0.8	0.85	0.9
0	20.000	20.000	20.000	20.000	20.000	20.000
1	13.333	8.571	6.667	5.000	3.529	2.222
2	11.272	6.034	4.229	2.816	1.721	0.894
3	9.909	4.610	2.983	1.812	0.991	0.445
4	8.889	3.673	2.222	1.250	0.623	0.247
5	8.078	3.008	1.715	0.901	0.414	0.147
6	7.408	2.510	1.356	0.670	0.286	0.092
7	6.841	2.125	1.093	0.511	0.203	0.060
8	6.353	1.821	0.894	0.396	0.148	0.040
9	5.926	1.574	0.741	0.313	0.110	0.027
10	5.549	1.372	0.620	0.250	0.083	0.019
11	5.212	1.204	0.523	0.201	0.063	0.014
12	4.909	1.062	0.445	0.164	0.049	0.010

Table 3. Weekly Growth Ratio after intervention by Level of social distance when $WGR_0=30$

WEEK	P					
	0.6	0.7	0.75	0.8	0.85	0.9
0	30.000	30.000	30.000	30.000	30.000	30.000
1	20.000	12.857	10.000	7.500	5.294	3.333
2	16.908	9.052	6.344	4.224	2.581	1.342
3	14.864	6.915	4.474	2.718	1.487	0.667
4	13.333	5.510	3.333	1.875	0.934	0.370
5	12.116	4.511	2.572	1.352	0.620	0.220
6	11.112	3.765	2.034	1.005	0.428	0.138
7	10.262	3.188	1.640	0.766	0.305	0.090
8	9.529	2.731	1.342	0.595	0.222	0.060
9	8.889	2.362	1.111	0.469	0.165	0.041
10	8.323	2.058	0.930	0.374	0.124	0.029
11	7.818	1.806	0.785	0.302	0.095	0.021
12	7.364	1.594	0.667	0.246	0.074	0.015

Table 4 Weekly Growth Ratio after intervention by Level of social distance when $WGR_{0i}=40$

WEEK	P					
	0.6	0.7	0.75	0.8	0.85	0.9
0	40.000	40.000	40.000	40.000	40.000	40.000
1	26.667	17.143	13.333	10.000	7.059	4.444
2	22.544	12.069	8.459	5.631	3.441	1.789
3	19.818	9.219	5.966	3.625	1.983	0.890
4	17.778	7.347	4.444	2.500	1.246	0.494
5	16.155	6.015	3.429	1.802	0.827	0.294
6	14.816	5.020	2.712	1.341	0.571	0.184
7	13.683	4.251	2.186	1.021	0.406	0.120
8	12.706	3.641	1.789	0.793	0.296	0.080
9	11.852	3.149	1.481	0.625	0.220	0.055
10	11.097	2.744	1.240	0.499	0.166	0.038
11	10.424	2.408	1.046	0.403	0.127	0.027
12	9.819	2.125	0.890	0.328	0.098	0.020

Figures

Figure 1

comparing weekly number of cases at 80%, 85% and 90% level of social distance when initial cases is $N_0=900$ and $WGR_0=30$

Figure 2

Comparing weekly number of new cases at 80%, 85% and 90% level of social distance when initial cases is $N_0=150$ and $WGR_0=30$

Figure 3

comparing the cumulative number of new cases at different level of social distances for 8 weeks $N_0=1000$ and $WGR_0=40$

Figure 4

Comparing predicted and observed weekly number of new cases for Hubei, China ($N_0=900$ and $WGR_0=60$, $p=0.90$)

Supplementary Files

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- [rprog.R](#)