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Article

Measuring time-varying effective reproduction (*Rt*) numbers for COVID-19 and their relationship with movement control order (MCO) in Malaysia

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Abstract: To quantify the time-varying reproduction number (*Rt*) for Malaysia using the COVID-19 incidence data., we used data the from the Johns Hopkins University Center for Systems Science and Engineering (JHU CCSE) Coronavirus repository. Day 1 was taken from the first assumed local transmission of COVID-19. Data was split into four intervals: a) Interval 1: from Day 1 to Day 10 MCO 1, b) Interval 2: from Day 1 to Day 10 MCO 2, c) Interval 3: from Day 1 to Day 10 MCO 3 and d) Interval 4: from Day 1 to Day 10 MCO 4. We estimated the *Rt* using the **EpiEstim** package. The means for *Rt* at Day 1, Day 5 and Day 10 for all MCOs ranged between 0.665 to 1.147. The average *Rt* gradually decreased in MCO 1 and MCO 2. However, *Rt* increased in MCO 3 before stabilized around 0.8 in MCO 4. MCO 1 and MCO 2 which were stricter coincide with the gradual reduction of *Rt*. However, the more relaxed MCO 3 and MCO 4 correspond to a slight increase in the *Rt* before it stabilized.

Keywords: Reproduction number; COVID-19; movement control order; epidemic curve

1. Introduction

1.1 Movement control orders in Malaysia

To combat with the COVID-19 pandemic, the Malaysia government has initiated the Movement Control Order (MCO), effective on March 18, 2020, with the aim to effectively contain the outbreak and slow down the transmission rate. This strategy was proclaimed under the Prevention and Control of Infectious Diseases Act 1988 (Act 342) and the Police Act 1967. Offenders violating the MCO's directives could face a maximum of RM 1000 fine and/or 6-months jail, or both, if convicted [1]. A total of seven-week MCO has been employed, containing four phases, followed by five-week conditional MCO (CMCO) and subsequently recovery MCO (RMCO) till to date (Figure 1) [2–4].

Various non-pharmacological interventions had been implemented in MCO 1, in which they were continued in MCO 2, and gradual relaxation of rules in subsequent MCO phases (Table 1). During the MCO 3, there were relaxations on the MCO's directives, where some sectors could operate, e.g. certain construction projects and automotive industry. However, the applications were subjected to approval from the International Trade and Industry Ministry (MITI), to reduce the number of employees in the workplace. Further expansion was allowed for almost all economic sectors to run at full capacity in MCO 4 [3,5]. It was reported that relaxation of the movement restrictions, in

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which people could go out in pairs, beyond 10km for daily essentials and medical needs, but the person must be from the same household or otherwise with a valid reason [2,4].

Enhanced MCO (MCO) was a targeted approach, applying the non-pharmacological interventions during the MCO Phase 1, but confined to certain affected localities, with the aim to restrict residents' movement in a particular area and subsequently reduced the interactions between high-risk group and the "naïve" populations. EMCO assisted in quicker active case detection, screening, testing and isolation of infected high-risk populations [3,4,6]

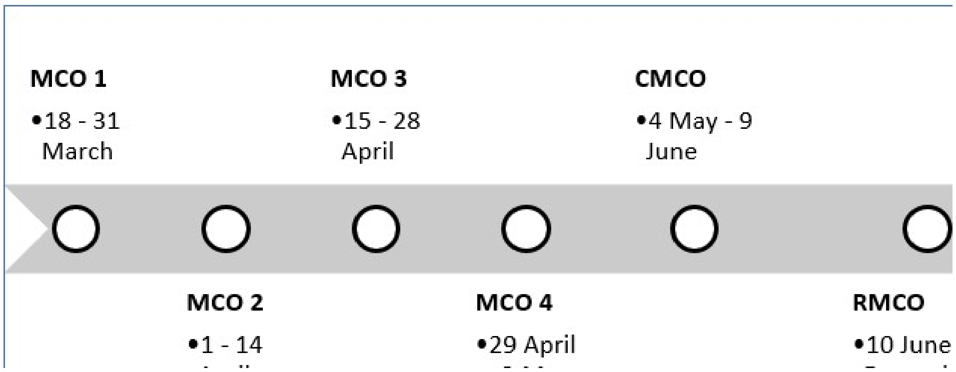

Figure 1: Phases of Movement Control Order (MCOs) in Malaysia. MCO: Movement Control Order; CMCO: Conditional Movement Control Order; RMCO: Recovery Movement Control Order. Source: [1,3,4,6]

1.2 Reproduction number and COVID-19

With the increasing number of cases and the introduction of the multiple non-pharmaceutical interventions (NPIs) by most countries, there is a need to assess and monitor the transmissibility of the disease as a measurement of the effectiveness of control measures. The time varying reproduction number, *Rt*, defined as the average number of secondary cases from a partially susceptible population per infectious case [7], is a universally applied indicator for assessing and monitoring the effectiveness of control measures.

Table 1. Non-pharmacological interventions: The Movement Control Orders in Malaysia.

Phases	Non-pharmaceutical interventions
MCO	**Movement control of the public** i. Prohibition of mass gatherings for religious, sports, social, and cultural activities. ii. Closure of all places of worship, including mosques, churches, and temples. iii. Closure of all business premises, with the exception for supermarkets, public markets, grocery stores and convenience stores. iv. Closure of all educational institutions, including pre-schools, government, and private schools (e.g. daily schools, Tahfiz centres, international schools) and higher education institutions. v. Closure of all government and private sector premises, except for those providing essential services e.g. water and electrical services, telecommunication services, transportation (air/land/sea), banking services, healthcare and medical services, fire and rescue, prisons, defence and security, cleaning, retail and food supply services. vi. Food premises are prohibited to provide dine-in services, take-away and food delivery services are allowed. vii. Limited operation hours of the public transport. viii. Only one person per household could leave home for daily necessities and medical care, unless the accompaniment is reasonably necessary, and the travel is subjected to a radius of 10km. **Border control by the government** ix. Suspension of Malaysians travelling abroad.

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	x. Mandatory medical examinations upon arrival and 14-day quarantine for all entries into Malaysia. xi. Prohibition of interstate travel unless obtain the written police permit with a valid reason. xii. Restrictions on the entry of all tourists and foreign visitors into the country.
CMCO	i. Closure of Malaysia borders and prohibition of international travelling. ii. Relaxation of restrictions to most economic sectors, with business standard operating procedures (SOPs) including physical distancing, temperature checks, recording the names and contacts of customers. iii. Prohibition of pubs, theme parks, cinemas, entertainment centres, conferences and exhibitions. iv. Suspension of sports activities involving mass gatherings, body contact, indoor and stadium sports events. v. Closure of all schools and education institutes. vi. Restriction of interstate travel except for work purposes and return to workplace/home after being stranded in the hometowns. vii. Prohibition of mass gatherings, including religious, social, and cultural activities.
RMCO	i. Closure of Malaysia borders and prohibition of international travelling, with the exception to specific categories of foreigners to enter Malaysia e.g. foreign diplomats and ambassadors, members of Malaysia My Second Home Program, foreigners under the medical tourism industry, expatriates with working visas, etc. ii. Mandatory health inspection and 14-day quarantine for all entries into Malaysia. All foreigners will bear the full cost of quarantine services. iii. Interstate travel is allowed, except for areas under Enhanced MCO (EMCO). iv. Prohibition of night pubs, theme parks, mass religious activities and social gatherings. v. Suspension of sports and games involving mass gatherings of supporters in stadiums. vi. Mandatory face mask-wearing in public places, from August 1 2020.

The basic reproductive number before mitigation starts is called *R0* and The reproduction number after mitigation starts is called as *Rt* to measure of the transmissibility of the infection. An *Rt* of more than one means that the infection is spreading, with more cases generated, whereas an *Rt* of lesse fewer than one means that the spread of infection is decreasing. Theoretically, we need information about the generation time—defined as the time period between the infection of the index and the next case. However, this information is usually difficult to ascertain. Therefore information regarding the serial interval (defined as the interval between disease onset in the index and the next case) distribution in the data is used instead [7–11].

A recent systematic review reported that the basic reproduction (*R0*) for COVID was 3.38 (SD=1.40) and a range of 1.90 to 6.49 [12]. An early report from Wuhan showed that the *R0* was estimated to be 2.2 (95% CI, 1.4 to 3.9) [9] or higher at 4.08 [10].

The relationship between MCO and the reproduction numbers may indicate the impact of MCO. The numbers could be quantified to indicate the effectiveness of the impact of MCO on the spread of the COVID-19. This in return, will provide vital information to help the epidemiologists and public health workers strategize their COVID-19 control programme.

The general objective of the paper is to use the daily incidence data for confirmed COVID-19 cases in Malaysia to quantify the time-varying effective reproduction number (*Rt*). Specifically, using the incidence number of confirmed COVID-19 cases between February 4, 2020 (assumed Day 1 of local COVID-19 case) until May 16, 2020 (Day 102), we would like to a) measure the *Rt* of SARS-Cov-2 at Day 1, Day 5 and Day 10 after the initiation of each of the four MCOs, and secondly, b) quantify the impact of each MCO by measuring the difference in the *Rt* between the beginning of MCO (Day 1) and Day 5 and between Day 5 and Day 10 of each MCO

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2. Materials and Methods

21. Data source and variables

Daily COVID-19 data were downloaded using the R software directly from GitHub (https://github.com/RamiKrispin/coronavirus/tree/master/csv) . This Github repository pulled these data earlier from the Johns Hopkins University Center for Systems Science and Engineering (JHU CCSE) Coronavirus repository (https://github.com/CSSEGISandData/COVID-19).

Data contains variable date, province, country, latitude, longitude, type and case. For the analysis, we filter observations to only include data from Malaysia and type equals 'confirmed' – which refers to confirmed COVID-19 cases. The variable case is the variable that contains the number of cases reported every day.

We considered the first day of our data on February 4, 2020, because we assumed that was the earliest evidence of local COVID-19 transmission as reported by the Ministry of Health, Malaysia. We include data up to May 16, 2020, that is Day 102.

The study did not require ethical approval because we used data that are publicly available from https://github.com/RamiKrispin/coronavirus/tree/master/csv and data are in aggregated format. The original source of data (raw data) came from the Johns Hopkins University Center for Systems Science and Engineering (JHU CCSE) Coronavirus repository https://github.com/CSSEGISandData/COVID-19 .

2.2 Movement control orders

There were four movement control orders (MCO) (see Figure 1). As the intervals between MCO was as small as 14 days, we split our data into four intervals: a) Interval 1: from Day 1 to Day 5 then from Day 5 to Day 10 MCO 1, b) Interval 2: from Day 1 to Day 5 then from Day 5 to Day 10 MCO 2, c) Interval 3: from Day 1 to Day 5 and Day 5 to Day 10 MCO 3, and finally d) Interval 4: from Day 1 to Day 5 and Day 5 to Day 10 MCO 4.

2.3 Estimating the time-varying reproduction number (*Rt*)

One of the parameters required to estimate the reproduction number for COVID-19 is the serial intervals. We used two mean serial intervals: mean of 7.5 days, SD of 3.4 days (95% CI: 5.3, 19) [9] and mean of 3.96 days (95% CI 3.53, 4.39); SD 4.75 days (95% CI 4.46, 5.07) [10]. We assumed that the serial intervals for COVID-19 resemble a normal distribution than the more commonly assumed gamma or Weibull distributions (that are limited to strictly positive values).

In R IDE, the **EpiEstim** package implements a Bayesian approach for quantifying transmissibility over time during an epidemic. More specifically, it allows estimating the instantaneous and case reproduction numbers during an epidemic for which a time series of incidence is available and the distribution of the serial interval (time between symptoms onset in a primary case and symptoms onset in secondary case) is more or less precisely known [12,13].

All data cleaning and statistical analyses were carried out using R software version 4.0.2 [14]. The R package was used to estimate the time-varying reproduction number - **EpiEstim** [12,13]. The comparison of *Rt* values for the different groups was performed using a simple line plot. The estimate-R function in the **EpiEstim** package assumes a gamma distribution of the SI and models the transmission of the infection using a Poisson likelihood to calculate the instantaneous reproduction number using the sliding window of seven days [8,12,13].

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3. Results

We analyzed the daily incidence data starting from February 4, 2020 (Day 1) until May 17, 2020 (Day 102). The incidence data reported by the Ministry of Health, Malaysia refers to the day of the patient detected positive by the RT-PCR test. In the data, the variable date corresponds to the date that the test became positive and not the onset of the symptoms. All COVID-19 tests in Malaysia are performed by the COVID-19 gazetted laboratories using the RT-PCR Antigen test.

Figure 2 shows the epidemic curve based on the daily confirmed COVID-19 cases reported by the Malaysia Ministry of Health. The growth of COVID-19 spread took place between Day 23 after the first local case of COVID-19 (February 4, 2020) until Day 43. From Day 40 to Day 60, the growth peaked.

Overall, this observation agrees with the number of reported active COVID-19 cases in Malaysia, which peaked around April 5 – 8, 2020, with the highest 2596 active cases recorded on April 5 [20]. Consequently, the number of active cases started to decrease and from Day 70 to Day 100 (May 14, 2020), the number of new daily COVID-19 cases slowly decreased and plateaued.

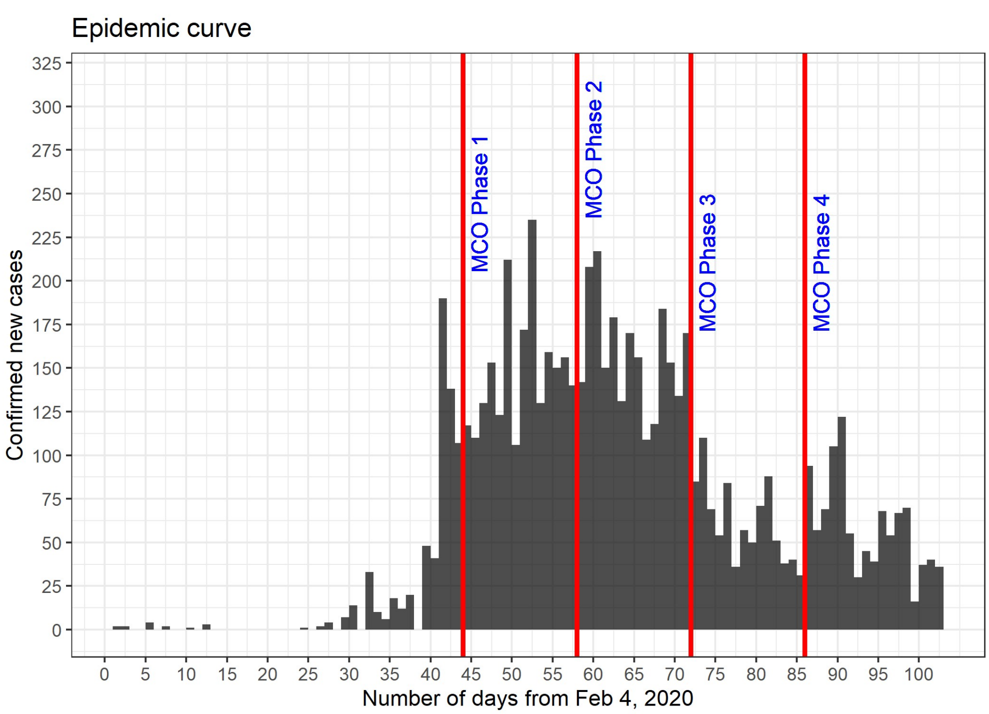

Figure 2: The epidemic curve between Day 1 (February 4,2020) and Day 102 (May 16, 2020) for Malaysia.

The transmissibility of COVID-19 in Malaysia was estimated based on the *Rt* from Day 1 (February 4, 2020) until Day 100 (May 14, 2020). The plot of *Rt* in Figure 3 is based on the serial interval with mean = 7.5 days and SD = 3.4 days. The *Rt* peaked between Day 28 to Day 32. There appears to be another smaller peak at Day 43. While the commencement of MCO 1 (Day 44) resulted in the drop of *Rt*, this quantity stayed above one (dotted line) from Day 58 till Day 64. Theoretically, *Rt* of more than one means that the infection is spreading, with more cases generated daily. This trend can be seen clearly

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from the epidemic curve in Figure 2 as well, where three-digit cases had been recorded during the MCO 1.

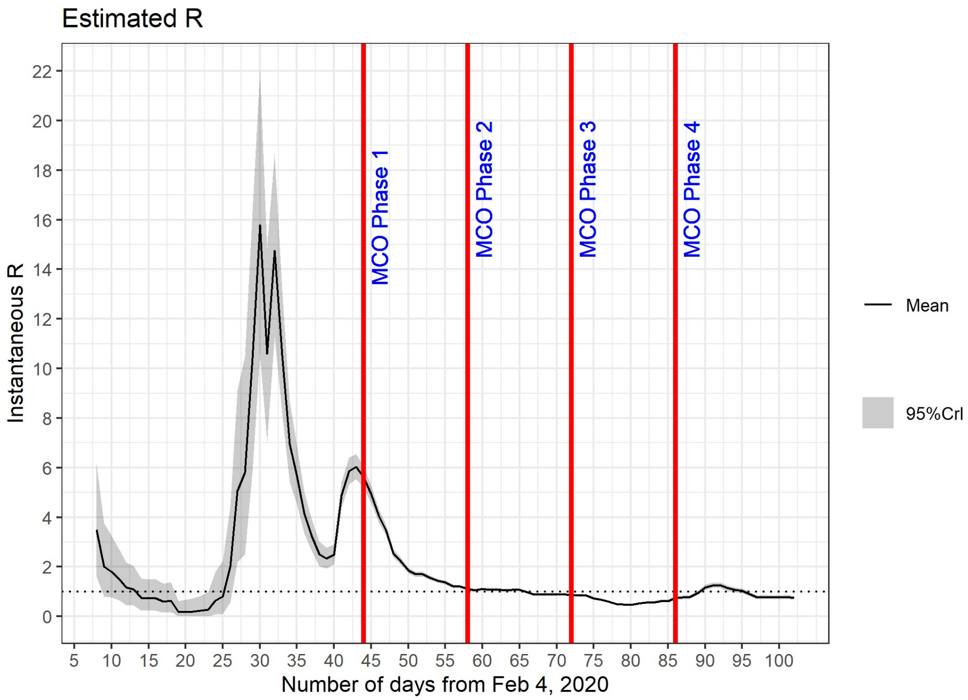

Figure 3: The country-wide time-varying reproduction numbers (*Rt*) Day 1 (February 4, 2020) and Day 102 (May 16, 2020). The estimate was based on the serial interval with mean = 7.5 days and SD = 3.4 days.

When the serial interval parameters were set at a mean of 3.96 days and the SD of 4.75 days, the Rt peaked less drastically (see Figure 4). There appears to be two peaked of Rt, first between Day 27 and Day 32 and the second peak, between day 40 and Day 42. The Rt was already on the way down before the start of MCO phase 1. It dropped until Day 57, but from then on, it plateaued around the value of 1 right until day 95. Between day 95 to Day 100 (May 14, 2020) the Rt was slightly below 1.

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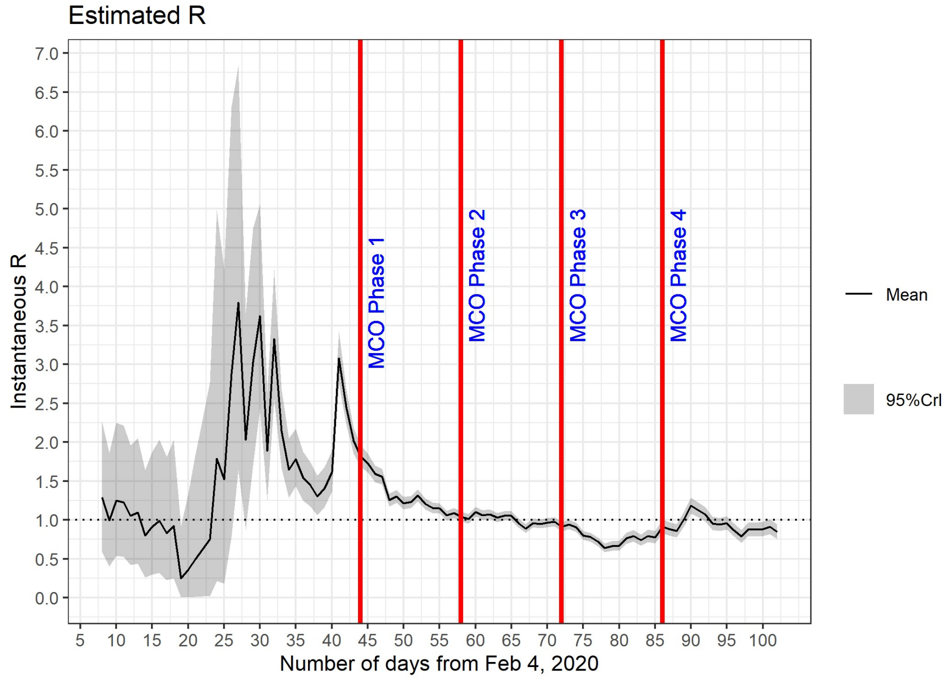

Figure 4: The country-wide time-varying reproduction numbers (*Rt*) Day 1 (February 4, 2020) and Day 102 (May 16, 2020). The estimate was based on the serial interval with mean = 3.96 days and SD = 4.75 days.

As stated above, both Figure 3 and Figure 4 show two peaks of *Rt*. The first peak – we will call this as Peak 1 – occurred roughly 15 days before the start of MCO Phase 1. This was due to an increased number of the confirmed case from 29 cases (on March 2, 2020) to 83 cases (on March 7, 2020). The second peak – Peak 2 – took place between Day 41 and 44, that is after 14 or 30 days the start of a large religious gathering (The Tabligh group) in Sri Petaling, Kuala Lumpur Malaysia. More than 16,000 attendees of the Tabligh group gather in this annual gathering taking place between February 27 and March 1 2020. During Peak 2, the number of cases increased from 428 (March 16, 2020) to 900 (March 20, 2020).

Using the *Rt* estimated from the second serial intervals (mean = 3.96 days, SD = 4.75 days), we show the values of *Rt* at Day 1, Day 5 and Day 10 for each MCO phase in Figure 5. There was a progressive drop in *Rt* from Day 1 to Day 10 for MCO 1 and subsequently from Day 1 to Day 10 of MCO 2. There was an increase in *Rt* during the first ten days of MCO 3. Between Day 1 to Day 10 in MCO 4, the *Rt* seems to plateau (around 0.8 to 0.9).

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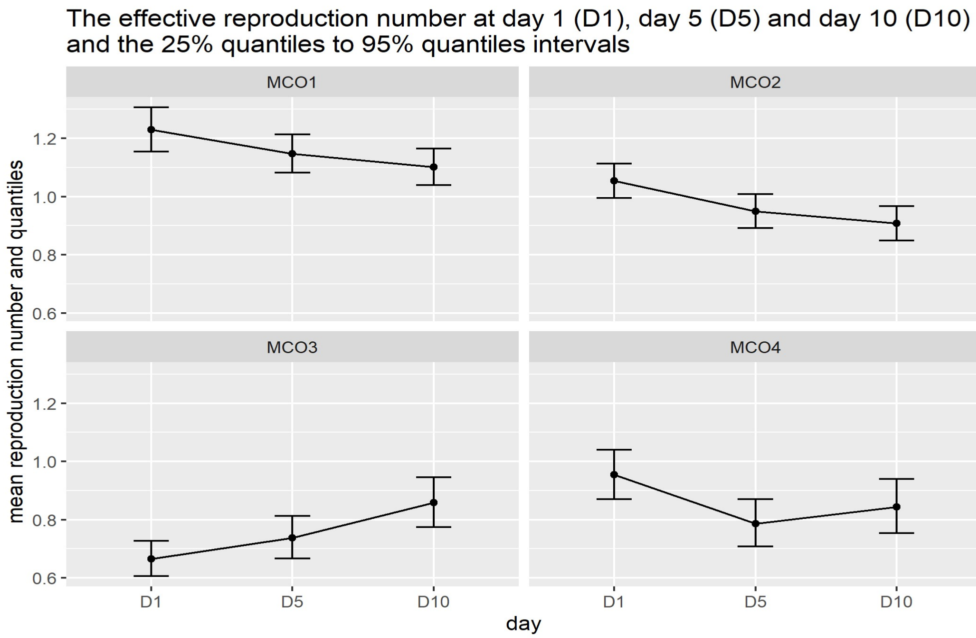

Figure 5: The reproduction numbers (*Rt*) and their 25% and 95% quartiles intervals at day 1 (D1), day 5(D5) and day 10 (D10) for each Movement Control Order (MCO) phase.

In Table 2, we show the mean and the difference in the means based on *Rt* values on Day 1, Day 5 and Day 10 for each MCO. Generally, there were reductions in *Rt* during MCO 1 and MCO 2 but an increase in the *Rt* in MCO 3. The day started and the day ended correspond to the period for the calculation based 7-day rolling average. The percentiles are reported for the 2.5 and 97.5 percentile of the Rt values. The 95% percentiles of all *Rt* values were above one in MCO 1.

Table 2: The mean value of *Rt* at Day 1, Day 5 and Day 10 for each movement control order in Malaysia

Day	MCO	Mean *Rt*	Difference	Difference (%)	day started	day ended	2.5 percentile	97.5 percentile
D1	1	1.23	REF	REF	45	51	1.155	1.307
D5		1.147	-0.082	-6.69	49	55	1.082	1.214
D10		1.101	-0.046	-4.023	54	60	1.039	1.165
D1	2	1.054	REF	REF	59	65	0.995	1.114
D5		0.949	-0.104	-9.913	63	69	0.892	1.008
D10		0.907	-0.042	-4.4	68	74	0.849	0.967
D1	3	0.665	REF	REF	73	79	0.606	0.728
D5		0.738	0.072	10.869	77	83	0.667	0.813
D10		0.858	0.12	16.283	82	88	0.774	0.946
D1	4	0.954	REF	REF	87	93	0.871	1.041
D5		0.787	-0.167	-17.526	91	97	0.707	0.87
D10		0.844	0.058	7.317	96	102	0.754	0.939

*Day 1 = D1, Day 5 = D5, Day 10 = D10 , REF = REFERENCE VALUE

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4. Discussion

We analyzed the daily confirmed COVID-19 cases from Day 1 (February 4, 2020) to Day 102 (May 16, 2020) compiled by the Johns Hopkins University Center for Systems Science and Engineering (JHU CCSE) Coronavirus repository. We showed that the Malaysia epidemic curve reached a peak between Day 40 to Day 70. The time-varying reproduction number (*Rt*) peaked between Day 25 to Day 35 that's before the start of MCO. The average *Rt* gradually decreased in MCO 1 and MCO 2. During MCO 2, Malaysia has been able to push *Rt* to be below than one; however, *Rt* started to increase in MCO 3 before hovered around the threshold unity in MCO 4 till the end of Day 100.

Non-pharmacological intervention (NPI) is the intervention proposed strongly by epidemiologist and infectious disease modeller to halt the transmissibility of SARS-COV-2 that aim to prevent and/or control SARS-CoV-2 transmission in the community [15,16]. Until a safe and effective vaccine is available to all those at risk of severe COVID-19 disease, NPI will continue to be the main public health tool against SARS-CoV-2. The intensive non-pharmaceutical interventions reduce the isolation delay period. Isolation of an infector one day earlier is expected to reduce the mean serial interval by 0.7 days and as a result, will lead to the shortening of the serial interval by more than three days if infectors were rapidly isolated [17]

The Malaysia government initiated the MCO on March 18, 2020, until May 3, 2020. The MCO has 4 phases (MCO 1, MCO 2, MCO 3 and MCO 4), enforced nationwide with the main objective to stop the spread of SARS-Cov-2 virus. The MCO 1 and MCO 2 - which were stricter that MCO 3 and MCO 4 – coincide with the gradual reduction of *Rt*. At the end of MCO Phase 2, Rt had been pushed to be below than one. However, the more relaxed MCO Phase 3 and MCO Phase 4 correspond to a slight increase in *Rt* before it stabilized. Generally, countries that enforced movement control or lock down experience reduction in the *Rt* [8,15,17,18].

Our results show that the spread of SAR-Cov-2 started to decline even before MCO. Figure 3 and Figure 4 show a taller and larger peak of Rt – we called this as Peak 1 - before the start of MCO phase 1. However, this peak has a wider 95% percentiles due to the small number of confirmed COVID-19 cases. Right after that, another smaller peak appeared (before MCO 1). This peak is due quick increased in COVID-19 transmission of COVID-19 among the religious group - The Tabligh Group – that performed a mass gathering at Sri Petaling, Kuala Lumpur. The gathering took place at Day 30 from the first local COVID-19 case.

The downward trend appears of *Rt* before MCO 1 is perhaps a) the evidence of the decreased SARS-Cov-2 transmissibility due to government intervention prior to to MCO, b) data quality due to unfamiliarity with COVID-19 among the public health care workers (as it was only day 20 from the first local case) and c) some other unknown infectious dynamics.

This study shows the feasibility of using the *Rt* to assess and explain transmissibility dynamics and epidemic progression [11,12,17]. *Rt* reflects – though with limitation – the spread of infection. In the case of COVID-19, the NPI has been thought to reduce the spread through isolation and contact tracing. Both reduce the time during which cases are infectious in the community, thereby reducing *Rt* [8,15,17]. If control efforts bring *Rt* below one, then on average there will be a decline in the number of new cases reported. The decline will become apparent after a delay of approximately one incubation period plus time to case detection and reporting following the implementation of the control measure (i.e., at least two weeks) [15]

From the context of a developing country such as Malaysia, a modelling work on the transmission dynamics of COVID-19 using daily confirmed cases of Malaysia be-

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tween March 24, and April 23, 2020, also discovered that the reproduction number during this period is below than 1 [19]. This modelling finding is in parallel with the analysis of *Rt* in our studies during the MCO Phase 1 and Phase 2. In theory, *Rt* below than unity indicates that the mitigation measures such as the non-pharmacological interventions introduced by the government may be effective in controlling this pandemic and breaking the chain of infections. However, our results should be interpreted with care given some developing countries may face the issues of limited medical resources and other pressing problems such as the possibility of under-screening.

Consistent with the aforementioned points, we caution that the insights from our analysis also depend on data that comes from Malaysia Ministry of Health (MOH), which includes the laboratory testing and contact tracing strategies. For instance, the number of confirmed cases often be determined by the speed of the notification of COVID-19 tests, the accuracy of the test and the maximum number of COVID-19 tests done daily by MOH. In simple words, with more tests conducted, more cases may be recorded. Still, the quality of the data would be better, and the predictability of the pandemic using quantities such as *Rt* can be further improved.

4.1 Limitations

The main source of limitation is the use of the date of notification of a positive COVID-19 test to construct the epidemic curve and to estimate the Rt. The idea parameter required to estimate *Rt* is the generation time. However, in most studies, generation time is not possible to ascertain. The next best parameters are the serial intervals of the infection. Unfortunately, we do not have data for infector an infectee to estimate the serial intervals. A few studies have shown that using laboratory notification can still provide a useful reference to the transmissibility of the SAR-Cov-2. The estimates of *Rt* reflects the average value for the country. However, it is more likely that different states and even different district within a state will have different *Rt* values because of the respond to MCO, the population density and the bulk of infections varies between them.

5. Conclusions

In Malaysia, the daily confirmed cases data shows that the epidemic curve for COVID-19 reached a peak between Day 40 to Day 70. However, the time-varying reproduction number (*Rt*) peaked earlier - between Day 25 to Day 35 that is before the start of MCO - which may reflect the response from the community and the government. The stricter MCO 1 and 2 correspond to a gradual decrease of *Rt*, but the more relaxed MCO 3 and MCO 4 correspond to a slight increase in *Rt* before it plateaud just below one.

Supplementary Materials: The analysis and R codes are available at https://github.com/drkamarul/R0_MYS/blob/master/repro_covid19_malaysia_06112020.md

Author Contributions: KIM and MHM proposed the research model and analyzed the datasets. CXW and SJ performed the data pre-processing. KIM wrote the first draft of the manuscript. NAA, TMH, WNA and AB revised the manuscript. All authors read and approved the final manuscript.

Institutional Review Board Statement: Ethical review and approval were waived for this study because the dataset is available on the public domain, aggregated and does not contain any identifier.

Informed Consent Statement: Patient consent was waived because the dataset was aggregated and available on the public domain.

Data Availability Statement: The dataset can be downloaded from https://github.com/RamiKrispin/coronavirus . Direct download of the data is available from https://raw.githubusercontent.com/RamiKrispin/coronavirus/master/csv/coronavirus.csv

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Conflicts of Interest: The authors declare no conflict of interest.

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