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COVID-19 Trend and Forecast in India: A Joinpoint Regression Analysis

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Abstract: This paper analyses the trend in daily reported confirmed cases of COVID-19 in India using joinpoint regression analysis. The analysis reveals that there has been little impact of the nation-wide lockdown and subsequent extension on the progress of the COVID-19 pandemic in the country and there is no empirical evidence to suggest that relaxations under the third and the fourth phase of the lockdown have resulted in a spike in the reported confirmed cases. The analysis calls for a population-wide testing approach to check the increase in the reported confirmed cases of COVID-19.

Keywords: COVID-19, Pandemic, India, Trend, Forecast, Joinpoint Regression

Background

Total number of reported confirmed cases of COVID-19 in India crossed 100 thousand mark on 19 May 2020 according to the database maintained by the World Health Organization. The first confirmed COVID-19 case in India was reported on 30 January 2020 but no confirmed COVID-19 case was reported during 4 February 2020 through 1 March 2020. By 15 March 2020, more than 100 confirmed cases of COVID-19 were reported which increased to 500 by 24 March 2020 when the nation-wide lockdown was announced in the country. Since then, the number of daily reported confirmed cases crossed the 10000 mark by 14 April 2020 and the 50000 mark by 7 May 2020. The progress of the disease presents a challenge for data scientists to model it as the epidemiological characteristics of the disease are yet to be fully explained. There is currently no treatment for COVID-19 and no vaccine is available to protect from novel coronavirus. The uncertainty about the progress of COVID-19pandemic therefore creates additional pressure on the epidemiologists and public health experts on how to control it. In such a situation, forecasting COVID-19 cases is very important for planning and implementing infection containment and pandemic control measures. In this context, an analysis of the trend in the daily reported confirmed cases of COVID-19 may provide useful information about how the COVID-19 pandemic has progressed in India. The trend analysis also permits forecasting the likely trend in the reported confirmed cases of COVID-19 in the immediate future.

A trend analysis of daily reported confirmed cases of COVID-19 is also needed as it is widely claimed that the imposition of the nation-wide lockdown in India on 25 March 2020 has significantly decelerated the progress of COVID-19 pandemic in the country. It has also been claimed that loosening the restrictions under the nation-wide lockdown during its third and the fourth phase has primarily been responsible for the recently witnessed spike in the number of daily reported confirmed cases of COVID-19 in the country. It has even been argued that re-imposing the harsh restrictions as part of the nation-wide lockdown is the only way of stopping or decelerating the progress of COVID-19 pandemic despite the fact that the

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social and economic cost of nation-wide lockdown has been found to be quite complex and exorbitant. It has repeatedly been stressed that because of serious social and economic implications of the nation-wide lockdown, it cannot be prolonged.

One way of empirically examining these and many other claims is whether the trend in the daily reported confirmed cases of COVID-19 has changed after the imposition of the nation-wide lockdown or after loosening the restrictions under the nation-wide lockdown. If the trend in the daily reported confirmed cases of COVID-19 has changed after the imposition of the nation-wide lockdown, then it can be inferred that the nation-wide lockdown has indeed an impact on the progress of the epidemic. Similarly, if it is found that the trend in the daily reported confirmed cases of COVID-19 has changed after loosening the restrictions under the nation-wide lockdown, then it can be concluded that loosening of the restrictions has been responsible for the spike in reported confirmed COVID-19 cases in the country. However, if there is no change in the trend, then there is little empirical evidence to suggest that either the nation-wide lockdown or loosening of restrictions under the nation-wide lockdown has any telling impact on the progress of the COVID-19 pandemic.

A review of the daily reporting of the confirmed COVID-19 cases in India reveals that during the 28 days from 4 February 2020 through 1 March 2020, no confirmed case of COVID-19 was reported in the country. Moreover, during the period 2 March 2020 through 31 March 2020, daily reporting of confirmed COVID-19 cases has been highly inconsistent. For example, no confirmed case of COVID-19 was reported on 3 March; 20 March; and 28 March 2020 whereas on 29 March 2020 alone, 255 confirmed cases of COVID-19 were reported (Table 1). These inconsistencies in the reporting of daily confirmed cases of COVID-19 may bias any analysis of the trend in the daily reported confirmed cases of COVID-19. It is therefore necessary that the irregular fluctuations in daily reporting of confirmed cases of COVID-19 resulting from the inconsistencies in reporting are ironed out before any analysis of the trend in the reported confirmed cases of COVID-19.

One approach to minimize the impact of reporting inconsistencies in the analysis of the trend in daily reporting of confirmed COVID-19 cases is to use moving average instead of actual daily reported confirmed cases of COVID-19. The same approach has been followed in the present analysis. To minimize the effect of irregular fluctuations in the reporting of COVID-19 cases in the trend analysis, five-day moving average has been used instead of daily reported confirmed cases of COVID-19. In other words, the reported confirmed cased of COVID-19 in a day used in the present analysis are actually the average of the reported confirmed cases of COVID-19 two days prior to the day in question; two days after the day in question; and the reported confirmed cases of COVID-19 on the day in question. For example, the reported confirmed cases of COVID-19 on 3 March 2020 used in the present analysis are actually the simple average of reported confirmed cases of COVID-19 on 1 March through 5 March 2020.

Table 1: Reported confirmed cases of COVID-19 in India, 1 March 2020 - 23 May 2020

Date	Reported confirmed cases	Cumulative confirmed cases	Five days moving average of reported confirmed cases	Date	Reported confirmed cases	Cumulative confirmed cases	Five days moving average of reported confirmed cases
March 1, 2020	0	3	0	April 12, 2020	909	8356	900
March 2, 2020	2	5	5	April 13, 2020	796	9152	1005
March 3, 2020	0	5	5	April 14, 2020	1211	10363	987
March 4, 2020	22	27	6	April 15, 2020	1076	11439	1006
March 5, 2020	2	29	6	April 16, 2020	941	12380	1045
March 6, 2020	2	31	7	April 17, 2020	1007	13387	1070
March 7, 2020	3	34	3	April 18, 2020	991	14378	1165
March 8, 2020	5	39	4	April 19, 2020	1334	15712	1244
March 9, 2020	5	44	6	April 20, 2020	1553	17265	1319
March 10, 2020	6	50	8	April 21, 2020	1336	18601	1403
March 11, 2020	10	60	8	April 22, 2020	1383	19984	1473
March 12, 2020	14	74	8	April 23, 2020	1409	21393	1448
March 13, 2020	7	81	11	April 24, 2020	1684	23077	1579
March 14, 2020	3	84	11	April 25, 2020	1429	24506	1582
March 15, 2020	23	107	13	April 26, 2020	1990	26496	1608
March 16, 2020	7	114	14	April 27, 2020	1396	27892	1651
March 17, 2020	23	137	22	April 28, 2020	1543	29435	1709
March 18, 2020	14	151	18	April 29, 2020	1897	31332	1709
March 19, 2020	44	195	34	April 30, 2020	1718	33050	1889
March 20, 2020	0	195	41	May 1, 2020	1993	35043	2109
March 21, 2020	88	283	57	May 2, 2020	2293	37336	2240
March 22, 2020	58	341	65	May 3, 2020	2644	39980	2677
March 23, 2020	93	434	82	May 4, 2020	2553	42533	2870
March 24, 2020	85	519	73	May 5, 2020	3900	46433	3123
March 25, 2020	87	606	77	May 6, 2020	2958	49391	3272
March 26, 2020	43	649	58	May 7, 2020	3561	52952	3426
March 27, 2020	75	724	92	May 8, 2020	3390	56342	3301
March 28, 2020	0	724	93	May 9, 2020	3320	59662	3552
March 29, 2020	255	979	120	May 10, 2020	3277	62939	3561
March 30, 2020	92	1071	182	May 11, 2020	4213	67152	3588
March 31, 2020	180	1251	248	May 12, 2020	3604	70756	3668
April 1, 2020	385	1636	264	May 13, 2020	3525	74281	3806
April 2, 2020	329	1965	366	May 14, 2020	3722	78003	3758
April 3, 2020	336	2301	425	May 15, 2020	3967	81970	4034
April 4, 2020	601	2902	486	May 16, 2020	3970	85940	4378
April 5, 2020	472	3374	491	May 17, 2020	4987	90927	4627
April 6, 2020	693	4067	595	May 18, 2020	5242	96169	4956
April 7, 2020	354	4421	593	May 19, 2020	4970	101139	5284
April 8, 2020	853	5274	608	May 20, 2020	5611	106750	5504
April 9, 2020	591	5865	676	May 21, 2020	5609	112359	5768
April 10, 2020	547	6412	787	May 22, 2020	6088	118447	
April 11, 2020	1035	7447	776	May 23, 2020	6564	125011	

Source: WHO COVID-19 database

The trend analysis presented in this paper is based on joinpoint regression analysis (Kim et al, 2000). Joinpoint regression analysis is used to study the trend that varies over time. This method first identifies the time point(s) at which the trend in the reported

confirmed cases of COVID-19 has changed or the joinpoint(s). Once the joinpoint(s) are identified, then the average per cent change between two joinpoints is calculated to reflect how the trend in the reported confirmed cases of COVID-19 has varied over time. The goal of the joinpoint regression analysis is not to provide the statistical model that best fits the time series data. Rather, the purpose is to provide that model which best summarizes the trend in the data (Marrot, 2010). The underlying assumption of joinpoint regression is that trend in the data is not the same throughout the period under reference but is essentially different in different segments of the reference period.

Joinpoint Regression Model

The joinpoint regression model is essentially different from the conventional piecewise or segmented regression model in the sense that the identification of joinpoint(s) and their location(s) is estimated within the model and are not set arbitrarily as is the case with the piecewise or segmented regression analysis. The minimum and the maximum number of joinpoint(s) are, however, set in advance but the final number of joinpoint(s) or the time point(s) when the trend changes are determined statistically. The model first identifies the time point(s) when there is a significant change in the trend and then calculates the average percentage change (*APC*) which reflects the rate of change between two joinpoint(s). When the number of joinpoint(s) is zero, the model reduces to simple linear regression model.

Let y_i denotes the reported confirmed COVID-19 cases on day t_i such that $t_1<t_2<...<t_n$. Then the joinpoint regression model is defined as

$$\ln y_i = \alpha + \beta_1 t_1 + \delta_1 u_1 + \delta_2 u_2 + ... + \delta_j u_j + \varepsilon_i \qquad (1)$$

$$\text{where } u_j = \begin{cases} (t_j - k_j) & \text{if } t_j > k_j \\ 0 & \text{otherwise} \end{cases}$$

and $k_1<k_2.....<k_j$ are joinpoints. The details of joinpoint regression analysis are given elsewhere (Kim et al, 2000; Kim et al, 2004).

Joinpoint regression analysis has commonly been used when the temporal trend of a given quantity, like incidence, prevalence and mortality is of interest (Tyczynski and Berkel, 2005; Doucet, Rochette and Hamel, 2016; John and Hanke, 2015; Chaurasia, 2020). However, this method has generally been applied with the calendar year as the time scale (Akinyede and Soyemi, 2016; Mogos et al, 2016; Chatenoud et al, 2015; Missikpodeet al, 2015). The joinpoint regression analysis can also be applied in epidemiological studies in which the starting date can be easily established such as the day when the disease is detected for the first time as is the case in the present analysis (Rea et al, 2017). Joinpoint regression analysis can, therefore, be applied in the public health framework also and can explore whether the number of reported cases of a specific disease has decreased after the introduction of an intervention to check or control the disease. In the present context, the application of the joinpoint regression analysis can answer the question whether the imposition of the nation-wide lockdown has resulted in the decrease in the reported confirmed cases of COVID-19 in the country or not. If the day of introducing the intervention turns out to be a joinpoint, then, a comparison of daily per cent change in the reported

confirmed cases of COVID-19 before and after the joinpoint can tell whether the intervention has been able to bring down the reported confirmed cases of COVID-19 or not.

Actual calculations in the present analysis are carried out using the Joinpoint Regression Program developed by the Statistical Research and Application Branch of the National Cancer Institute of the United States of America (NIC, 2013). The software requires specification of minimum (0) and maximum number of joinpoints (>0) in advance. In the present analysis, the minimum number of joinpoints is specified as 0 while the maximum number of joinpoints have been specified as 5. The programme starts with the minimum number of joinpoints (0, which is actually a straight line and the model is simple linear regression model) and tests whether more joinpoints are statistically significant and must be added to the model (up to the pre-specified maximum number of joinpoints). The tests of significance are based on a Monte Carlo Permutation method (Kim et al, 2000).

This study uses the Bayesian Information Criterion (BIC) to identify the number of joinpoints in the model. The equation for computing the BIC for a *k*-joinpoints model is:

$$BIC(k) = \ln\left[\frac{SSE(k)}{n}\right] + \frac{2(k+1)\times \ln(n)}{n} \tag{2}$$

Where SSE is the sum of squared errors of the *k*-joinpoints regression model and *n* is the number of observations. The model which has the minimum value of BIC(*k*) is selected as the final model. There are other methods also for identifying the joinpoints. These include the permutation test method and the data driven BIC methods. Relative merits and demerits of different methods of identifying the joinpoints are discussed elsewhere (NIC, 2013). The permutation test method is regarded as the best method but it is computationally very intensive. It controls the error probability of selecting the wrong model at a certain level (i.e. 0.05). The BIC method, on the other hand, is less computationally intensive.

The Joinpoint Regression Program provides estimates of annual per cent change (*APC*) as it is designed primarily for analyzing calendar year data. *APC* is one way to characterize the trend over time. In this approach, a rate or a number is assumed to change at a constant percentage of the rate or the number of the previous year. The rate or the number that changes at a constant percentage every year, changes linearly on a logarithmic scale. In the present case, data on the reported confirmed cases of COVID-19 are available on a daily, not yearly, basis. This means that the *APC* of the Joinpoint Regression Program output is actually the daily percent change (*DPC*) in the present context. The *DPC* from day *t* to day (*t*+1) is defined as

$$DPC = \left(\frac{y_{t+1} - y_t}{y_t}\right)\times 100 \tag{3}$$

If the trend in the daily reported confirmed cases of COVID-19 is modeled as

$$\ln(y_t) = b_0 + b_1 t + \varepsilon \tag{4}$$

then, it can be shown that the *DPC* is equal to

$$DPC = (e^{b_1} - 1)\times 100 \tag{5}$$

The positive value of *DPC* suggests an increasing trend while the negative value of APC suggests a decreasing trend. The *DPC* reflects the trend in the reported confirmed cases of COVID-19 in different time segments of the reference period identified through joinpoint

regression analysis. For the entire reference period, it is possible to estimate average daily percent change (*ADPC*) which is the weighted average of *DPC* in different time segments of the reference period with weights equal to the length of different time segments. However, when the trend changes frequently, *ADPC* has little meaning.

Other epidemiological and statistical approaches have been used to analyze the trend and forecast cases of COVID-19. The epidemiological approach is essentially built around the SIR (susceptible, infectious, removed or recovered) model and its extension SEIR (susceptible, exposed, infectious, removed or recovered) model and their numerous extensions and versions. These models are based on key epidemiological parameters such as basic reproduction number, case fatality rate, case recovery rate, etc. in analyzing the progress of the epidemic. The major challenge in the application of these models is the estimation of the parameters of the model. For example, an important parameter of these models is the proportion of individuals who got infected through contact with someone already infected and, in most of the situation, it is a mere guess. In any case, once the parameters are known, the progress of the epidemic can be analyzed and alternative courses of the epidemic may be explored just by changing the parameters of the model which introduces a fair degree of subjectivity in the application of the model.

On the other hand, time series analysis may be used to analyze the trend and forecast the number of COVID-19 cases. One limitation of time series analysis is that it takes into account the entire reference period to forecast the number of cases. In situations where the trend changes with time, time series analysis may not be appropriate to analyze the trend and for forecasting, the underlying assumption in the joinpoint regression is that the trend changes over time. The change in the trend may be the result of the interventions introduced to control the spread of the disease or otherwise. In other words, the joinpoints regression permits to explore whether an intervention introduced to control the epidemic has actually been effective in reducing the reported number of cases of the disease so that the trend in the number of reported cases has changed. If there is no change in the trend, then it may be concluded that the intervention has not been able to change the trend in the reported number of cases of the disease and, therefore, has not been effective enough to control the spread of the disease. The joinpoint regression is entirely data driven. It makes no assumption about the progress of the epidemic or the change in parameters as is the case with the SIR or SEIR or similar other models of describing the progress of the epidemic.

Trend in Daily Reported Confirmed Cases of COVID-19

Results of the joinpoint regression analysis of the five-days moving average of the daily reported confirmed cases of COVID-19 in India for the period 1 March 2020 through 23 May 2020 are summarized in Table 2 and Figure 1. The five-days moving average is centred at the mid-point of the five-day interval. For example, the five-day moving average of the period 1 March through 5 March 2020 is centred on 3 March 2020. In other words, the joinpoint regression analysis is carried out for the period 3 March 2020 through 21 May 2020, although, it covers the data on daily reported confirmed cases of COVID-19 from 1 March 2020 through 23 May 2020. The period prior to 1 March 2020 has not been included in the analysis as the daily reported confirmed cases of COVID-19 during the period 30 January 2020 through 1 March 2020 have mostly been found to be zero.

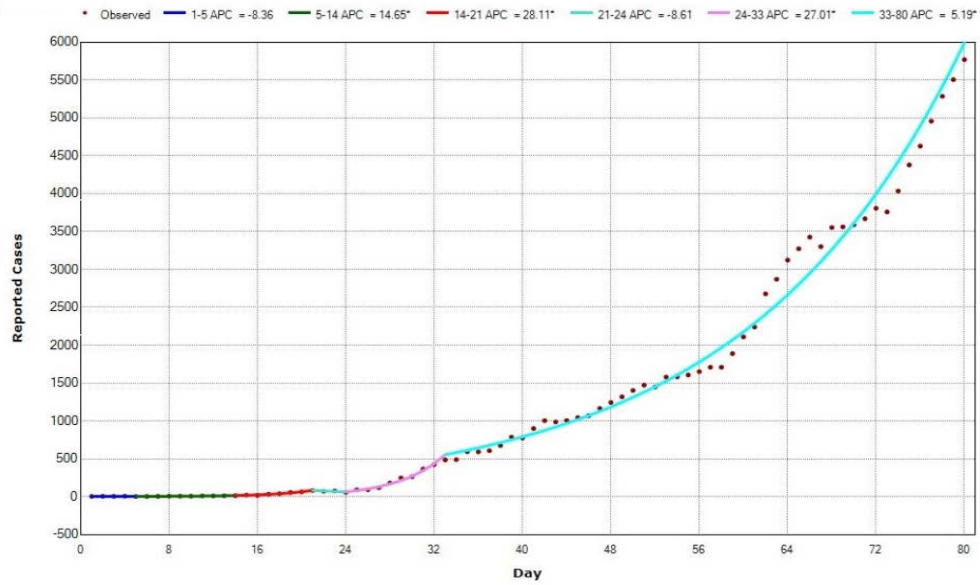
Table 2: Results of the joinpoint regression analysis

Segment	Lower Endpoint	Upper Endpoint	Number of days	Daily per cent change (*DPC*)	95 per cent confidence interval		't'	p>|t|
					Lower	Upper		
1	3 March 2020	7 March 2020	5	-8.363	-16.063	0.044	-1.988	0.051
2	7 March 2020	16 March 2020	10	14.648*	11.228	18.173	9.021	0.000
3	16 March 2020	23 March 2020	8	28.113*	22.242	34.267	10.553	0.000
4	23 March 2020	26 March 2020	4	-8.612	-30.761	20.622	-0.648	0.519
5	26 March 2020	4 April 2020	10	27.008*	23.219	30.913	15.777	0.000
6	4 April 2020	21 May 2020	48	5.194*	4.972	5.416	47.944	0.000
All	3 March 2020	21 May 2020	80	9.094#	7.694	10.513	13.206	0.000

Source: Author's calculations

Note: * Statistically significant, # Average daily per cent change (*ADPC*), Number of days in a segment include both lower endpoint and upper endpoint.

Figure 1: Trend in daily reported confirmed cases of COVID-19 in India during 1 March through 23 May 2020 using joinpoint regression analysis with BIC criterion



The application of the joinpoint regression analysis divides the duration 1 March 2020 through 23 May 2020 or a period of 84 days into five-time segments and the trend in the daily reported confirmed cases of COVID-19 is found to be different in different time segments. During the first five days of the period under reference - 3 March 2020 (day 1) through 7 March 2020 (day 5), the trend in the daily reported confirmed cases of COVID-19 in the country has been found to be negative which means that daily reported confirmed cases of COVID-19 in the country actually decreased, instead increased, during this period at a daily per cent decrease (*DPC*) of around 8 per cent per day. This decrease in the reported confirmed cases of COVID-19 may be attributed to reporting inconsistencies, although the *DPC* during this period has been found to be statistically significant. On the other hand, during the next 10 days - from 7 March 2020 (day 5) through 16 March 2020 (day 14) - the daily reported confirmed cases of COVID-19 increased daily per cent increase (*DPC*) of almost 15 per cent. The increase in the daily reported confirmed cases of COVID-19 accelerated further during the next eight days - from 16 March 2020 (day 14) through 23 March 2020 (day 21) - when the daily reported confirmed cases of COVID-19 in the country increased at a *DPC* of more than 28 per cent. However, during the next five days - between

23 March 2020 (day 21) through 26 March 2020 (day 24) - the reported confirmed cases of COVID-19 decreased again with a *DPC* of almost -9 per cent, although the daily per cent decrease in during this period has not been found to be statistically significant. The daily reported confirmed cases of COVID-19 increased again with a *DPC* of around 27 per cent during the next 10 days - from 26 March 2020 (day 24) through 4 April 2020 (day 33). After 4 April 2020, however, there has been no change in the trend in the daily reported number of confirmed cases of COVID-19 till 21 May 2020. During the 43 days from 4 April 2020 through 21 May 2020, the daily reported confirmed cases of COVID-19 in the country increased at a *DPC* of almost 5.2 per cent.

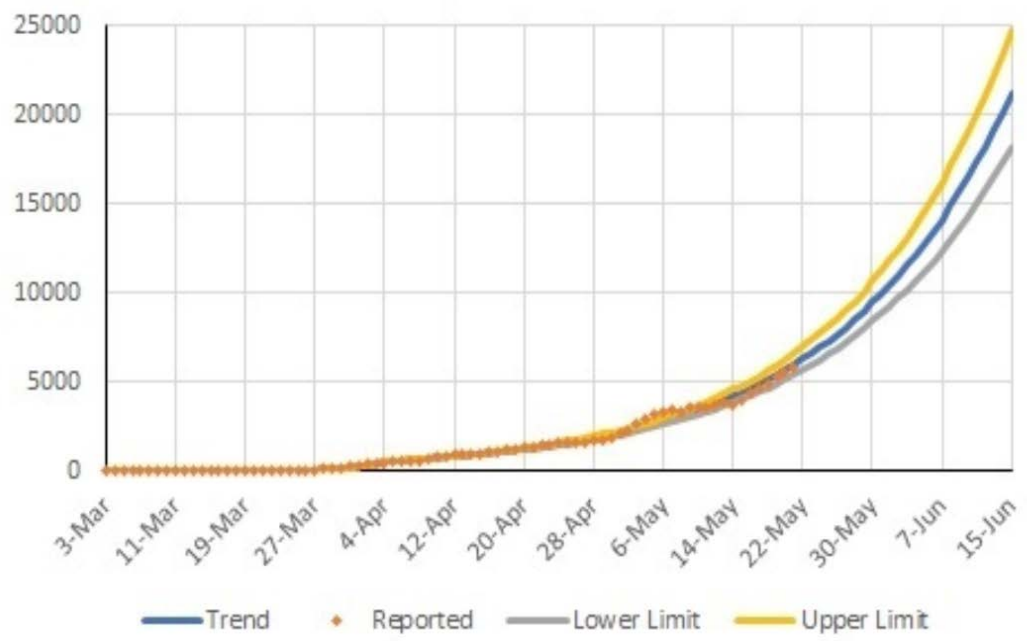
It is also possible to estimate the average daily per cent change (*ADPC*) in the reported confirmed cases of COVID-19 in the country during the period 3 March 2020 through 21 2020. The joinpoint regression analysis suggests that the reported confirmed cases of COVID-19 in the country increased at an *ADPC* of slightly more than 9 per cent during this period (Table 3). The *APDC*, however, has little relevance in the present case as the trend in the reported confirmed cases of COVID-19 during this period has been quite erratic, particularly during the period 3 March 2020 through 4 April 2020. After 4 April 2020, however, there is no change in the trend and, therefore, the *ADPC* is the same as *APC* during this period.

Table 3: Forecast of daily reported confirmed cases of COVID-19 till 15 June 2020

Date	Estimate	95% Confidence interval	
		Lower	Upper
May 22, 2020	6301	5694	6972
May 23, 2020	6629	5977	7350
May 24, 2020	6973	6274	7748
May 25, 2020	7335	6586	8168
May 26, 2020	7716	6913	8610
May 27, 2020	8117	7257	9076
May 28, 2020	8539	7618	9568
May 29, 2020	8982	7997	10086
May 30, 2020	9449	8394	10633
May 31, 2020	9939	8812	11208
June 1, 2020	10456	9250	11815
June 2, 2020	10999	9710	12455
June 3, 2020	11570	10192	13130
June 4, 2020	12171	10699	13841
June 5, 2020	12803	11231	14591
June 6, 2020	13468	11790	15381
June 7, 2020	14167	12376	16214
June 8, 2020	14903	12991	17092
June 9, 2020	15677	13637	18018
June 10, 2020	16492	14315	18994
June 11, 2020	17348	15027	20022
June 12, 2020	18249	15774	21107
June 13, 2020	19197	16558	22250
June 14, 2020	20194	17381	23455
June 15, 2020	21243	18246	24725

Source: Author's calculations

Figure 2: Forecast of daily reported confirmed COVID-19 cases in India up to 15 June 2020



The joinpoint regression analysis suggests that the trend in the daily reported confirmed cases of COVID-19 changed statistically significantly at the 5th day (7 March 2020); 14th day (16 March 2020); 24th day (26 March 2020); and 33rd day (4 May 2020) of the period beginning 3 March 2020. The nation-wide lockdown in the country was imposed on 25 March 2020 initially for a period of 21 days which was then extended to 3 May 2020 on 15 April 2020. On 4 May 2020, the lockdown was again extended up to 17 May 2020 but with a relaxed set of restrictions which, on 18 May 2020, was further extended to 31 May 2020 with even more relaxed set of restrictions. The present analysis suggests that the day of the change in the trend in daily reported confirmed cases of COVID-19 in the country has never matched with the date of imposing the lockdown or dates of first, second and third extensions of the lockdown. There has also been no change in the trend in the daily reported confirmed cases of COVID-19 after 4 April 2020. If the change in the trend is any indication of the effectiveness of the interventions directed towards changing the course of the pandemic, then, it is obvious from the present analysis that, there is little evidence that the lockdown imposed on 25 March 2020 nor the three extensions of the lockdown have resulted in any significant change in the trend in the reported number of confirmed cases of COVID-19 in the country in terms of the decrease in *DPC*. In other words, it may be concluded that the strategy of the nation-wide lockdown has not been effective in changing the course of the COVID-19 pandemic in the country in a statistically significant manner. There are some studies which have concluded that the nation-wide lockdown has resulted in a decrease in the number of cases of COVID-19 in the country under the assumption that the proportion of individuals who got infected through contact with someone already infected decreased because of strict social distancing and masking norms imposed during lockdown. However, this assumption does not hold empirically as the present analysis reveals.

The joinpoint regression analysis also suggests that the trend in the reported confirmed cases of COVID-19 has been different during the period 4 April 2020 onwards as compared to the trend prior to 4 April 2020. Before 4 April 2020, the trend in the reported

confirmed cases of COVID-19 in the country has been very erratic and is characterized by change in the direction of the trend in a very short duration. There is no apparent reason for the observed frequent changes in the direction of the trend in the reported confirmed cases of COVID-19 and that too in a short to very short duration. It therefore appears that the observed frequent changes in the trend in a very short duration in the reported confirmed cases of COVID-19 in the country prior to 4 April 2020 are essentially the result of the inconsistencies in the reporting of COVID-19 cases. It is only after 4 April 2020 that the consistency in the daily reporting of the confirmed cases of COVID-19 appears to have improved. Because of the highly erratic nature of the trend in the reported confirmed cases of COVID-19 prior to 4 April 2020, any inference about the progress of the COVID-19 pandemic on the basis of the trend during any period before 4 April 2020 should be desisted and the interpretations about the progress of the pandemic on the basis of the trend in the reported confirmed cases of COVID-19 prior to 4 April 2020 should be made with caution. The consistency of the trend in the reported confirmed cases of COVID-19 after 4 April 2020 suggests that any inference about the progress of the COVID-19 pandemic in the country should be made on the basis of the trend in the reported confirmed cases of COVID-19 during the period 4 April 2020 through 21 May 2020 only which shows that there has been little change in the progress of the COVID-19 pandemic in the country since 4 April 2020.

Forecasting Number of COVID-19 Cases

The *DPC* in the daily reported confirmed cases of COVID-19 during the period 4 April 2020 through 21 May 2020 may be used for forecasting the daily reported confirmed cases of COVID-19 in the immediate future under the assumption that the trend in the daily reported confirmed cases of COVID-19 remains unchanged. This exercise suggests that by 15 June 2020, the daily reported confirmed cases of COVID-19 in the country is likely to increase to 21243 with a 95 per cent confidence interval of 18246 - 24725 (Table 3 and Figure 2). This increase in the daily reported confirmed cases of COVID-19 may change only when there is a significant change in the trend which is possible only when an appropriate set of new interventions are introduced to combat COVID-19 pandemic in the country. The trend during 4 April 2020 through 21 May 20202 in the reported confirmed cases of COVID-19 in the country suggests that the nation-wide lockdown imposed on 25 March 2020 and extended three times subsequently has largely been irrelevant in checking the progress of the COVID-19 pandemic because of a host of factors. It was expected that the nation-wide lockdown will be able to break the transmission of the novel coronavirus which causes COVID-19. However, the national-wide lockdown could not check large scale movement, especially of migrant workers from urban areas to rural hinterland which appears to be largely responsible for the increase in the reported confirmed cases of COVID-19 in the country. In order to change the course of the pandemic, it is, therefore, imperative that efforts beyond the lockdown should be undertaken to modify the course of the pandemic. One such intervention is the population-wide testing for COVID-19 followed by isolation of the positive cases and their contacts. The need for such a strategy also stems from the fact that a very large proportion of the individuals tested positive for COVID-19 have been found to be asymptomatic. Chaurasia (2020a) has suggested a cluster-based approach of population-wide testing for COVID-19 in the country which significantly reduces the number of tests to be done.

The forecast of the daily reported confirmed cases of COVID-19, on the basis of the joinpoint regression analysis also suggests that the total number of confirmed COVID-19 cases in the country are likely to increase to almost 422 thousand by 15 June 2020 with a 95

per cent confidence interval ranging from around 376 thousand to around 473 thousand if the present trend in the daily reported confirmed cases of COVID-19 continues in the days to come. This implies that the daily reported confirmed cases of COVID-19 in the country are bound to increase quite rapidly in the days to come. This forecast about the increase in the reported confirmed cases of COVID-19 in the country in the days to come can be changed only through the introduction of appropriate interventions.

The analysis presented above is confined to the daily reported confirmed cases of COVID-19 at the national level. The available evidence suggests that the progress of the COVID-19 epidemic in different states of the country has essentially been different. A better understanding of the progress of the epidemic in the country may be obtained by analyzing the progress of the epidemic at the state level. This is a major task as joinpoint regression analysis is a very time intensive process. Efforts to carry out state-specific analysis of the progress of the COVID-19 epidemic using joinpoint regression approach is already in progress and the results of the analysis will be made available as and when the analysis is completed.

Conclusions

The present analysis, based on the daily reported confirmed cases of COVID-19, suggests that there has virtually been little impact of the nation-wide lockdown and its subsequent extensions and relaxations in restrictions on the progress of the COVID-19 pandemic in India. There has also been little empirical evidence to suggest that relaxations in the restrictions under the third and the fourth extension of the nation-wide lockdown have resulted in spiking of the reported confirmed cases of COVID-19 in the country as is generally claimed. This conclusion is based on the hypothesis that if the nation-wide lockdown and extensions that followed have been effective, the trend in the reported confirmed cases of COVID-19 in the country would have changed statistically significantly. The present analysis suggests that any change in the trend in the reported confirmed cases of COVID-19 appears to be largely the result of the inconsistencies in the reporting of COVID-19 cases.

Based on the trend in the reported confirmed cases of COVID-19 during the period 4 April 2020 through 21 May 2020, the analysis also suggests that the daily reported confirmed cases of COVID-19 in the country are likely to increase to somewhere between 18246 to 24726 with an average of around 21 thousand by 15 June 2020 whereas the total number of confirmed cases of COVID-19 are the most likely to increase to somewhere between around 422 thousand with a 95 per cent confidence interval of 376 to 473 thousand by 15 June 2020. Appropriate interventions, in addition to the nation-wide lockdown, are needed to change this trend in the progress of the COVID-19 pandemic in the country. One such intervention that may contribute to modifying the progress of the pandemic in the country may be population-wide testing for COVID-19 along with isolation of positive cases and quarantine of contacts to the identified positive cases.

Limitations of the Study

There are no specific limitations of the study. The method adopted for the analysis is entirely data driven which makes no assumption about the data and the future course of the epidemic. The forecast is based on the assumption that the *DPC* in the recent past will

continue in the immediate future if no interventions to change the course of the epidemic are introduced which is a valid assumption.

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