**eSIR lockdown modeling**

**Goal**

To estimate the impact of a lockdown on the number of reported cases and deaths during the second wave of the COVID-19 pandemic in India

**Methods**

We implement a modified version of the traditional susceptible-infected-recovered (SIR) model, called extended SIR (or eSIR), which allows for a time-varying effective reproduction number (Rt). This model was developed by Wang et al. [[CITE](https://jds-online.org/journal/JDS/article/28/info)] to model the COVID-19 outbreak in China and was made available in the eSIR R package [[CITE](https://github.com/lilywang1988/eSIR)]. We allow the model to run and estimate Rt using observed data and then implement the effect of a lockdown. That is, we impose a time-varying schedule , which represents the proportion of Rt under a lockdown scenario.

The primary challenge for obtaining a realistic lockdown intervention is, of course, the choice of the schedule. Thankfully, we have two real-world examples from the COVID-19 pandemic in India on which to draw such a schedule: the national lockdown beginning in March 2020 in response to the first wave and the Maharashtra lockdown beginning in April 2021 in response to the second wave. We calculate the respective schedules as the ratio of the Rt following the lockdown over the Rt the day the lockdown started. We begin the India lockdown schedule on March 27, 2020, and the Maharashtra lockdown schedule on April 14, 2021. The nationwide lockdown was swift and had relatively strong immediate and long-term reductions in Rt and represents a best-case or optimistic scenario. The Maharashtra lockdown had a more subdued impact on Rt relative to the national lockdown the previous year and represents what we consider to be a moderate scenario.

Using these schedules and the tvt.eSIR function from the eSIR R package, we are able to impose lockdowns at various timepoints to assess the impact of a lockdown had it been implemented. Because Rt first rose above 1 in mid-February, an early warning sign of a forthcoming surge in cases, we assess lockdowns had they been implemented on March 1, March 15, March 30, April 15, and April 30, 2021. We project each scenario out to May 15 and compare the forecasted results to observed, reported counts.

We can also estimate the number of deaths under these lockdown scenarios. To do this, we apply a case-fatality rate (CFR) schedule, which was calculated as the observed, trailing 7-day average CFR (i.e., ratio of daily deaths to daily cases) for India, for Maharashtra, and for Kerala through May 15. We include the Kerala CFR schedule because of their relatively low COVID-19 CFR and their robust healthcare system, which can be interpreted as a best-case scenario. We then multiply the projected case counts by the CFR schedule to obtain an estimate of the number of COVID-19 deaths.

**Results**

As we would expect, implementing a lockdown at various points has short- and long-term benefits with respect to case counts. This result is consistent regardless of whether the stricter India lockdown schedule (**Figure 1**) or more relaxed Maharashtra schedule (**Figure 2**) is used. Indeed, had a lockdown been instituted in mid- to late-March, the case counts would have almost immediately started to decline, with daily case count peaks around 18 thousand and 45 thousand, respectively. To put this in perspective, a March 15 lockdown under the Maharashtra schedule, approximately 2.7 million cases (**Table 1**) could have been avoided by April 15, representing a 18.7% reduction in total case counts. These reductions would only continue to grow through May 15.

For an intervention taking place in mid-April, the benefits are not as clear. A peak would have occurred shortly after the lockdown if it were as strict as the nationwide lockdown that took place in March 2020. Under the more recent April 2021 Maharashtra lockdown scenario, a near term peak is not obvious; however, it would have represented a significant reduction (approximately 22.8%) in total case counts through May 15.

Finally, we see that a lockdown instituted at the end of April would have essentially no effect on case counts. To put it bluntly, an end-of-April lockdown would have been too late for any benefit because the outbreak had already run its course, as is evident by the slowing growth of observed cases through early May.

A similar story can be seen with respect to death counts. Clear benefits to lockdowns beginning in mid- and late-March and early April are present under both scenarios through mid-May (**Figures 2** and **3**). However, the early April intervention with the Maharashtra schedule does not appear to lead to sustained benefits (though there is still a 13.7% reduction in deaths through May 15 [**Table 2**]). The apparent ineffectiveness of the late lockdown scenarios on deaths is due in part to the use of data prior to the case slowdown and in part due to the increase in CFR seen in early-to-mid May (i.e., the CFR used to estimate deaths under lockdown).

We also estimated deaths using the observed CFR schedule in Kerala – a state with a low COVID-19 CFR and robust healthcare system. We can see that if, regardless of the level of impact a lockdown would have had and regardless of the timing of the lockdown (**Figure 4** and **5**), there is sufficient healthcare capacity that a lockdown would have remarkable benefits in terms of death counts. For example, a March 15 lockdown would have resulted in an 8.1% (14 thousand deaths averted) reduction in total deaths by April 15 and a 40.7% (110 thousand deaths averted) reduction by May 15 (**Table 3**).

Case projections under the India lockdown are shown in **Figure 1** and under the Maharashtra lockdown in **Figure 2**, with accompanying data in **Table 1**. The analogous figures for deaths are shown in **Figures 3** and **4**, respectively, with accompanying data in **Table 2**. The death projections with the Kerala CFR schedule are visualized in **Figure 5** and enumerated in **Table 3**.

**Figures**



**Figure 1**. Observed and predicted daily cases under lockdown scenarios starting on different dates using the India lockdown schedule from February 15 to May 15, 2021.



**Figure 2**. Observed and predicted daily cases under lockdown scenarios starting on different dates using the Maharashtra lockdown schedule from February 15 to May 15, 2021.



**Figure 3**. Observed and predicted daily deaths under lockdown scenarios starting on different dates using the India lockdown and case-fatality rate schedules from February 15 to May 15, 2021.



**Figure 4**. Observed and predicted daily deaths under lockdown scenarios starting on different dates using the Maharashtra lockdown and case-fatality rate schedules from February 15 to May 15, 2021.



**Figure 5**. Observed and predicted daily deaths under lockdown scenarios starting on different dates using the India (**panel A**) and Maharashtra (**panel B**) lockdown and Kerala case-fatality rate schedules from February 15 to May 15, 2021.

**Tables**

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| **Table 1**. Predicted total case counts and cases averted different lockdown interventions | | | | | | |
| INDIA LOCKDOWN SCHEDULE | | | | | | |
|  |  | Lockdown start | | | | |
| Date | Observed | March 1 | March 15 | March 30 | April 15 | April 30 |
| 3/1/21 | 11,124,248 | 11,117,325 | - | - | - | - |
| 3/15/21 | 11,409,517 | 11,197,591 | 11,387,982 | - | - | - |
| 3/30/21 | 12,148,521 | 11,247,983 | 11,494,778 | 12,114,144 | - | - |
| 4/15/21 | 14,287,843 | 11,277,868 | 11,561,550 | 12,473,697 | 14,176,161 | - |
| 4/30/21 | 19,156,979 | 11,292,034 | 11,599,729 | 12,713,444 | 15,976,228 | 19,140,222 |
| 5/15/21 | 24,683,025 | 11,300,197 | 11,623,270 | 12,878,145 | 17,566,407 | 24,566,809 |
|  |  | Cases averted | | | | |
| 3/1/21 | 11,124,248 | 7,367 | - | - | - | - |
| 3/15/21 | 11,409,517 | 211,940 | 20,948 | - | - | - |
| 3/30/21 | 12,148,521 | 900,578 | 653,627 | 34,851 | - | - |
| 4/15/21 | 14,287,843 | 3,011,628 | 2,726,322 | 1,817,227 | 109,858 | - |
| 4/30/21 | 19,156,979 | 7,863,339 | 7,556,965 | 6,447,428 | 3,178,199 | 16,171 |
| 5/15/21 | 24,683,025 | 13,379,076 | 13,060,706 | 11,810,237 | 7,112,187 | 113,538 |
| MAHARASHTRA LOCKDOWN SCHEDULE | | | | | | |
|  |  | Lockdown start | | | | |
| Date | Observed | March 1 | March 15 | March 30 | April 15 | April 30 |
| 3/1/21 | 11,124,248 | 11,117,271 | - | - | - | - |
| 3/15/21 | 11,409,517 | 11,211,635 | 11,388,905 | - | - | - |
| 3/30/21 | 12,148,521 | 11,289,133 | 11,515,587 | 12,114,535 | - | - |
| 4/15/21 | 14,287,843 | 11,353,944 | 11,620,920 | 12,534,258 | 14,176,643 | - |
| 4/30/21 | 19,156,979 | 11,402,383 | 11,703,864 | 12,927,246 | 16,302,250 | 19,140,699 |
| 5/15/21 | 24,683,025 | 11,441,407 | 11,776,206 | 13,311,531 | 19,050,961 | 25,633,642 |
|  |  | Cases averted | | | | |
| 3/1/21 | 11,124,248 | 6,977 | - | - | - | - |
| 3/15/21 | 11,409,517 | 197,882 | 20,612 | - | - | - |
| 3/30/21 | 12,148,521 | 859,388 | 632,934 | 33,986 | - | - |
| 4/15/21 | 14,287,843 | 2,933,899 | 2,666,923 | 1,753,585 | 111,200 | - |
| 4/30/21 | 19,156,979 | 7,754,596 | 7,453,115 | 6,229,733 | 2,854,729 | 16,280 |
| 5/15/21 | 24,683,025 | 13,241,618 | 12,906,819 | 11,371,494 | 5,632,064 | -950,617 |

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| **Table 2**. Predicted total deaths counts and cases averted different lockdown interventions | | | | | | |
| INDIA LOCKDOWN AND CFR SCHEDULE | | | | | | |
|  |  | Lockdown start | | | | |
| Date | Observed | March 1 | March 15 | March 30 | April 15 | April 30 |
| 3/1/21 | 156,695 | 156,695 | - | - | - | - |
| 3/15/21 | 158,301 | 157,187 | 158,301 | - | - | - |
| 3/30/21 | 161,911 | 157,439 | 158,833 | 161,911 | - | - |
| 4/15/21 | 173,746 | 157,605 | 159,206 | 163,917 | 173,746 | - |
| 4/30/21 | 211,248 | 157,700 | 159,464 | 165,526 | 186,011 | 211,248 |
| 5/15/21 | 269,728 | 157,781 | 159,698 | 167,165 | 201,886 | 265,714 |
|  |  | Deaths averted | | | | |
| 3/1/21 | 156,695 | 0 | - | - | - | - |
| 3/15/21 | 158,301 | 1,114 | 0 | - | - | - |
| 3/30/21 | 161,911 | 4,472 | 3,078 | 0 | - | - |
| 4/15/21 | 173,746 | 16,141 | 14,540 | 9,829 | 0 | - |
| 4/30/21 | 211,248 | 53,548 | 51,784 | 45,722 | 25,237 | 0 |
| 5/15/21 | 269,728 | 111,947 | 110,030 | 102,563 | 67,842 | 4,014 |
| MAHARASHTRA LOCKDOWN AND CFR SCHEDULE | | | | | | |
|  |  | Lockdown start | | | | |
| Date | Observed | March 1 | March 15 | March 30 | April 15 | April 30 |
| 3/1/21 | 156,695 | 156,695 | - | - | - | - |
| 3/15/21 | 158,301 | 157,170 | 158,301 | - | - | - |
| 3/30/21 | 161,911 | 157,438 | 158,739 | 161,911 | - | - |
| 4/15/21 | 173,746 | 157,779 | 159,290 | 164,112 | 173,746 | - |
| 4/30/21 | 211,248 | 158,187 | 159,977 | 167,424 | 192,090 | 211,248 |
| 5/15/21 | 269,728 | 158,752 | 161,032 | 173,063 | 232,710 | 307,540 |
|  |  | Deaths averted | | | | |
| 3/1/21 | 156,695 | 0 | - | - | - | - |
| 3/15/21 | 158,301 | 1,131 | 0 | - | - | - |
| 3/30/21 | 161,911 | 4,473 | 3,172 | 0 | - | - |
| 4/15/21 | 173,746 | 15,967 | 14,456 | 9,634 | 0 | - |
| 4/30/21 | 211,248 | 53,061 | 51,271 | 43,824 | 19,158 | 0 |
| 5/15/21 | 269,728 | 110,976 | 108,696 | 96,665 | 37,018 | -37,812 |
| NOTE: Using observed trailing 7-day average CFRs. Abbrev: CFR, case-fatality rate | | | | | | |

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| **Table 3**. Predicted total deaths counts and cases averted different lockdown interventions using Kerala case-fatality rate schedule | | | | | | |
| INDIA LOCKDOWN AND KERALA CFR SCHEDULE | | | | | | |
|  |  | Lockdown start | | | | |
| Date | Observed | March 1 | March 15 | March 30 | April 15 | April 30 |
| 3/1/21 | 156,695 | 156,695 | - | - | - | - |
| 3/15/21 | 158,301 | 157,169 | 158,301 | - | - | - |
| 3/30/21 | 161,911 | 157,534 | 159,074 | 161,911 | - | - |
| 4/15/21 | 173,746 | 157,674 | 159,387 | 163,576 | 173,746 | - |
| 4/30/21 | 211,248 | 157,697 | 159,447 | 163,953 | 176,507 | 211,248 |
| 5/15/21 | 269,728 | 157,712 | 159,485 | 164,219 | 179,070 | 220,106 |
|  |  | Deaths averted | | | | |
| 3/1/21 | 156,695 | 0 | - | - | - | - |
| 3/15/21 | 158,301 | 1,132 | 0 | - | - | - |
| 3/30/21 | 161,911 | 4,377 | 2,837 | 0 | - | - |
| 4/15/21 | 173,746 | 16,072 | 14,359 | 10,170 | 0 | - |
| 4/30/21 | 211,248 | 53,551 | 51,801 | 47,295 | 34,741 | 0 |
| 5/15/21 | 269,728 | 112,016 | 110,243 | 105,509 | 90,658 | 49,622 |
| MAHARASHTRA LOCKDOWN AND KERALA CFR SCHEDULE | | | | | | |
|  |  | Lockdown start | | | | |
| Date | Observed | March 1 | March 15 | March 30 | April 15 | April 30 |
| 3/1/21 | 156,695 | 156,695 | - | - | - | - |
| 3/15/21 | 158,301 | 157,259 | 158,301 | - | - | - |
| 3/30/21 | 161,911 | 157,816 | 159,210 | 161,911 | - | - |
| 4/15/21 | 173,746 | 158,116 | 159,696 | 163,819 | 173,746 | - |
| 4/30/21 | 211,248 | 158,192 | 159,824 | 164,421 | 176,927 | 211,248 |
| 5/15/21 | 269,728 | 158,254 | 159,941 | 165,046 | 181,471 | 222,048 |
|  |  | Deaths averted | | | | |
| 3/1/21 | 156,695 | 0 | - | - | - | - |
| 3/15/21 | 158,301 | 1,042 | 0 | - | - | - |
| 3/30/21 | 161,911 | 4,095 | 2,701 | 0 | - | - |
| 4/15/21 | 173,746 | 15,630 | 14,050 | 9,927 | 0 | - |
| 4/30/21 | 211,248 | 53,056 | 51,424 | 46,827 | 34,321 | 0 |
| 5/15/21 | 269,728 | 111,474 | 109,787 | 104,682 | 88,257 | 47,680 |
| NOTE: Using observed trailing 7-day average CFRs. Abbrev: CFR, case-fatality rate | | | | | | |