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India's Second Covid Wave

by Arvind Virmani

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Abstract

The second covid wave hit India with a bang during March-April 2021. This paper examines the date, models the two waves, makes out of sample projections using these models. It uses the basic S curve function, to develop a Dual -S curve model, which allows us to judge the predictability of the second wave. It matches the timing and duration of these events with the second wave to examine whether they could have set-off the second wave.

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1. Introduction

Virmani (2020) used the "Gompers Sigmund curve" to model the evolution of cases and deaths from covid over time. It used cross country panel regressions to estimate the parameters of the model and used these to analyse the effect of different country factors like average temperature, degree of urbanization and age distribution of population, on the rate of growth of Covid cases. The paper found that the rate of growth of cases was faster in countries with greater urbanization and greater percent of aged population and lower in countries with higher average temperature. Similar results were found for Covid related deaths. In addition, countries with higher number of hospital beds per capita had significantly lower deaths.

In a recent set of blogs (29/4/21) the author had argued that India's second wave was driven by virus mutations, increased mobility, and failure to follow Covid safety precautions. This note investigates these assertions in greater detail, with data from the 21 largest States. The paper presents a State wise picture of the explosive spread of the new variants of the virus (like B1.167, B1.17). Other events, like elections, farmers agitations and Religious functions are also be analysed. The next section presents the data, the model, and the estimates of the first wave. In section 3 the second wave is analysed by dividing the confirmed cases into two series, representing the original and mutated variants. The latter is then fitted to the same model a one used in the first part and used to project the spread of the mutated variants. These are then recombined to forecast the total cases. Section 4 analysis mobility data, the timing of public events and the breakout/take-off of cases. This helps differentiate between events which could have contribute to the take-off of the mutated virus and those could merely have helped sustain or broaden the spread. Section 5 compares the nature & pattern of the first wave with the second wave, to determine its relative severity. Section 6 summarises the State wise data on Covid fatality data and section 7 concludes the paper.

2. Data & Model

We start by sketching a picture of the spread of covid across India. The data was available only up to May 9, when the analysis was done. The States are ordered by deaths, with Bihar have the lowest death rate and Delhi the highest. Maharashtra, Chhattisgarh, and Punjab are the other States having a high death rate from covid (rhs), while Bihar, Odisha, Assam, and Uttar Pradesh and Telangana had a low one (figure 1). Comparing the case rate (lhs) with the

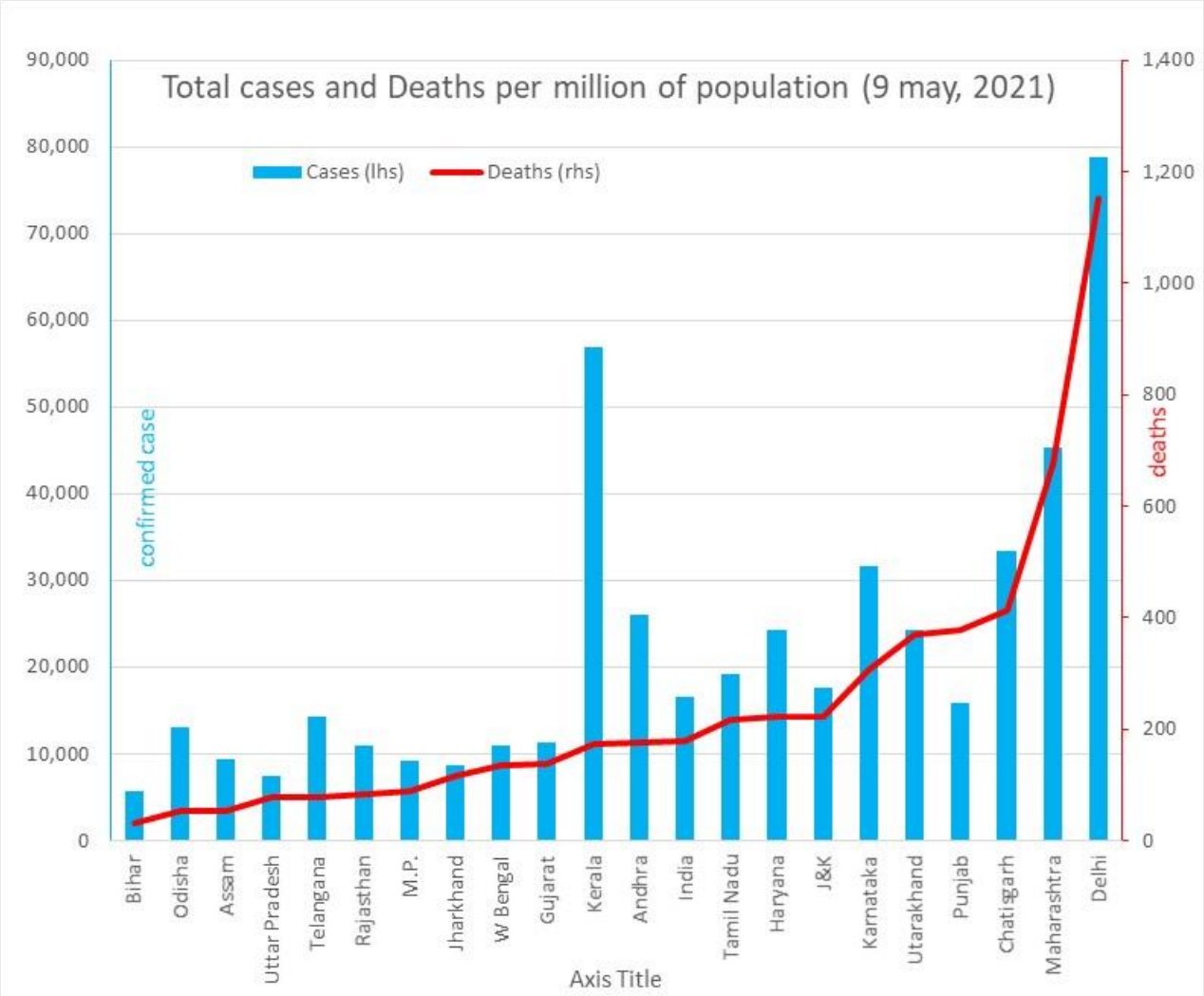
death rate (rhs), four States have a high number of per capita cases compared to per capita deaths from Covid. These are Kerala, Andhra, Karnataka, and Haryana. Punjab stands out for the opposite reason, a high death rate compared to the lower-case rate. A potential reason is the degree of efficiency of the health system in dealing with the new disease. Greater under-counting of covid related cases and deaths in the rural areas is another possibility. Delhi is a city State, with a high population density and higher per capita income with the lifestyle which goes with it and needs to be compared with metro cities like Mumbai, Bangalore, and Chennai. The high per capita cases are less puzzling than the comparatively high death rate as medical facilities is not known to be any worse than in the other metro cities. City level analysis is however beyond the scope of the current paper.

The second distinct feature of the Indian second wave is that the peak of daily new cases is more than four times the peak of the first wave and the time for the formation of the peak was much shorter (figure 2). A similar pattern is seen in virtually every State, though the height of the second peak relative to first peak differs across States. It is difficult to think of any other fundamental explanation of this pattern than the arrival. or evolution, of a much faster spreading mutations. We model and analyse this hypothesis in the current paper as well as other hypothesis such as international travel between India and countries with new virus varieties, and large public, market, and social gatherings with inadequate protective measures.

2.1 Model: Dual S curve

The logic of the Gompers sigmoid curve, also called the S curve, as applied to epidemics, is the changing balance between those who have been infected or vaccinated, do not get infected by the same virus again. Initially the virus spreads at a faster and faster rate as the pool of infected people rises. As the pool of uninfected people shrinks, there are fewer potential new people to be infected, so the rate of spreads declines progressively, till it reaches zero. The process starts again when a new mutation arises.

Figure 1: Total cases and deaths (cumulative) by million population as of 9 May 2021



We analyse the 21 largest States, by identifying the point at which the rate of growth of new cases bottomed out. Then we fit the S curve, with 3 parameters, to the data, with best fit measured in terms of R squared. The equation of the S-curve is,

$$CVC = A / [1 + Exp (-b^* (days\_1cvc - c))]$$

Where, CVC = Corona virus cases (confirmed total cumulative)

A = the maximum number of cases at which the curve plateaus

Days_1cvc = Number of days from start of first Covid case,

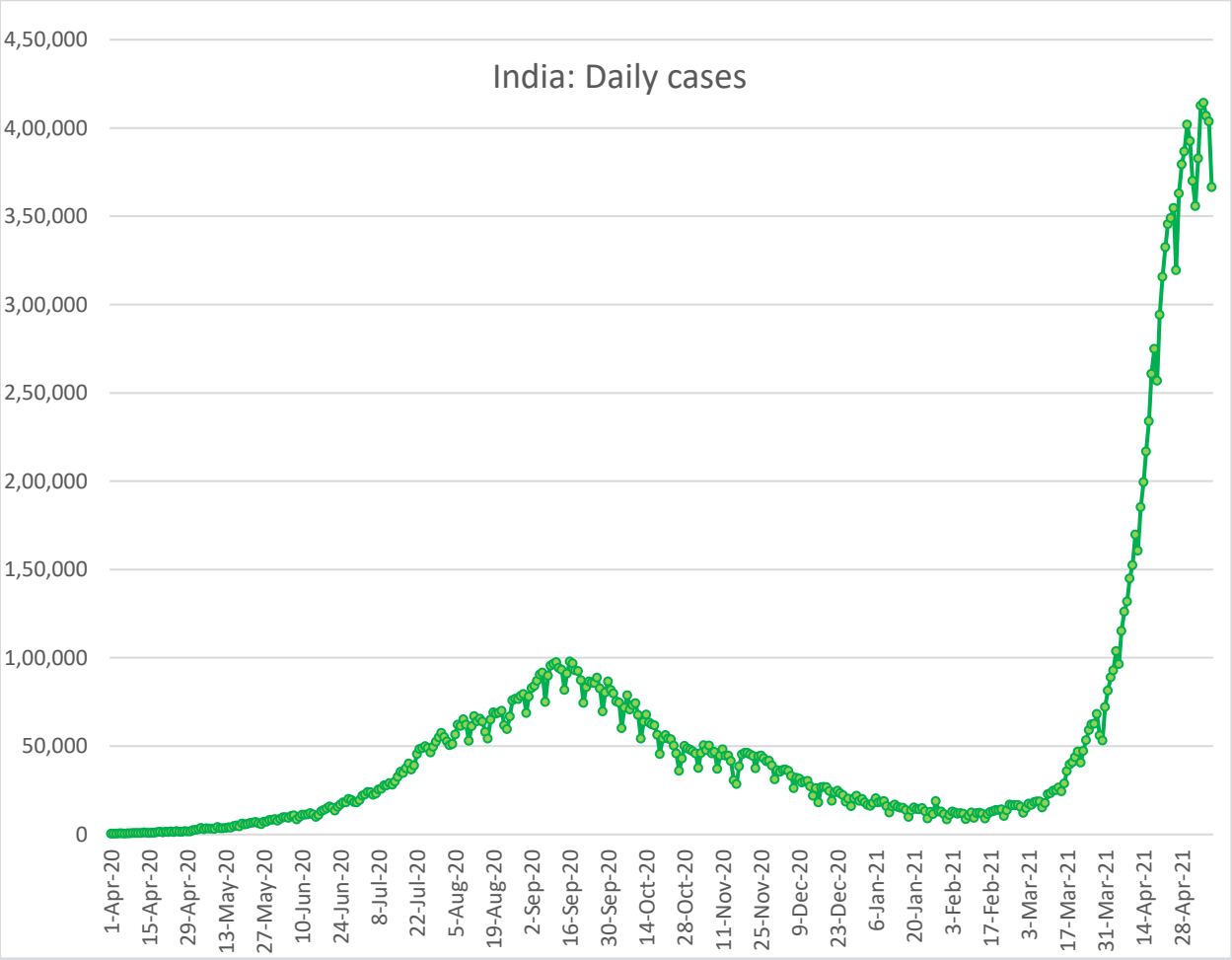
b = slope co-efficient of the S curve

c = day of inflection from accelerating to decelerating growth rate of cases.

The complete details of the basic S-curve model are given in Virmani (2020).[1]

[1] See also Virmani and Bhalla (2020) for another application of the S curve model of epidemic propagation.

Figure 2: Double peak of daily cases

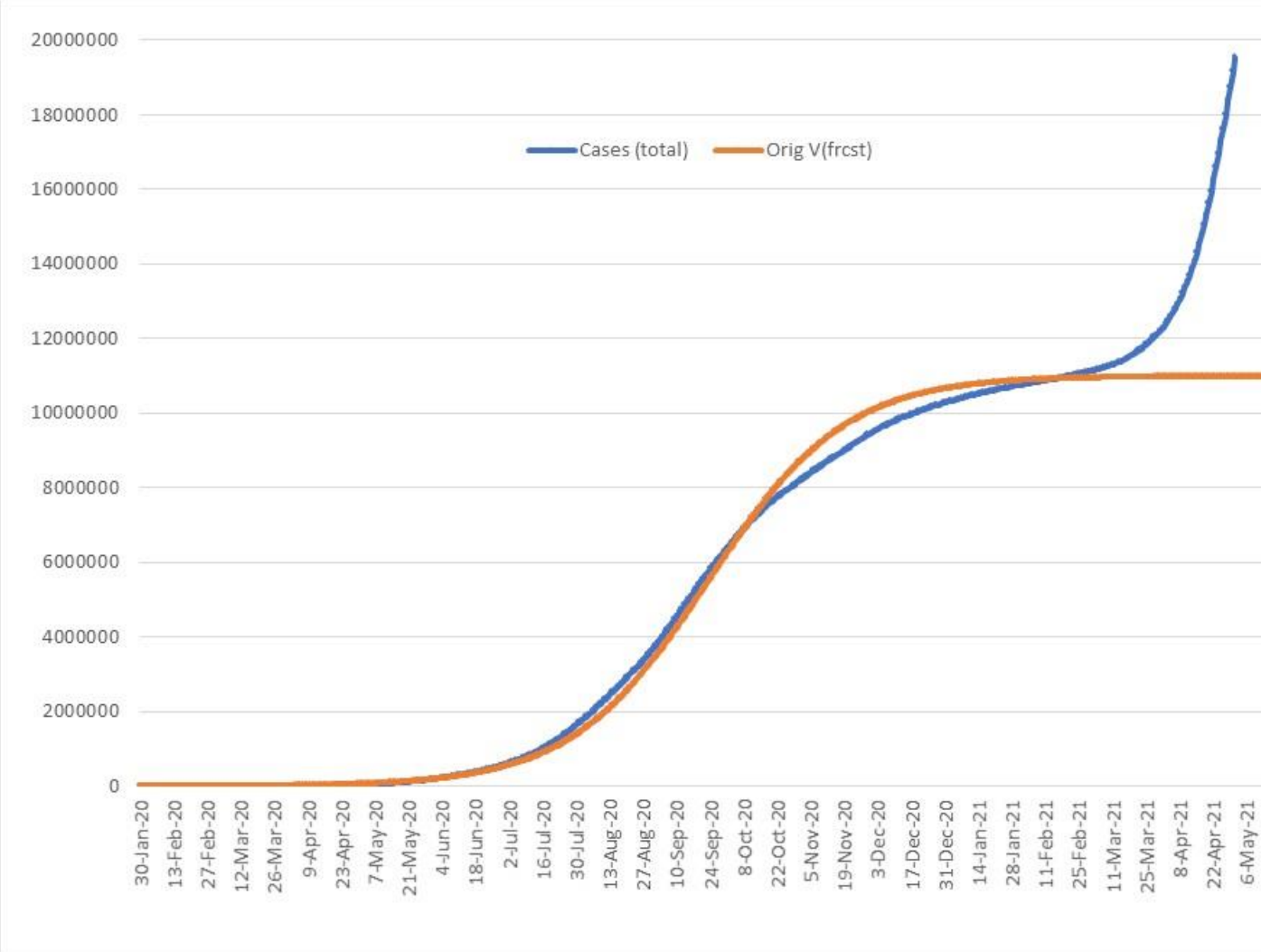


The results are presented in Appendix Table A1. The row titled India shows that it took 210 ten days from the detection of the first case to reach the inflection point and the R squared for the model fit is 0.996. Table 1 shows the lowest growth rate of 0.71% was reached on 14th February 2021, with cumulative confirmed cases equal to 10.9 million(1.09cr) and the active cases equal to 1.4 lakhs (table A1). Punjab stands out as the earliest State to reach a trough in the rate of growth of cases, but there were six other States whose trough proceeded the All-India trough (col 1, table 1). Bihar, Odisha, and Kerala were the last three States to reach the trough, but Kerala stands out as the only State whose growth rate of cases was more than 1% even at the low point (col4, table 1).

Figure 3 shows the actual trajectory of cases and the cases projected by the model. It is seen that the second wave breaks through the projected trajectory of the first wave around mid-February 2021. Such a breakout implies the development of a new mutation, whose spread is not constrained by the fact that a substantial proportion of the population has developed "herd

immunity" through exposure to the original virus. This is confirmed by the fact that the same trajectory is found in all 21 States, with the second wave breaking out of the projected S curve trajectory, after the trough is reached. This is illustrated in figures 2 & 3 for Maharashtra and Kerala. Maharashtra is a State where the second wave started early, around end -February 2021 and Kerala where it started late, around beginning of April 2021. The pattern of growth of covid cases, the fitted S-curve, and the breakout of cases, above the forecast values, are like those for India as a whole.[2]

Figure 3: India's S-curve of Confirmed cases



Note: Orig V(frcst) is the forecast based on the S curve fitted to the original virus data, up to the date, at which the slowest rate of growth of confirmed cases is reached.

[2] Out of the 21 States whose data was analyzed, three States (Maharashtra, Chhattisgarh, and Tamil Nadu) show an anomaly in the estimated S curve: The actual cases shoot through the estimated curve, weeks before the rate of growth of cases reaches its minimum. In all three cases, even the active cases are still on a clear declining trend.

Figure 4: Maharashtra's S curve of confirmed cases

(at end of paper)

Figure 5: Kerala's S-curve of Confirmed cases

(at end of paper)

Column 6 of Table 1 shows the date on which the inflection point, at which the rate of growth of cases stops increasing ad starts decreasing, as estimated using parameter c (days) of the S curve (table A1). This is not identical to the actual peak growth rate because there are sometimes two peaks in the actual curve, and the curve may fit better in some periods than in others even though there is only one R-squares less than 0.997(table A1). The first point to note is that the all-India inflection date is, a week short of, five months before the lowest growth rate (row India, cols 1 & 6). This means it took four to five months from peak growth to reach the trough.

Table 1: First wave of corona virus cases

State	Actual confirmed cases on date of lowest growth rate of cases					S curve based estimate Inflection	A(max)
	Date	Cases/th	rank	gr rt	Active/mi	**Date**	**Cases/th**
	1	2	3	4	5	6	7
Punjab	27-Jan-21	6	7	0.74%	75	19-Sep-20	6
J&K	6-Feb-21	10	13	0.32%	51	22-Sep-20	10
Haryana	8-Feb-21	11	14	0.23%	32	9-Oct-20	11
Gujarat	10-Feb-21	4	5	0.67%	30	1-Oct-20	5
Maharashtra	11-Feb-21	18	19	0.83%	280	9-Sep-20	18
Madhya Pradesh	13-Feb-21	4	3	0.47%	25	9-Oct-20	4
Delhi	13-Feb-21	38	21	0.14%	62	11-Oct-20	39
India	14-Feb-21	8		0.71%	102	21-Sep-20	8
Chhattisgarh	14-Feb-21	12	16	0.51%	128	24-Nov-20	12
Assam	16-Feb-21	7	9	0.02%	51	30-Aug-20	7
Jharkhand	18-Feb-21	4	4	0.23%	14	10-Sep-20	4
West Bengal	18-Feb-21	6	8	0.20%	40	9-Oct-20	7
Andhra Pradesh	18-Feb-21	18	18	0.04%	12	2-Sep-20	18
Rajesthan	21-Feb-21	5	6	0.19%	18	13-Oct-20	5
Uttar Pradesh	22-Feb-21	3	2	0.09%	12	14-Sep-20	3
Telengana	23-Feb-21	9	11	0.31%	49	12-Sep-20	9
Tamil Nadu	23-Feb-21	12	15	0.37%	56	29-Aug-20	11
Karnataka	24-Feb-21	16	17	0.29%	100	13-Sep-20	15
Uttarakhand	25-Feb-21	10	12	-0.17%	173	10-Oct-20	10
Bihar	6-Mar-21	3	1	0.08%	3	1-Sep-20	3
Oddisha	12-Mar-21	8	10	0.13%	14	17-Sep-20	8
Kerala	18-Mar-21	33	20	1.16%	762	7-Dec-20	39

Note: Active = Total cases - recovered cases – deaths.
Author's calculations based on official data and estimated S curve (parameters in appendix table A1).

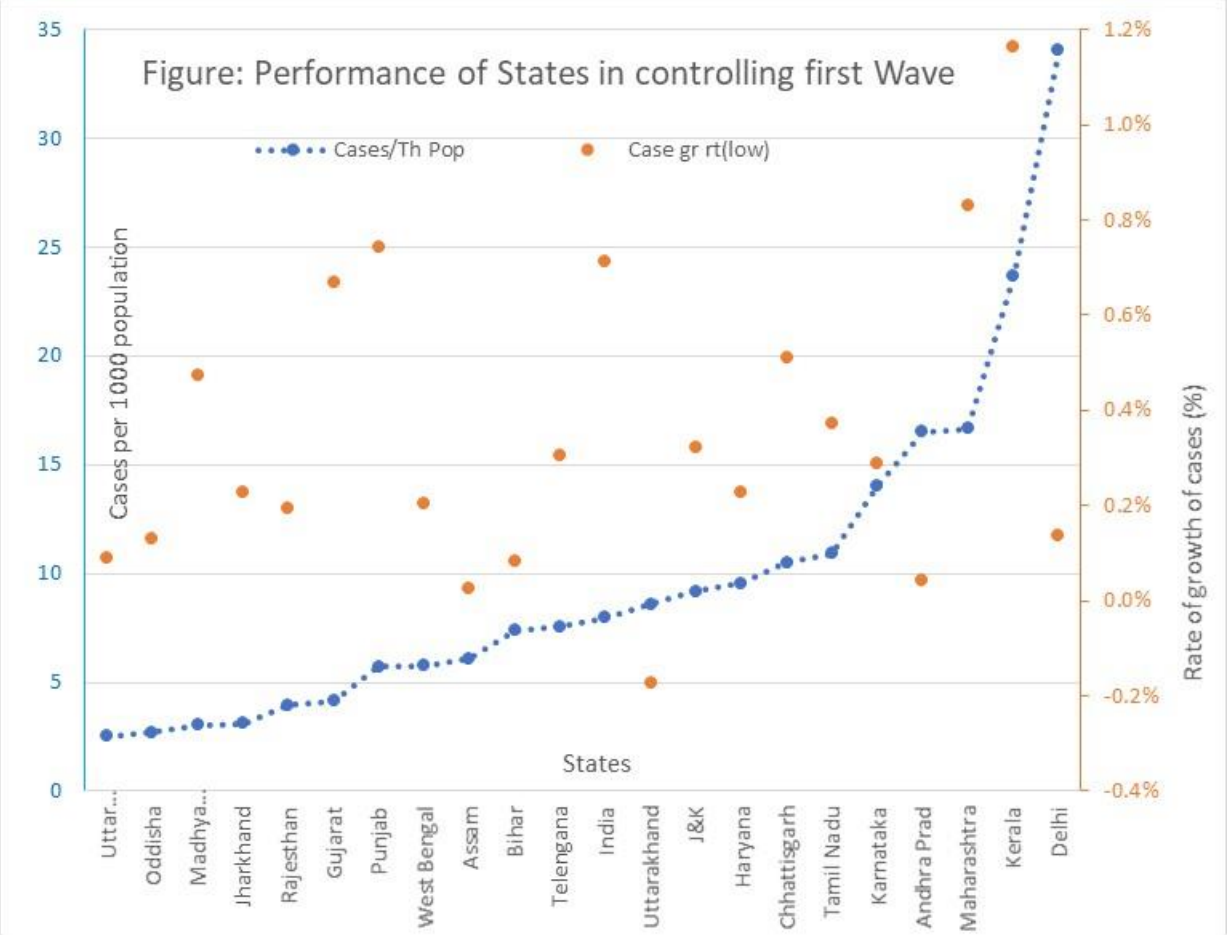
The second point to note is that the S curve estimate of the asymptotic cases per thousand of population, is almost the same as the cases seen at the lowest point of the growth rate. For all States is almost identical to the actual number of cases (cols2 & 7, table 1), except Kerala. This suggests that case growth reduced rapidly once the peak of new cases was reached.

The third point to note is that measured in per capita terms the infected cases during the first wave, were the lowest at 3/1000 in the States of UP, Odisha, MP, Jharkhand, 4/1000 in Rajasthan and Gujrat, and 6/1000 in Punjab, West Bengal and Assam, and 8/1000 in Bihar and Telangana (col 2, 3, table 1). Bihar, Assam, U, Jharkhand, and Rajasthan are five of seven States with the lowest rate of Urbanization in India. Gujrat stands out in this group with a relatively high urbanization.

Haryana, Tamil Nadu, Karnataka, Andhra, Maharashtra, Kerala, and Delhi were the worst performers in terms of per capita covid cases (table 1). Delhi, Tamil Nadu, Kerala, Maharashtra, and Karnataka are five of the seven most urbanized States in the country. Andhra stands out in this group as a State with relatively low urbanization. There is a high correlation of 0.78 between the per capita cases during the first wave and the degree of urbanization. This is consistent with the results found in Virmani (2020) for cross country variation in urbanization and covid cases.

The relative performance of States is ordered from best to worst in terms of cases per 1000 of population and plotted in Figure 6 with the best performer UP (2.5 cases/1000) on the left side of the x axis and the worst performer Delhi (34 cases per 1000) on the right side. The 2nd worst performer is Odisha (24). The average for India is 8 corona virus cases per 1000 of population (table 1 & figure 6). Figure 6 also depicts the growth rate of cases for each state, on the date on which the State reached its lowest point. Kerala, Maharashtra, and Madhya Pradesh had the highest growth rate of cases at the trough of the first wave, Uttarakhand was the best.

Figure 6: Comparative performance of States in flattening curve of cases (first wave)



3. Second Wave

Small samples of corona virus from Maharashtra and Punjab have been tested for DNA to determine whether new variants of the original virus have started spreading. These show that the proportion of the B1.167 version of the corona virus has increased in Maharashtra over a few months. Vidarbha region of Maharashtra as also been identified as the area where the B1.167 variant was first found.[3] A similar increase in the B1.17 variant of the virus has been found in Punjab. Given that that all States have the same pattern of decline in cases, followed by the start of a second explosive growth of cases of corona virus infection, we hypothesis that the second wave has been caused by the arrival of new mutations in India. It may be recalled that the trough was reached in 19 out of 21 States in February, before vaccination of over 60-year-old, and 45–60-year-old with co-morbidities, started on March 1st, 2021.

[3] Amitabh Sinha, "Explained: Variants and The Covid-19 surge, The Indian Express, May 8, 2021 (https://t.co/Oau9YNNiih).

To see whether the data is consistent with this hypothesis, we create a hypothetical series of cases infected by the mutated virus variants. This is based on two assumptions. One, that the original form of the virus continues to spread at the rate observed at the low point (see appendix figure A1 for justification). Two, that any additional cases are due to the mutated virus whose pattern of spread is distinct from that of the original virus. An S-curve is then fitted to the cases calculated to be infected by the variants/mutated viruses. The parameters of the new S curve are then used to project the mutated cases forward. The two series are subsequently added back together to get projections for the total cases (original + mutated). The estimated parameters are in appendix table A2, and per capita estimates given in table 2.

The States can be classified into early, middle & late take-offs categories, depending on the month of the case explosion or second wave breakout. Maharashtra, J&K and Chhattisgarh were the first three States in which take off of cases is observed, after first wave was under control (col1, table 2). Tamil Nadu and Karnataka in 4th week. Gujrat, Madhya Pradesh Delhi and Rajasthan, epidemic exploded in March, while that of UP, Bihar, west Bengal and Kerala cases took off in April (col 1, table 2).

Maharashtra, Punjab, and Chhattisgarh were the first three States to reach their estimated inflection points on April 13th, April 17^{th,} and April 19th respectively (col 3, table 2). Given that DNA tests have shown that the double mutated virus spread rapidly in Maharashtra, it is further hypothesized that it is a major source of the second wave in India. Chhattisgarh has been identified by the Chief Labour commissioner as having the largest number (10.85) of migrant workers out of a total of 26.17 identified, i.e., 41% of total. Many of them work in Maharashtra industrial belt and in April, the Chhattisgarh govt identified Rajnandgaon district bordering Vidarbha region of Maharashtra, which has a large "migratory population there and people keep going and coming. Several families have temporary homes in Nagpur (Maharashtra), and they work there" "around Holi people suddenly came back to villages in Rajnandgaon, which is why we saw a huge spike in April" after being under control in March.[4]

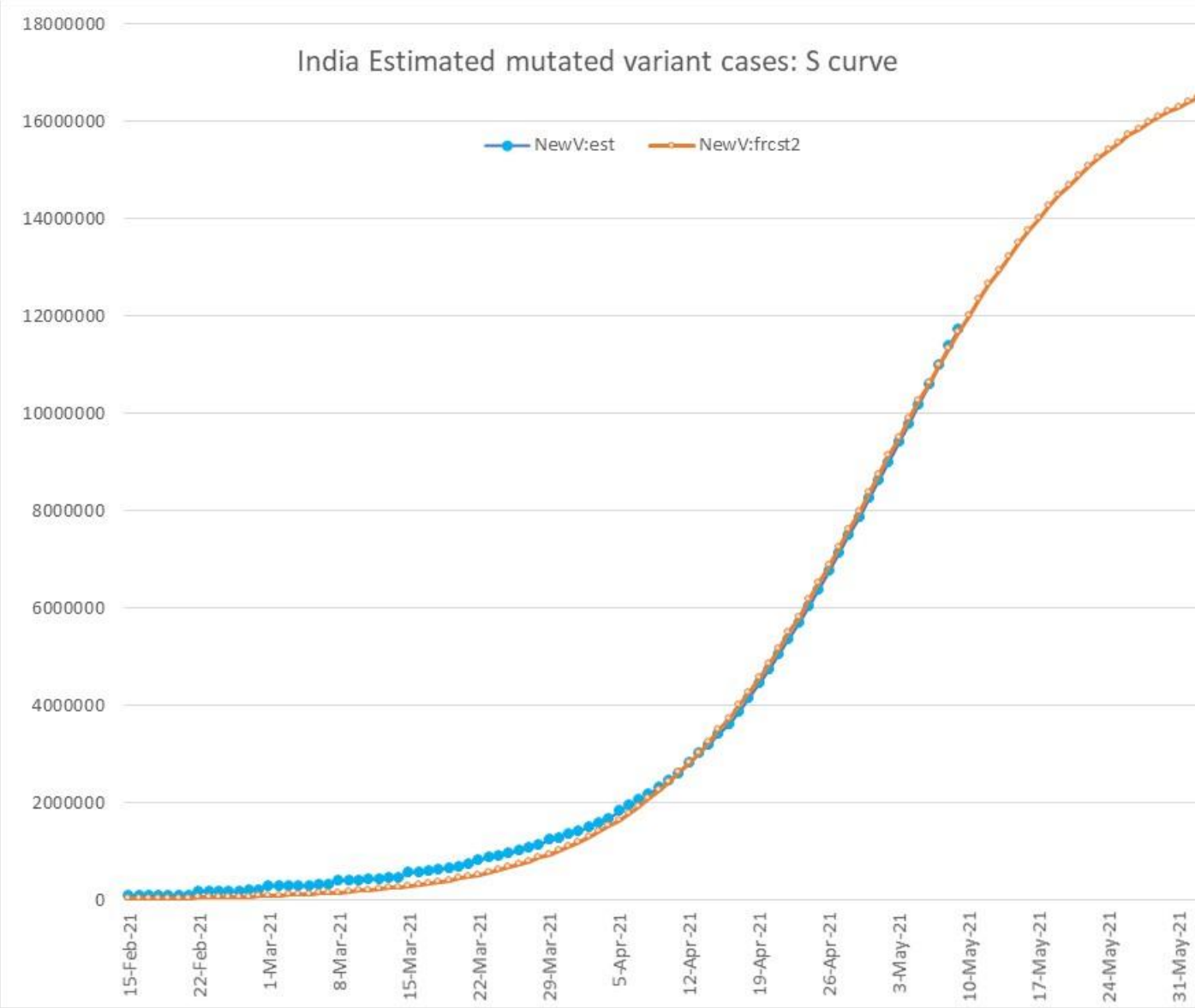
Given that DNA tests have indicated the rapid spread of the UK variant in Punjab and Punjabis are the largest Indian community in the UK with family ties to Punjabis in the three States of Punjab, Haryana, and Delhi. It is hypothesized that Punjab-Haryana-Delhi is a potential source of the UK variant of COVID. Other States could also be the source of fast

[4] The Print's Sravasti Dasgupta quotes CM Baghel of Chhattisgarh, in a report dated 22 April 2021 (https://t.co/KyooTBBLR9).

spreading mutations, but we do not have any intertemporal DNA tests to identify these mutations and their spread. An Andhra variant has been identified, but there is no indication that it spread fast, even in Andhra Pradesh.

Figure 7 shows the graph of all India S curve fitted to the assumed estimate of the cases infected by the mutated virus. The 20 States investigated have remarkably similar graphs. The estimated parameters are presented in appendix table A2. These parameters are used to derive the cases per thousand shown Columns 4 & 5 of table 2; Col 4 is based on asymptotic (max)cases given by parameter A, for the spread of the mutated virus. Column 5 gives the rank based on col 4 and this can be used to judge the relative performance of the States with respect to the second wave. The States least infected by the second wave are Bihar, Karnataka, Uttar Pradesh.

Figure 7: India's S-curve of spread of mutated virus cases.



New V (est) = Total cases – Cases estimated on assumption that the original virus continues to grow at the rate prevailing at the trough. New V frcst is the forecast made based on the S curve fitted to "New V (est)"; R square of fitted curve with 3 parameters is 0.9965.

The most accurate predictions can be made for the States in which there is most data. For India as a whole, the fitted model predicts confirmed cases to peak at 23.2 million in first half of June, with 5 mi in Maharashtra, >1.6 mi in Tamil Nadu, 1.2 mi in Delhi and 1.5 mi in Utter Pradesh (appendix table A2).

Table 2, Col 6 gives the total (original + mutated) cases per thousand population projected for May 31, and col 7 gives the average daily cases projected by our model for month of June. Col 8 gives the actual daily cases on June 9th for comparison. The worst performing states are Delhi (47 cases/thousand), whose mutation explosion started in March, Kerala (33

cases/1000), whose explosive growth of mutations started in April, and Maharashtra (33 cases/1000), which exploded in February. Other badly affected States are Chhattisgarh (26/1000) and Karnataka (24/1000).

Table 2: Second wave of Covid -Mutations

	Mutation take-off		Mutated cases per 1000 pop(prj)			Total cases/1000 (frcst)		Actual	Urban
State	Date	Cases/th	Inflection date	A(max)	rank	31-May-21	June avg	9-May	(%)
	1	2	3	4	5	6	7	8	
Maharashtra	12-Feb-21	17	13-Apr-21	33	20	50	5,177	48,401	0.45
J&K	13-Feb-21	10	5-May-21	18	13	25	927	5,190	0.26
Chhattisgarh	15-Feb-21	12	19-Apr-21	26	18	37	368	9,120	0.23
India	16-Feb-21	8	24-Apr-21	13		20	35,877	366,455	0.35
Tamil Nadu	24-Feb-21	12	4-May-21	13	11	24	2,364	28,897	0.48
Karnataka	25-Feb-21	15	27-Apr-21	24	17	39	1,495	47,930	0.39
Gujarat	4-Mar-21	4	22-Apr-21	9	10	13	486	11,084	0.43
Punjab	#	6	17-Apr-21	19	14	21	3,254	8,436	0.37
Haryana	14-Mar-21	11	23-Apr-21	21	16	31	795	13,548	0.35
Madhya Pradesh	14-Mar-21	4	20-Apr-21	7	7	11	546	11,051	0.28
Jharkhand	18-Mar-21	4	27-Apr-21	7	5	10	133	4,169	0.24
Telengana	24-Mar-21	9	30-Apr-21	8	8	16	285	4,976	0.39
Delhi	25-Mar-21	39	20-Apr-21	47	21	85	163	13,336	0.98
Rajesthan	25-Mar-21	5	27-Apr-21	8	9	13	323	17,921	0.25
Oddisha	28-Mar-21	8	3-May-21	7	6	15	267	10,635	0.17
Uttar Pradesh	4-Apr-21	6	24-Apr-21	6	3	9	369	23,175	0.22
Andhra Pradesh	6-Apr-21	18	7-May-21	15	12	32	1,336	22,164	0.29
West Bengal	6-Apr-21	7	1-May-21	6	4	12	351	19,441	0.32
Bihar	6-Apr-21	3	26-Apr-21	4	1	7	5	11,259	0.11
Assam	11-Apr-21	7	7-May-21	5	2	12	279	3,299	0.14
Kerala	18-Apr-21	37	1-May-21	33	19	65	841	35,801	0.48
Uttarkhand	21-Apr-21	13	6-May-21	21	15	30	151	5,890	0.30

Note: Mutation Take-off date is defined as the date on which actual cases exceed, the cases predicted by the S curve model of the first wave. There are 3 exceptions, Maharashtra, Chhattisgarh, and Tamil Nadu, in which the cross over point occurs before the trough. In these three cases the date is taken as the day after the trough.
= For Punjab strict application of the S curve gives a date of 2nd February, but the take-off seems to have occurred in first week of March (figure 10). So, we use the latter date for analysis.

The severity of a virus, across countries, States, or epidemics, is defined as the total cases per capita at the end of the epidemic. In the middle of an epidemic, we have to project the final tally with a model. States with the lowest severity of the mutated variants, as projected by the dual S curve model, are Bihar (4 cases/1000), Assam (5/1000), Uttar Pradesh (6/1000) and West Bengal (6/1000). There is much greater uncertainty about the estimate of the late take-off States like Kerala, Assam, Bihar, West Bengal, and Uttar Pradesh, given the fewer

data points. Jharkhand, Odisha, Madhya Pradesh, and Telangana are projected to have lower severity of variants, among the States (col 4, 5, table 2).

3.1 Urbanization

There is a high correlation between the degree of urbanization of a State and the per capita cases given in columns 6, 4 and 2 of table, with a correlation coefficient of 0.8, 0.77 and 0.76, respectively. This suggests urban areas are more susceptible to the spread of COVID in India, as shown by Virmani (2020) on a cross country basis. Rural work and social interaction take place in more open and ventilated space, while urban spaces are more likely to have a higher density of people, with more activity indoors and more meetings in closed air-conditioned spaces with less than the highest quality of filters.

Gujrat and Tamil Nadu show much lower severity than suggested by their degree of urbanization. This is consistent with either a laxity in confirmation of cases or greater compliance to safety procedures by the public and/or more effective TTQ and better enforcement of distancing requirements, indoors. The last could also be achieved by well targeted closure of contact services which result in large indoor crowds. On the other hand, Chhattisgarh (and perhaps Uttarakhand and J&K), shows higher severity for the variants, than suggested by its degree of urbanization, which may be linked to weaker compliance with COVID safety protocols.

3.2 Projections: May, June 2021

Column 7, table 2 gives average daily additions to total cases during June 2021, projected by the dual S curve model. At the all-India level, new cases will decline to an estimated average of over 35,000 per day, with the highest contributions of over 5000 per day from Maharashtra, over 3,000 from Punjab, over 2000 from Tamil Nadu, followed by Karnataka & Andhra between 1300 & 1500 each. This compares with their respective new cases on May 9, 2021 of 3.66 lakh for India, 48 thousand in Maharashtra, over 8 thousand in Punjab, and 28.8 thousand in Tamil Nadu (col 8, table 2). The lowest addition is projected to be in Bihar, followed by Jharkhand, Uttarakhand, and Delhi at less than 200 each. many states below 500 (col 7, table 2).

Figure 8 shows the graph of the spread of the mutated virus, for Maharashtra, indicating that the number of cases in Maharashtra is likely to plateau out in next two weeks. [5] Figure 9 shows the corresponding graph for Punjab. All the other States shown in Table 2, have a similar evolution of new cases and the S curve for new cases.

Figure 8: Maharashtra's S-curve of spread of mutated cases.

(at end of paper)

Figure 9: Punjab's S-curve of spread of mutated cases.

(at end of paper)

3.3 Weather

Virmani (2020) had assumed that, like the common cold (flu), the spread of the virus would be facilitated by cold dry weather and found a negative effect of average country temperature on speed of spread of corona virus infection. We are now hypothesizing a behavioural channel, in which the change of weather from mild-moderate to hot, will drive people from outdoors to indoors, where the closed environment facilitates transmission and increases contagion. A similar effect will occur when the weather changes from mild-moderate to cold, driving public indoors to heated homes and malls.

The all-India average monthly maximum temperature during March 2021 with 32.65 degrees Celsius is the warmest in the last 11 years, and third warmest in the last 121 years with 2010 and 2004 as the ever warmest and second warmest month with 33.09 degrees Celsius and 32.82 degrees Celsius, respectively," the IMD said. [6] This meant a shift of outdoor activities to poorly ventilated indoors, greater use of air-conditioning, with poor filters for eliminating viruses from recirculated air, increasing the probability of faster spread of virus, even with COVID safety precautions unchanged. Precautions like masking and distancing are more critical indoors. This could have speeded up the spread of new mutated virus.

[5] Maharashtra is one of three States in which the Dual S curve model, produces anomalous results, with second wave breakout occurring before the trough of growth rate of cases is reached.

[6] Reference, Live Mint at https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwiRvbqyn8fwAhX9yzgGHfRJBVUQFjABegQIBRAD&url=https%3A%2F%2Fwww.livemint.com%2Fnews%2Findia%2Fmarch-third-warmest-in-121-years-as-per-monthly-average-temperature-imd-11617628409310.html&usg=AOvVaw0Q1hKuf6xPFcil7Nq4hxqS

4. Google mobility during second wave

4.1 Origin: Maharashtra & Punjab

Mobility and social interaction are commonly considered to be significant determining factors in the propagation of aerosol borne viruses like the SARS Corona Virus 2. There were reports of covid protocols relating to masking and distancing being ignored at marriages and other parties in late 2020 and early 2021. To the extent that Indian marriages and related parties, as well as birthday, anniversaries, and other celebrations, are usually held in gardens and parks during the winter period, google mobility index of Parks can serve as an index of such activities and help explore role of marriages & parties in the second wave. Table 3 shows that park related mobility increased sharply in December, but then remained steady during January-March 2021. It fell sharply in April, possible because the weather turned too hot for outdoor functions. The google mobility data relating to recreation and shopping was virtually flat in November 2020 to January 21 after rising steadily during August-October (table 3).

Table 3: Monthly average of google mobility index for India.

	CVC grrt	Retail & recreation	Parks	Transit stations	Work places	Resid ential	Grocery, pharmacy
	1	2	3	4	5	6	7
Aug-20	20%	-52	-52	-38	-29	13	-11
Sep-20	15%	-42	-45	-30	-24	13	-5
Oct-20	8%	-34	-42	-21	-24	12	7
Nov-20	2%	-28	-34	-18	-24	10	10
Dec-20	1%	-27	-17	-11	-18	11	10
Jan-21	1%	-28	-13	-13	-17	10	7
Feb-21	0%	-23	-13	-7	-15	7	16
Mar-21	1%	-22	-12	-7	-14	9	19
Apr-21	10%	-38	-26	-24	-29	16	6
9 feb to 9 apr	1%	-22	-12	-7	-15	8	18

The rate of growth of cases, however decelerated sharply during Aug-Oct 2020 and then more gradually during November 2020 to February 2021, before taking off 16 February (table 3). During the period 9 February to 9 April (growth trough) when the mobility index for retail & recreation was only -22 below the pre-pandemic base of 100, the rate of growth of cases averaged a low of 2% (table 3). The correlation between per capita cases and all six mobility indicators is of the order of -0.05. Mobility data does not therefore provide a direct explanation of the explosive second wave.

Increased mobility in February-March seems to have contributed to the propagation of the second wave in Punjab after the mutated variant (B1.17) arrived by January. The mobility was higher in retail and recreation, parks, and transit stations. Mobility was also higher in Haryana in March table 4). In Haryana retail & recreation mobility is up significantly in February-March and park mobility higher in March. Transit station mobility also rose in thee two months after a fall in January (table 4).

Table 4: Mobility in Punjab, Haryana, and Uttarakhand

	Punjab(early 2nd wave)				Harayana (miidle)				Uttarakhand (kumbh)			
	CVC grrt	Retail & recreatn	Parks	Transit stations	CVC grrt	Retail & recreatn	Parks	Transit stations	CVC grrt	Retail & recreatn	Parks	Transit stations
Aug-20	26%	-46	-62	-39	15%	-41	-70	-40	25%	-38	-41	-28
Sep-20	32%	-43	-60	-39	15%	-34	-64	-35	15%	-30	-36	-24
Oct-20	15%	-38	-53	-37	8%	-25	-57	-27	8%	-15	-21	-4
Nov-20	8%	-26	-46	-29	2%	-20	-52	-25	2%	-8	-15	2
Dec-20	2%	-21	-42	-28	1%	-23	-35	-22	1%	-13	-1	7
Jan-21	1%	-27	-26	-27	1%	-27	-35	-27	1%	-15	-4	1
Feb-21	0%	-23	-19	-22	0%	-22	-27	-19	0%	-9	-7	11
Mar-21	1%	-22	-15	-21	1%	-18	-20	-16	1%	-4	3	23
Apr-21	10%	-28	-22	-27	11%	-26	-27	-25	12%	-20	-16	2

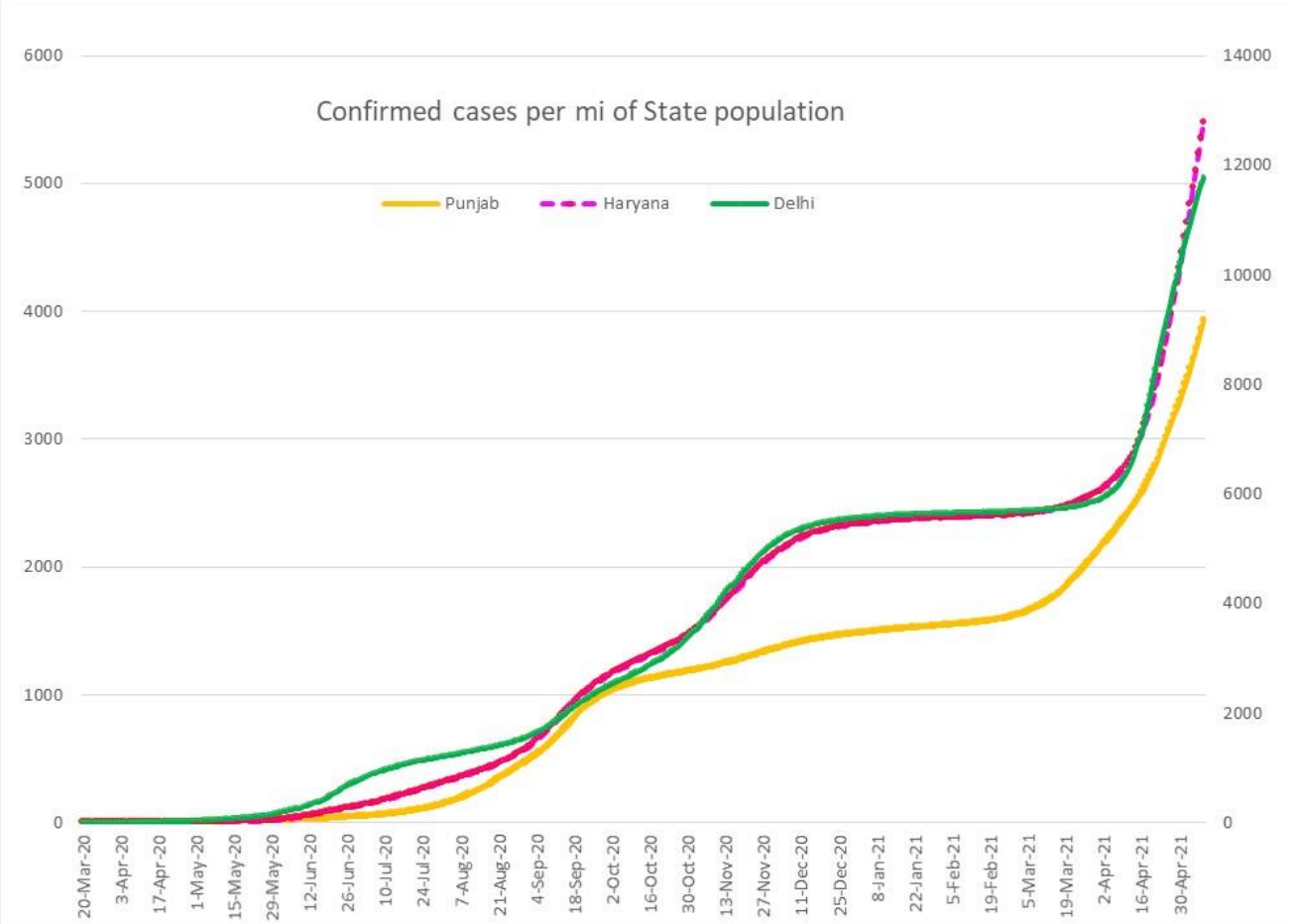
The UK variant (B1.17) is hypothesized to have arrived in Punjab during early March and in Haryana and Delhi during late March. Punjabis are the largest Indian community in the UK with close family links to Punjab, Haryana, and Delhi. IGIDR is also the airport through which travel to and from UK takes place. Opening of foreign travel may have facilitated return migration from Europe, UK, and USA. This normally happens during the Christmas holidays in these countries and extends to the marriage season in January-February and traditional festivals in March-April.[7] Two-way travel could have played a role in the import of the UK mutation of the virus to India.

Figure 10 shows that the rate of growth of cases accelerated during August-September in Punjab and Haryana. They continued at the accelerated pace in Haryana, followed by an acceleration in Delhi, but growth rate of cases slowed considerably during October-February. Punjab re-accelerated in March followed by a much sharper and unprecedented acceleration in Haryana and Delhi reflective of the arrival of faster spreading mutations. The pattern of spread in Haryana and Delhi, from September onwards, is identical, and suggests a

[7] Festival season in this region ends with Baisakhi on April 13.

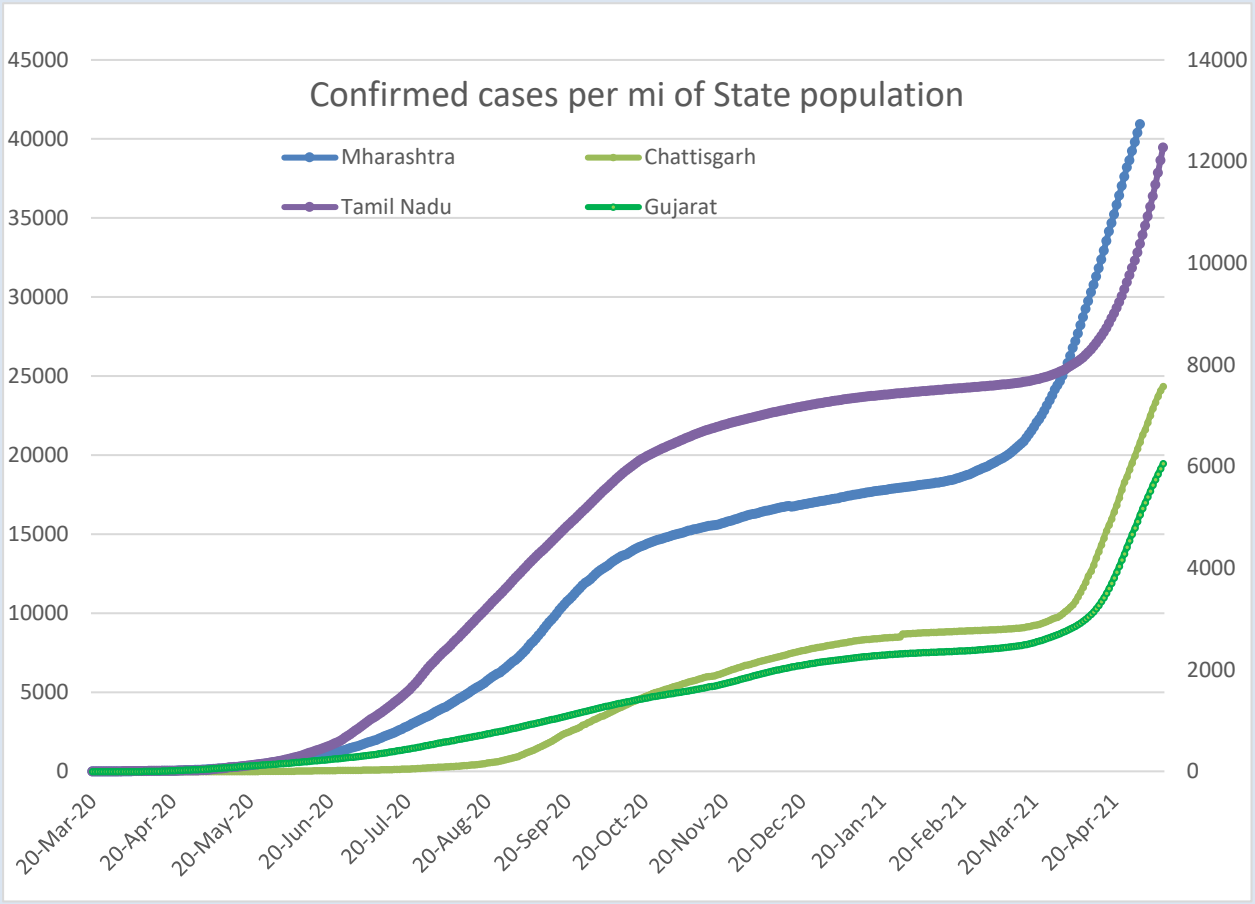
simultaneous arrival of mutated variants and their spread in the NCR regions of Haryana (Gurgaon & Faridabad).

Figure 10: Spread of new mutations from Punjab to Haryana and Delhi.



In Maharashtra, the evidence is the opposite with reduced mobility during March in these three categories, while mobility in February was lower than in January for two indicators and higher in one (transit stations) was lower in (table 4). The last suggests increased migration of workers out of Maharashtra into other States such as Chhattisgarh. The mobility data shows increased mobility during December-March in Parks, during February-March in transit stations and during March in retail and recreation. These are consistent with the explanation, that the new variant of the virus spread from Vidarbha, Maharashtra to Rajnandgaon, Chhattisgarh, through migrants living/working in Nagpur and other cities, and then spread rapidly within Chhattisgarh, through increased social functions in parks, recreation activities and shopping. Figure 11 clears show that the spread of the corona virus in Chhattisgarh reflects that in, and follows that of, Maharashtra.

Figure 11: Spread of Mutations from Maharashtra to Chhattisgarh



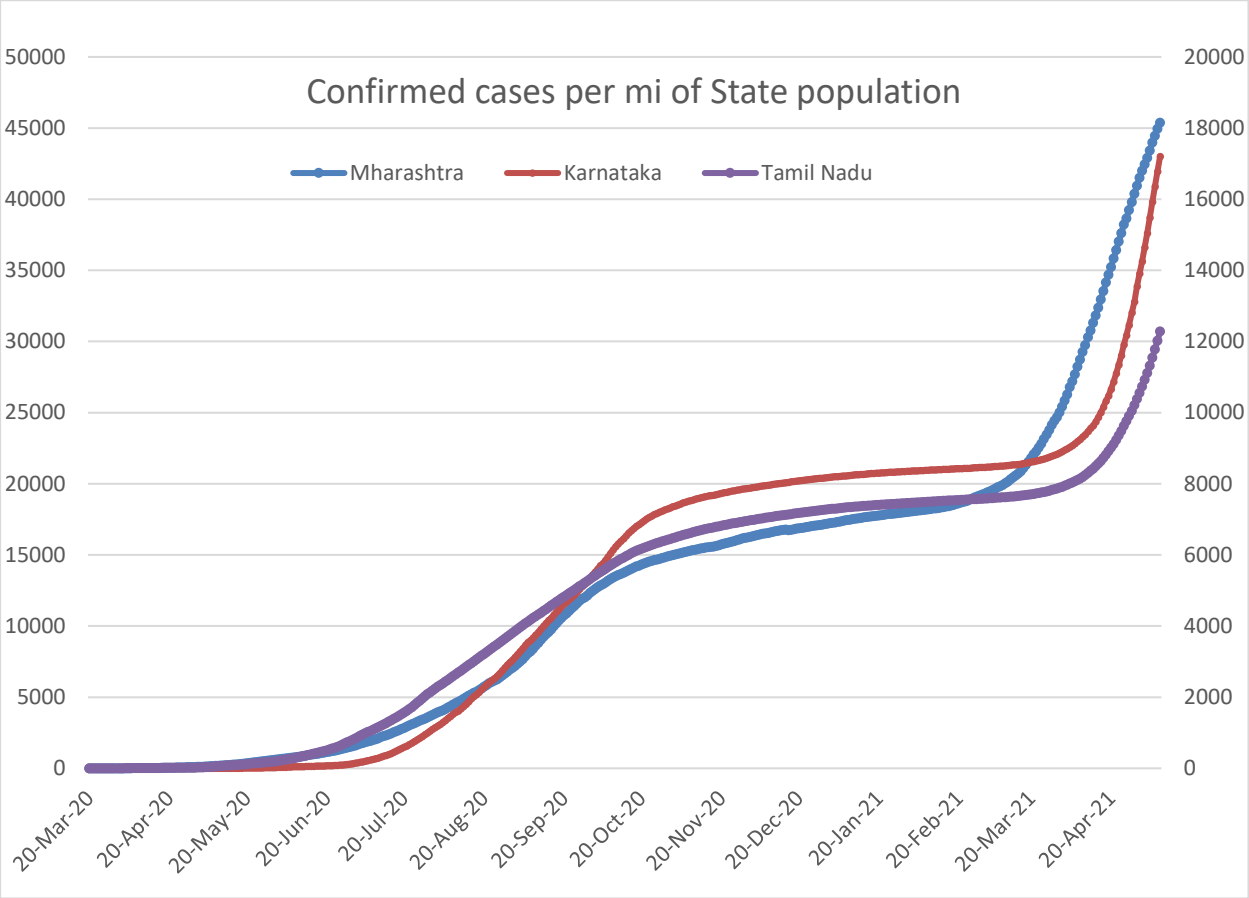
The other early second wave States are Karnataka and Tamil Nadu with second wave take off in end-February. The take-off of cases in Karnataka reflects and follows that in Maharashtra (figure 12). As Karnataka borders Maharashtra, one possibility is direct cross-border transmission of the double mutation. The other possibility is direct arrival of virus Mutation into Bangalore, which is an international centre for info tech. The fact that park linked mobility was higher during January-March, and Transit station mobility was higher during February-March (table 5), is consistent with the hypothesis of arrival of mutations from Maharashtra and travellers from UK and its internal spread facilitated by increased wedding & other parties in parks, gardens, increased travel, and tourism & a slow but steady increase in recreation & retail activity (table 5).

Table 5: Mobility in Early Second Wave States

	Maharashtra				Chattisgarh				Karnataka				Gujarat (middle)			
	CVC grrt	Retail & recreatn	Parks	Transit stations	CVC grrt	Retail & recreatn	Parks	Transit stations	CVC grrt	Retail & recreatn	Parks	Transit stations	CVC grrt	Retail & recreatn	Parks	Transit stations
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Nov-20	2%	-35	-42	-24	2%	-25	-39	-21	2%	-35	-44	-18	2%	-31	-40	-15
Dec-20	1%	-33	-28	-18	1%	-24	-10	-11	1%	-32	-27	-11	1%	-34	-36	-14
Jan-21	1%	-33	-22	-16	1%	-23	0	-14	1%	-31	-23	-11	1%	-32	-29	-13
Feb-21	0%	-30	-22	-11	0%	-20	-3	-8	0%	-27	-22	-7	0%	-26	-27	-7
Mar-21	1%	-35	-26	-16	1%	-19	1	-6	1%	-25	-19	-7	1%	-27	-28	-8
Apr-21	12%	-62	-49	-44	18%	-61	-43	-50	9%	-40	-32	-24	14%	-46	-47	-29

We hypothesize that Covid variant B1.167 was also carried by Maharashtra residents who went to Tamil Nadu for campaigning and the increased mobility at transit stations is indicative of this travel (table 6). The same variant also spread to Gujrat given the close personal and business ties and the usual travel between the two (figure 12). The increase in Transit station mobility in February-March 2021 is consistent with this hypothesis of slower spread (table 5). Madhya Pradesh is another State to which the mutated virus could have spread from Maharashtra, and whose pattern of spread is identical to that in Gujrat (figure 12).

Figure 12: Spread of mutations from Maharashtra to Karnataka and Tamil Nadu



4.2 Super Spreader Events

Several events have been mentioned as super spreader events responsible for the second wave in India. These include the farmers' agitation on the out skirts of Delhi, the election rallies in five States which went to the polls in April and the Kumbh Mela in April. It is especially important to distinguish between events which were responsible for the explosive take off of Covid cases and those which may have contributed to the faster spread of corona virus cases, during the event.

The farmers rally started in the second week of August and continued till Republic Day in end-January. Business Standard reported that of the four organizers of the protests and rallies in and around Delhi, one was high tech NRI/PIO two were CPM organizers from Kerala and one was a well-known leader of the Shiromani Akali Dal. As the agitation was around Delhi and media management was an important job of the social media savvy NRI/PIO, the base for these organizers was likely Delhi.

Park mobility in Punjab rose steadily from August 2020 to March 2021. During most of this period, however, the rate of growth of cases in Punjab continued to decline and remained low till mid-February. So there does not appear to be any direct link with the accelerated growth of cases in Punjab, after mid-February 2021. However, as the mutated virus arrived in February and the Parks related mobility data shows a significant increase in mobility in February to -19, from -26 in January (table 5). The increased movement of people in marriages and festivals could have facilitated its spread in February and March.[8] Increased retail and recreation movement during February-March in Haryana could also be associated with marriages and festivals. Further as Haryana is the transit route from Punjab to Delhi, this data is consistent with spread of mutations among the three States during late February & early March.

The Tamil Nadu Election was scheduled for April 6th, but the electioneering started at least a month before the election. Google mobility data shows an increase in mobility during Jan-Mar 2021 from its level in December 2020, in parks and transit stations and in retail and recreation in March 2020 (table 6). The rate of growth of cases declined in February but rose in March. This data is consistent with the hypothesis that election campaigners from Maharashtra brought the B.1.167 variant to Tamil Nadu during February, and the election campaigning in March helped spread it directly to the public.[9]

In Kerala, where the election was on the same day, mobility in parks rose sharply in November and further in December. It was steady in January but rose again in February. There was no further increase in the electioneering month of March (table 6). The growth rate of cases was declining throughout February and till 18 March but rose slowly but steadily thereafter. The explosive spread of the virus is dated from 18th April, two weeks after the election. Only if the mutated virus arrived in late March, could it have contributed to the spread of the virus (table 6).

In Assam, the elections were from 27-29 April, and google mobility data shows a jump in parks mobility in Dec-Jan and a decline in Feb-March and even further in April (table 6). The growth rate of cases reached a trough on 16th February (table 1) and increased slowly and steadily thereafter till 6 April. It then exploded and burst through the projected rate within a

[8] It has been speculated that PIOs and or NRIs from UK could have brought the UK variant of virus back to their home villages, during Winter months (November-February), which is the usual season for holiday visits to India.

[9] The picture is however somewhat confusing because Tamil Nadu is one of three States in which breakout of second wave, occurred in February, while the rate of growth of cases was still trending down 5 weeks before the election.

week. The arrival of mutations from outside the State and its subsequent spread is consistent with the data.

Table 6: Mobility in Election States

	Tamil Nadu (early)				Kerala (late)				Assam (late)				West Bengal (late)			
	CVC grrt	Retail & recreatn	Parks	Transit stations	CVC grrt	Retail & recreatn	Parks	Transit stations	CVC grrt	Retail & recreatn	Parks	Transit stations	CVC grrt	Retail & recreatn	Parks	Transit stations
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Nov-20	2%	-31	-30	-17	2%	-36	-11	-24	2%	-19	-12	-13	2%	-29	-28	-22
Dec-20	1%	-29	-14	-10	1%	-29	8	-12	1%	-19	7	-2	1%	-27	-12	-11
Jan-21	1%	-25	-4	-8	1%	-25	9	-14	1%	-20	12	-6	1%	-27	-7	-11
Feb-21	0%	-20	-7	-3	0%	-21	1	-14	0%	-15	0	-1	0%	-24	-8	-6
Mar-21	1%	-17	-4	-2	1%	-14	2	-10	1%	-15	1	-2	1%	-23	-9	-4
Apr-21	6%	-24	-14	-12	7%	-23	-5	-18	3%	-19	-5	-9	7%	-27	-15	-11

In West Bengal, the five-phase election was strung out over a month from 27th March to 29th April, with campaign dragging out over two months. Park mobility increased in December 2020, and marginally in January 2021, and remained unchanged till March (table 6). It than dropped significantly in April 2021. The rate of growth of cases reached a trough on 18 February (table 1) and accelerated slowly thereafter; with breakout occurring on 6 April, few weeks before the campaigning ended. Its therefore possible that laxity in Covid prevention measures during the election campaign helped accelerate the arrival of the second wave in West Bengal. To the extent that campaign workers of National parties came from States with new mutations, they could have helped spread the faster spreading variants.

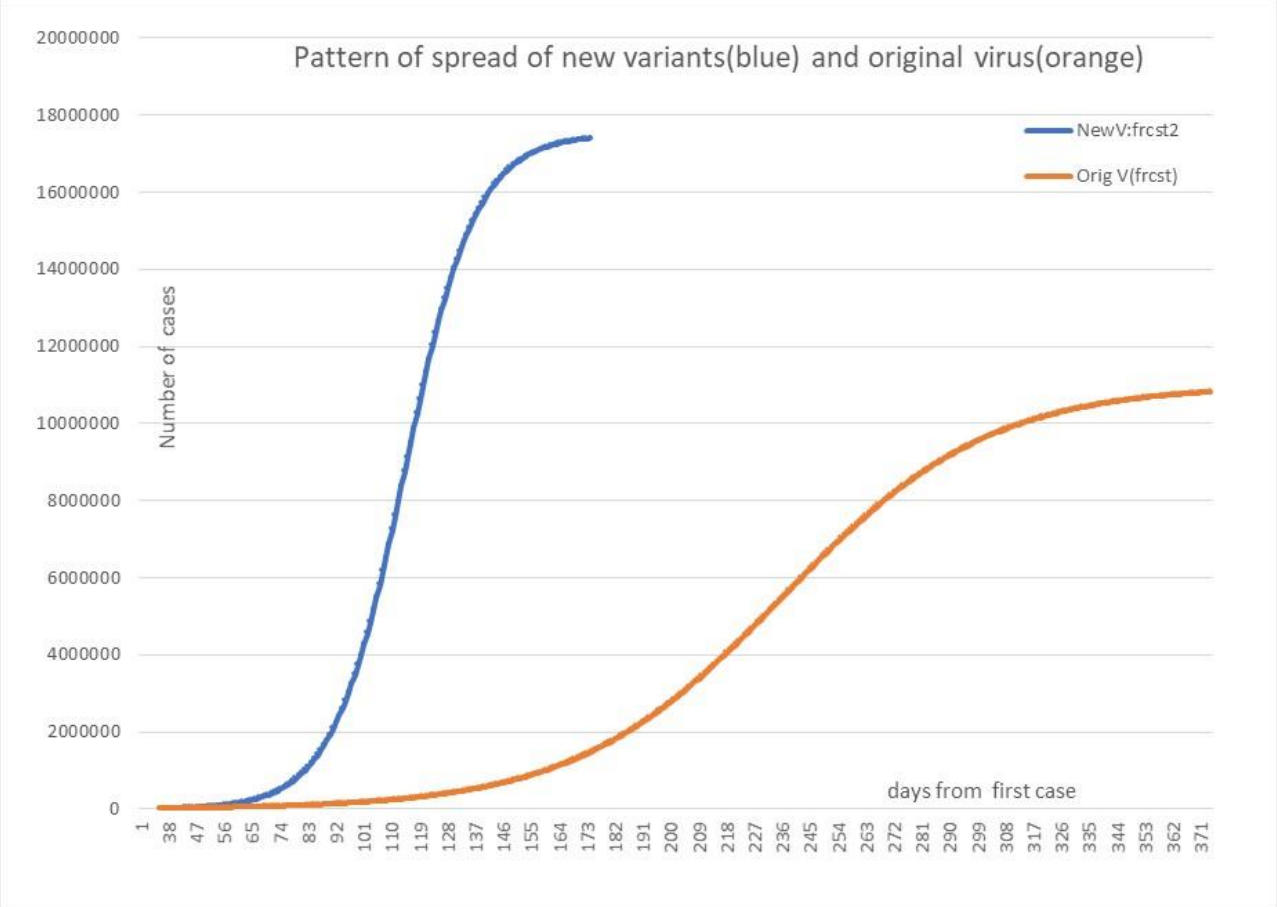
The Kumbh mela in Uttarakhand was scheduled from April 12th to April 27th. The rate of growth of cases in Uttarakhand had been accelerating steadily since 25th February and accelerated sharply in the weeks before the Kumbh Mela started. The breakout did, however, occur on April 21, 9-10 days after the Mela started. The breakout in every other State, besides Kerala occurred before the Mela started (table 5). It cannot therefore be a cause of the explosive second wave in the rest of the country.

5. Transmissibility & Severity: Variants vs Original Virus

We can use the double s-curve model to compare the mutated variants responsible for the second wave in India with those responsible for the first wave. The numbers in the column titled "days" are all negative, while those in the column titled "speed" are all positive (appendix table A3), indicating the mutations spread much faster in every State and across India. The all-India comparison is shown in figure 13, with the inflection point being reached

124 days earlier (table A3). The mutations responsible for India's second wave clearly spread much faster than the original version of the virus. This echoes what was found in earlier studies of speed of spread of the B1.17 variant of the virus. The obverse of the faster spread of the virus is the expectation that the plateau at which the curve flattens, will be reached much faster than in the original virus (figure 13). The maximum cases of the mutated variations at the end of second wave, is projected to be 6.5 mi more than the maximum for the original virus at the end of the first wave (appendix table A3).

Figure 13: India's S-curve of Old(orange) virus & New mutations(blue)



The estimated parameters of the S curve of the original virus (table A1) and the mutated variants (table A2), is used to estimate the transmissibility and severity of each and then used to compare the two. We define Transmissibility as the inverse of the number of days taken from the first case of the virus to the estimated inflection point (c), which is the day on which the rate of growth of cases moves from acceleration to deceleration. The transmissibility index for the new variants and the original version of the virus are shown in columns 2 & 3 of table 7, respectively and the ratio of the two in column 1. The severity index is defined as the

projected asymptote or maximum cases (A) per 1000 of population. This is shown in columns 5 & 6 for the variants and the original virus respectively, with the ratio in column 4 of table 7.

The relative transmissibility of the new variants is estimated to be 2.4 times that of the old (original) virus (row India, col 1, table 7), with limited variability among States (coefficient of variation is 0.3). Kerala is however an outlier with a ratio 3 standard deviation from the average of States. Kerala was the only state in which the daily rate of growth of cases(w-o-w) at the trough of the first wave was greater than 1%. The ratio for Odisha, Rajasthan, Delhi, and Chhattisgarh is also higher by around one standard deviations. On the other end Punjab and J&K have the lowest ratio, one standard deviation below the average (col 1, table 7).

Table 7: Comparison of S curve of original virus with S curve of Mutation

	Transmissability Index (1/c)			Severity index(A/1000 pop)		
	ratio	1/c(new)	1/c(old)	ratio	Anew	Aold
	1	2	3	4	5	6
Andhra Pradesh	2.1	1.2	0.6	0.8	15	18
Assam	1.8	1.2	0.7	0.8	5	7
Bihar	2.7	1.6	0.6	1.6	4	3
Chhattisgarh	2.8	1.3	0.5	2.1	26	12
Delhi	2.9	1.3	0.4	1.2	47	39
Gujarat	2.3	1.2	0.5	1.9	9	5
Haryana	2.4	1.1	0.5	1.9	21	11
J&K	1.9	1.0	0.5	1.7	18	10
Jharkhand	2.2	1.3	0.6	1.8	7	4
Karnataka	2.5	1.3	0.5	1.6	24	15
Kerala	5.6	2.0	0.4	0.9	33	39
Madhya Pradesh	2.5	1.2	0.5	2.0	7	4
Maharashtra	2.3	1.3	0.5	1.9	33	18
Oddisha	3.2	1.7	0.5	0.9	7	8
Punjab	1.8	0.9	0.5	3.1	19	6
Rajesthan	3.0	1.4	0.4	1.7	8	5
Tamil Nadu	2.2	1.3	0.6	1.1	13	11
Telengana	2.6	1.3	0.5	1.0	8	9
Uttar Pradesh	2.9	1.5	0.5	1.7	6	3
Uttarakhand	2.9	1.4	0.5	2.1	21	10
West Bengal	2.6	1.3	0.5	0.9	6	7
India	2.4	1.2	0.5	1.6	13	8
Average	2.6	1.3	0.5	1.5	16	12
Standard Dev	0.8	0.2	0.1	0.6	12	10
Coeff of Variation	0.3	0.2	0.1	0.4	0.7	0.9

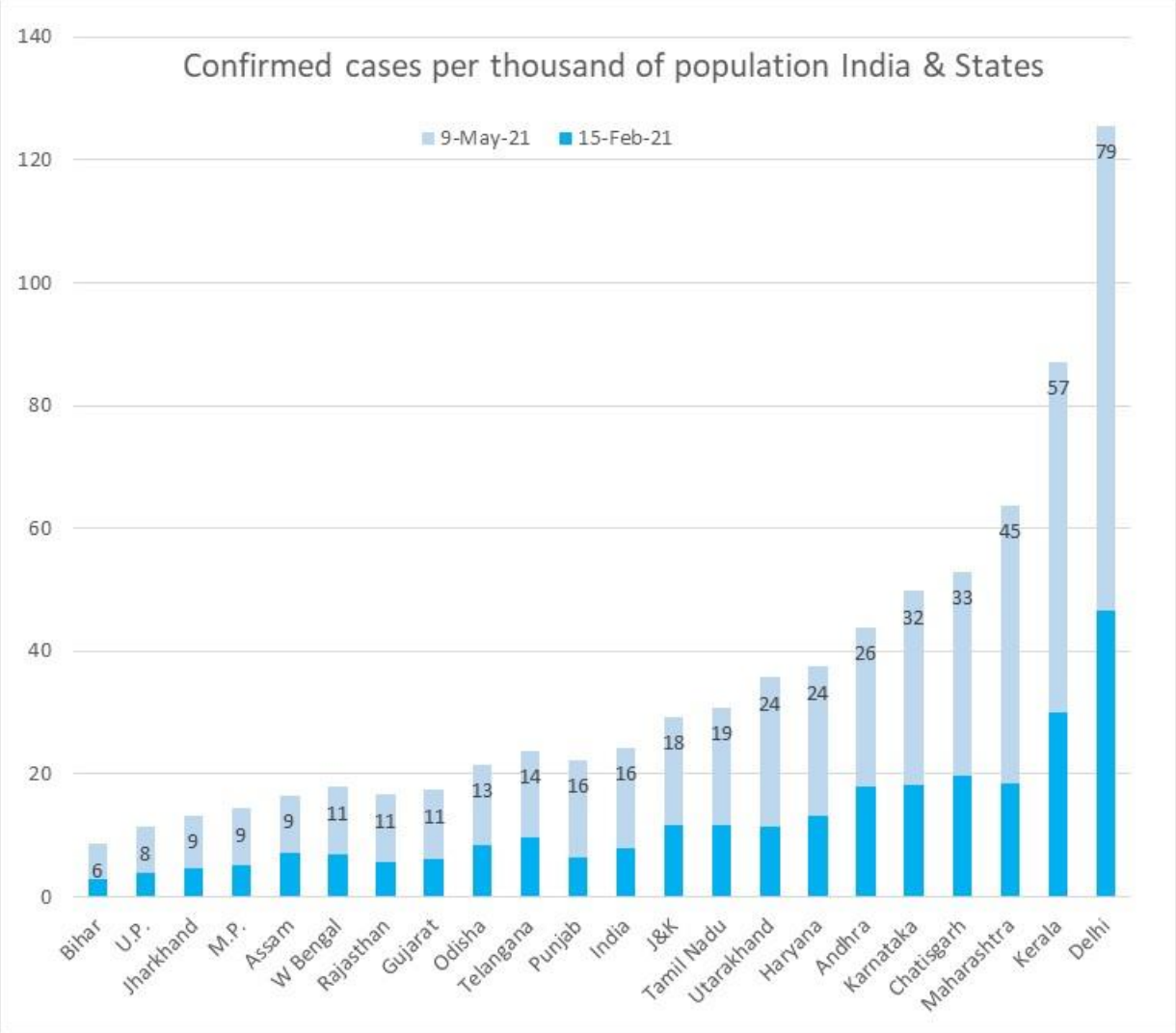
The relative severity of the mutated variations is estimated to be 1.6 times that of the old/original virus (row India, col4, table 7), with a greater variability among states (CV = 0.4)

than for transmissibility (CV=0.3). This is consistent with the hypothesis that the safety precautions taken by the public (masking) and government actions (TTQ, vaccination) affect the total number of cases (peak) as do restrictions on indoor social gatherings & operation of contact services.

Punjab is the outlier in this case with a ratio of 3.1, almost three standard deviations above the average. The severity ratio of new to old virus is also high in Chhattisgarh and Uttarakhand at 2.1, one standard deviation above the average (col 4, table 7). Assam, Andhra Pradesh, Odisha, and West Bengal show a marginally lower severity index for the new variants than the original. The election does not seem to have affected the severity in Assam or West Bengal. Given that our data ends on May 9, 2021 close to the inflection date for these States, more data could change the parameters on which this result is based.

Figure 14 compares the spread of the confirmed corona virus cases by State per 1000 of State population, with the all-India levels as benchmark. The February 15 date is taken as the point at which the first wave reached its low point. May 9 is the latest date for which the data was available when the dual S curve model was estimated. The States are ordered by number of cases per capita, with lowest on left and highest on the right. Delhi & Kerala are the worst affected states. The most noticeable change in ranking is the movement is Telangana from above the national average (10/8) to below the national average (14/16). Orissa has similarly reduced its relative per capita cases from above the national average (9/8) to below the national average (13/16). Punjab stands out as a State which has moved in the other direction from a rate (6/8) in the low quarter of States to just below the all-India average of 16(figure 14). There are other small changes in ordering between the end of the first wave and the middle of the second wave, but the correlation between the two is high at 0.98.

Figure 14: Confirmed cases per thousand of State population



6. Fatality Rates and Death Rates

Table 8 presents the Covid Fatality rates per 1000 of population (Deaths/Cases) and the Covid Death rates per million of population of each State, ordered by the former. Delhi, Punjab, Maharashtra, and Uttarakhand were the worst performers in preventing COVID deaths. Odisha, Telangana, Bihar, assam, Andhra Pradesh, Rajasthan were the best. Kerala has the lowest fatality rate but a moderate death rate. Karnataka has a high death rate mut moderate fatality rate.

Table 8: Case Fatality rates & Deaths per capita (9 May 2021)

		Per capita (/pop)			
	Fatality /th	Cases/th	Deaths/mi	Cases	Deaths
	1	2	3	4	5
Kerala	3	57	174	1902629	5815
Oddisha	4	13	54	544873	2250
Telengana	6	14	78	497361	2739
Bihar	6	6	32	591476	3282
Assam	6	9	54	292368	1676
Andhra Pradesh	7	26	176	1287603	8707
Rajesthan	7	11	83	756707	5665
Haryana	9	24	221	615897	5605
Madhya Pradesh	10	9	88	671763	6420
Karnataka	10	32	307	1934378	18776
Uttar Pradesh	10	8	77	1503490	15464
Tamil Nadu	11	19	217	1380259	15648
Gujarat	12	11	139	681012	8394
West Bengal	12	11	135	993159	12327
Chhattisgarh	12	33	414	851476	10570
J&K	13	18	222	216932	2726
Jharkhand	13	9	117	286343	3853
Delhi	15	79	1152	1323567	19344
Maharashtra	15	45	675	5101737	75849
Uttarkhand	15	24	370	244273	3728
Punjab	24	16	379	442125	10506
India	11	16	178	22662548	246148
Average	10	23	246		
Standard Dev	5	18	260		
Coeff of Variation	0.5	0.8	1.1		

The all-India fatality rate on May 9 was 10.9 per thousand. As this may underestimate the fatality rate during a big upsurge in cases, we use the higher fatality of 16.2 when active cases were at their peak on 17th September 2020, to estimate total covid fatalities at the end of May and end of June. Based on the projected total cases, this yields a total of 3.59 lakh Covid deaths by 31st May 2021 and 4.06 lakh covid deaths by 30th June 2021.

7. Conclusion

This paper shows that the sharpness and ferocity of the second wave, immediately after the first wave had subsided, can only be explained by the arrival of mutated variants like B1.167 and B1.17 whose transmissibility was significantly faster than the original Corona virus. In some States, the arrival of viral mutations from outside the State or outside the country, could have triggered the explosive spread. The dual S curve model used to model the two waves, fits the data for all the States and all-India case trajectory exceptionally well.

Even when the number of Active cases were declining significantly across every State, reports started trickling in of laxity of the public at marriage parties and other social events, followed by hints of broader increase in risky behaviour. This included the strange belief that Covid was somehow not real, but an artificial scare created by Governments. The consequent failure to follow the global lesson of masking, distancing, and care & caution in eating, drinking, and talking with family, friends, colleagues, indoors and in poorly ventilated spaces without good air filtration systems, started to be ignored. After March 1st, when vaccination of public started, there was an additional factor arising from ignorance or misunderstanding; that even the promised immunity would take a couple of months, provided the second shot was taken at the appropriate time. The early arrival in March, and the severity of summer heat, also contributed to the second wave, by driving people indoors, where the risk of contagion is far higher than outdoors. In a few States, elections campaigns & rallies, political agitations and large religious gatherings also contributed to the second wave; Even though the risks of contagion outdoors are far lower than indoors, these events are associated with crowded transport to and from the event, queues and crowding in eating establishments, toilets, and tourist accommodation, where risk of contagion is much higher.

The paper hypothesizes, that the mutations first arrived from outside the country and perhaps mutated further. Travel from these regions then help spread the variants rapidly within the State and to other States linked to it by high two-way interaction. There was likely to have been a linkage between Maharashtra (B1.167)) and Chhattisgarh, Karnataka & Tamil Nadu, and to a smaller degree with Gujrat, Madhya Pradesh, and Assam. Punjab and Haryana & Delhi seemed to form another set in which the B1.17 variant of the virus could have spread. State wise mobility data helps trace these movements. In some States, higher mobility can be linked to the spread of the mutated virus after the take-off stage but does not appear to be a causal factor in the take-off of cases. A faster spreading mutation of the SARS corona virus remains the best explanation for the second wave in India.

If the Dual S curve model is correct, the explosive spread of the mutated varieties of the SAARS Corona Virus 2, will be followed by an equally quick plateauing of the total number of cases, with new cases falling rapidly to lows seen in February 2021. Based on this model, the paper predicts that the totals confirmed Covid cases will plateau at a little over 27 million, at end-May with less than a million additional cases in the entire month of June. Estimates for 21 large States are also made (appendix table A2). A care full examination of the errors, however suggests that the model may be under estimating the final tally by about ten percent.

There are considerable inter-state differences in the date of plateauing of cases, depending on the take-off date (February, March, or April) and the projected date of inflection, i.e., change in rate of growth from rising to declining (March, April, or May). States like Maharashtra and Chhattisgarh in which the 2nd wave took-off early (February) and have reached their inflection point in April will plateau early, followed by those Delhi and Bihar.

The paper constructs indices of transmissibility and Severity and uses these to compare the mutated viruses with the original virus. Based on the index, the average transmissibility of the mutated virus is estimated to be 2.4 times that of the original version, with an inter-State coefficient of variation of 0.3. The severity of the variants causing the 2nd wave, is estimated to be 1.6 times that of the original virus, with and inter-State coefficient of variation of 0.4. One possible reason for variability is the existence of different mix of mutated variants. Other potential reasons are the measures taken by the government and private individuals in protecting themselves from the original virus and the mutated variants.

The severity of both the first wave, the estimated mutated cases, and the actual total cases in the second wave, are highly correlated with the degree of Urbanization, with rural States having lower cases than the more urbanized ones. Gujrat & Tamil Nadu on one side and Chhattisgarh & J&K on the other, are exceptions; the former does better and the latter worse, than expected by the degree of their urbanization. This may indicate either data weakness or the good/bad performance of the State government and State residents.

Based on the dual S curve model's projection of cases, and some simple estimates of case fatality rates, we estimate covid deaths of 3.59 lakhs at end May and 4.06 lakhs by June end. Compared to recorded deaths of 2.46 lakhs on 9th May 2020, this suggests 1.19 lakh more deaths in May and 47,000 more in June 2021.

India's actual second wave peak is about four times that of the first wave peak, a much higher differential than seen in UK or other countries, even though the per capita severity of Indian peak is still lower than in these countries. The pattern seen in India (not the severity) is more redolent of the relative peaks of the Spanish flu. The third wave of the Spanish flu therefore serves as a warning to us, to be prepared for a third wave, based on new mutations emerging in India or abroad, while working diligently to prevent a recurrence.

Given the danger of other new mutations emerging, we will have to follow the masking and distancing protocols and hand washing & sanitization procedures for the next 9-12 months. In addition, we need to improve the air quality in indoor public spaces. This requires a

combination of better ventilation, high quality air filters in air conditioning systems and Ultraviolet ceiling lights in small shops, restaurants, pubs, and public toilets. These measures can reduce the density of Corona virus indoors, including any new mutations and variants which arise in future, and thus reduce the probability of contagion.

In parallel, we will have to reform the Epidemic Act (1987), and reorganize & upgrade our pandemic emergency response systems, just in case the generation of a more transmissible, severe or antibody resistant mutation of the SARS Corona virus 2, sets off a third COVID wave. Govt should consider setting up dual purpose facilities, which can be used for sports, cultural, educational or community activities in normal times, secondary health facilities like quarantine centres during epidemics.

Universal Vaccination is, however, the only long-term solution, for reducing infection and deaths from Covid, given that vaccines are close to 100% effective against severe Covid infection. The eligibility condition for free vaccination at GOI vaccination centres, should be extended to all adults with "co-morbidities," at the earliest.

8. References

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9. Appendix: Figures

Figure 4: Maharashtra's S curve of confirmed cases

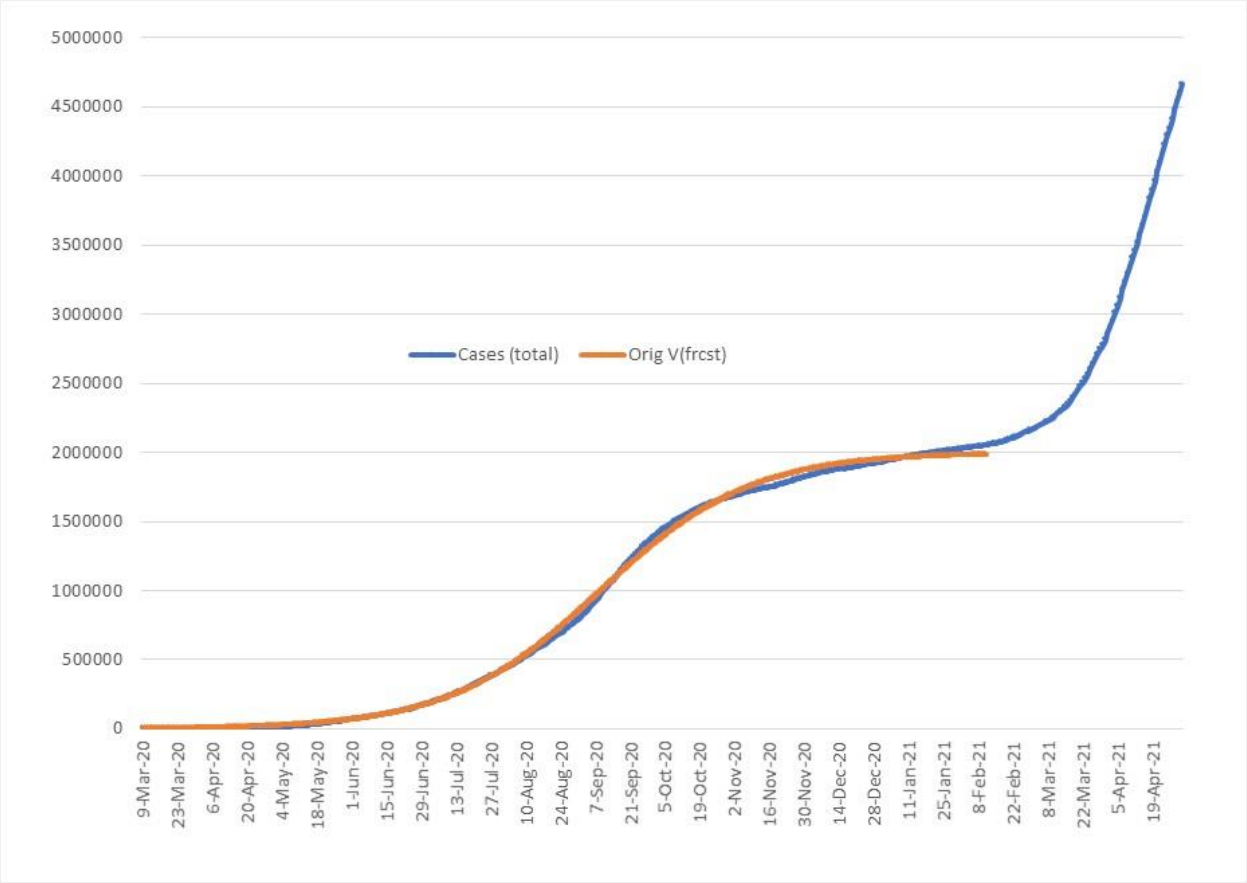


Figure 5: Kerala's S-curve of Confirmed cases

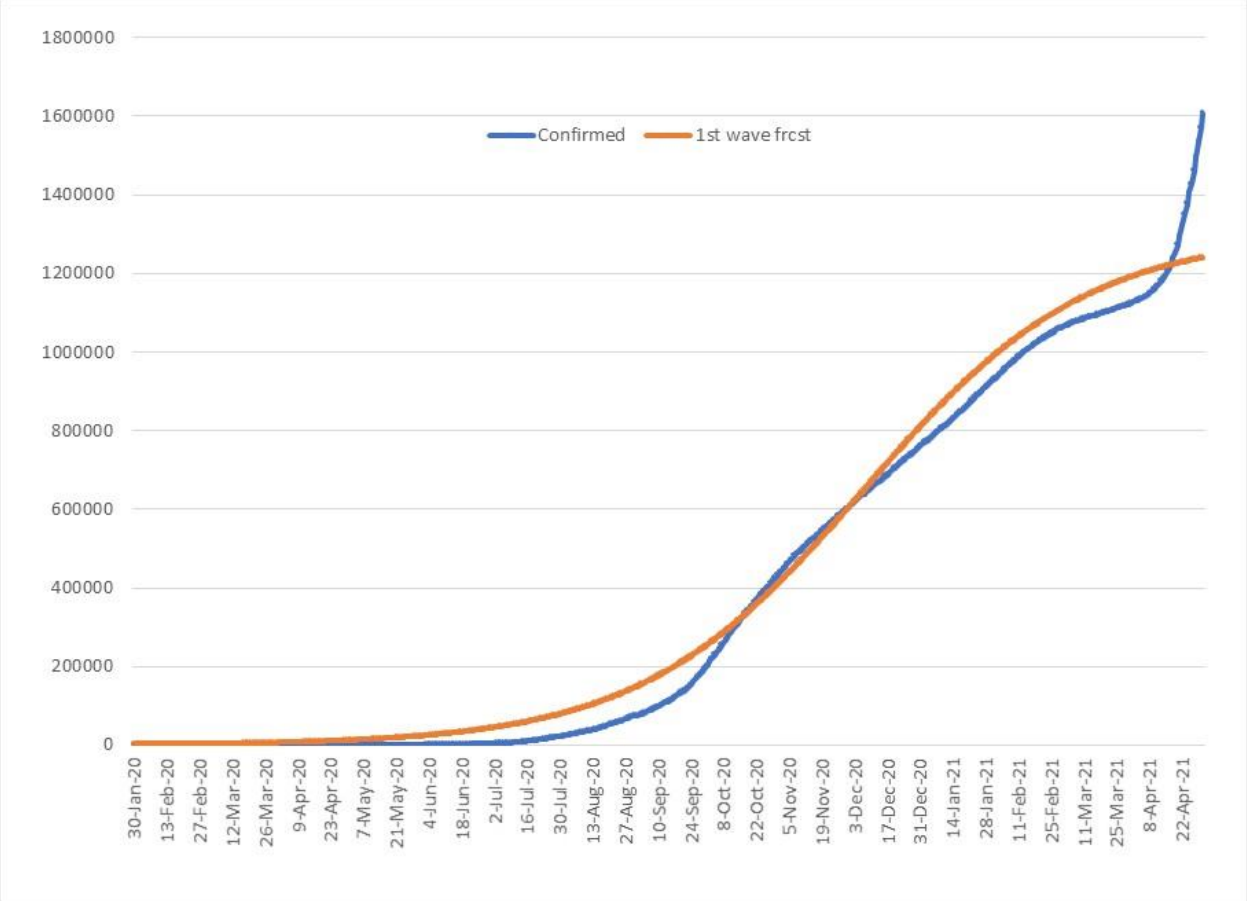
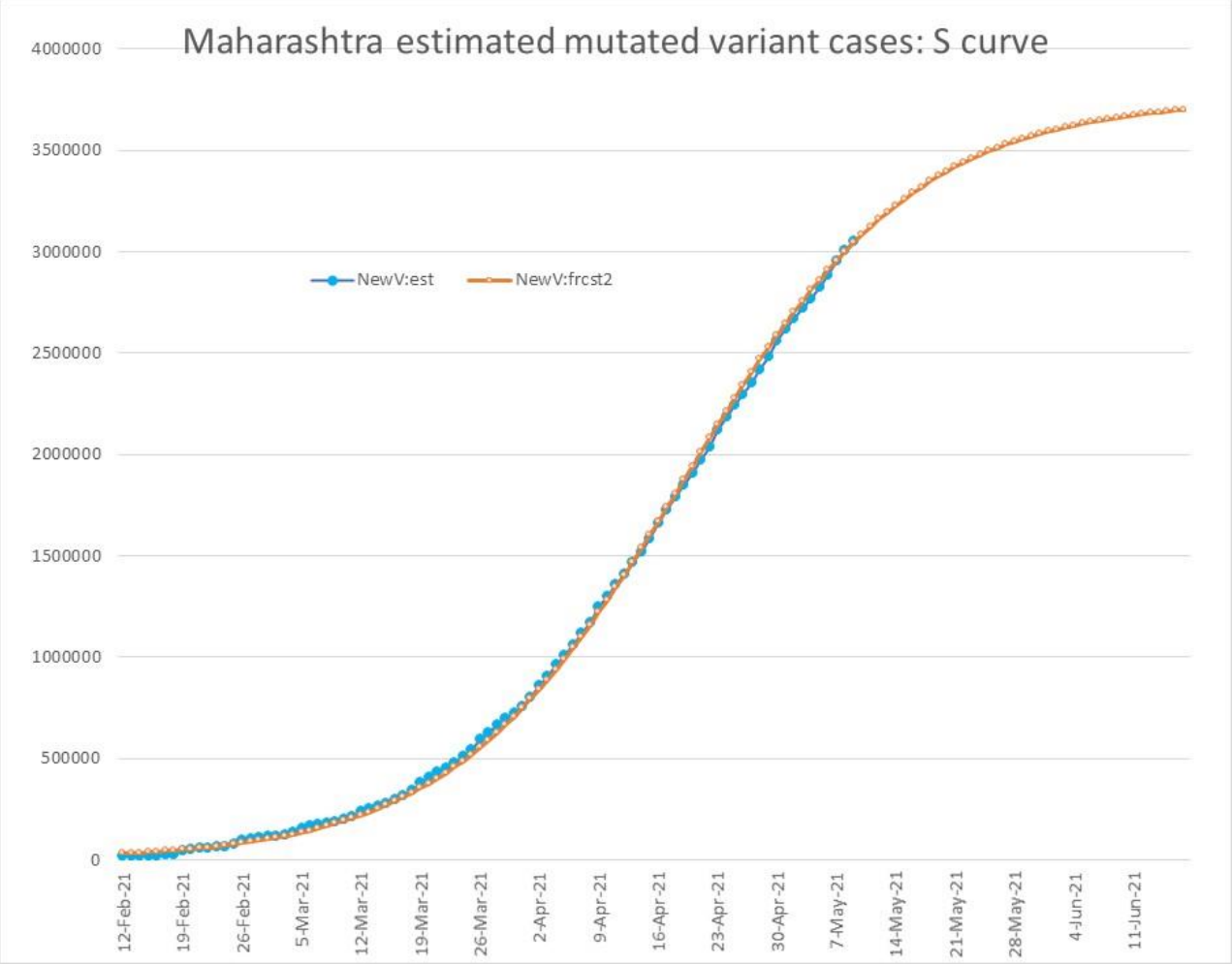
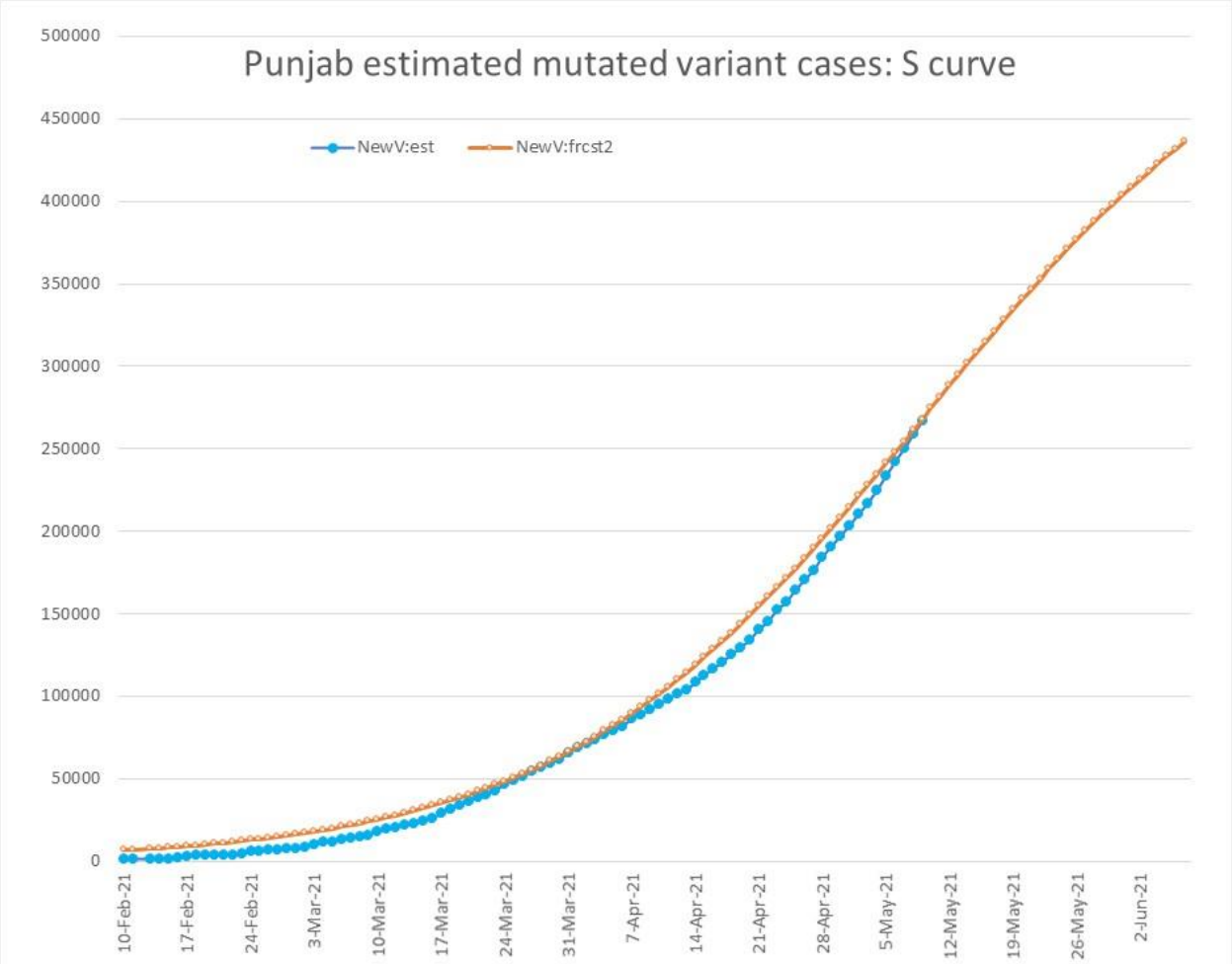


Figure 8: Maharashtra's S-curve of spread of mutated cases.



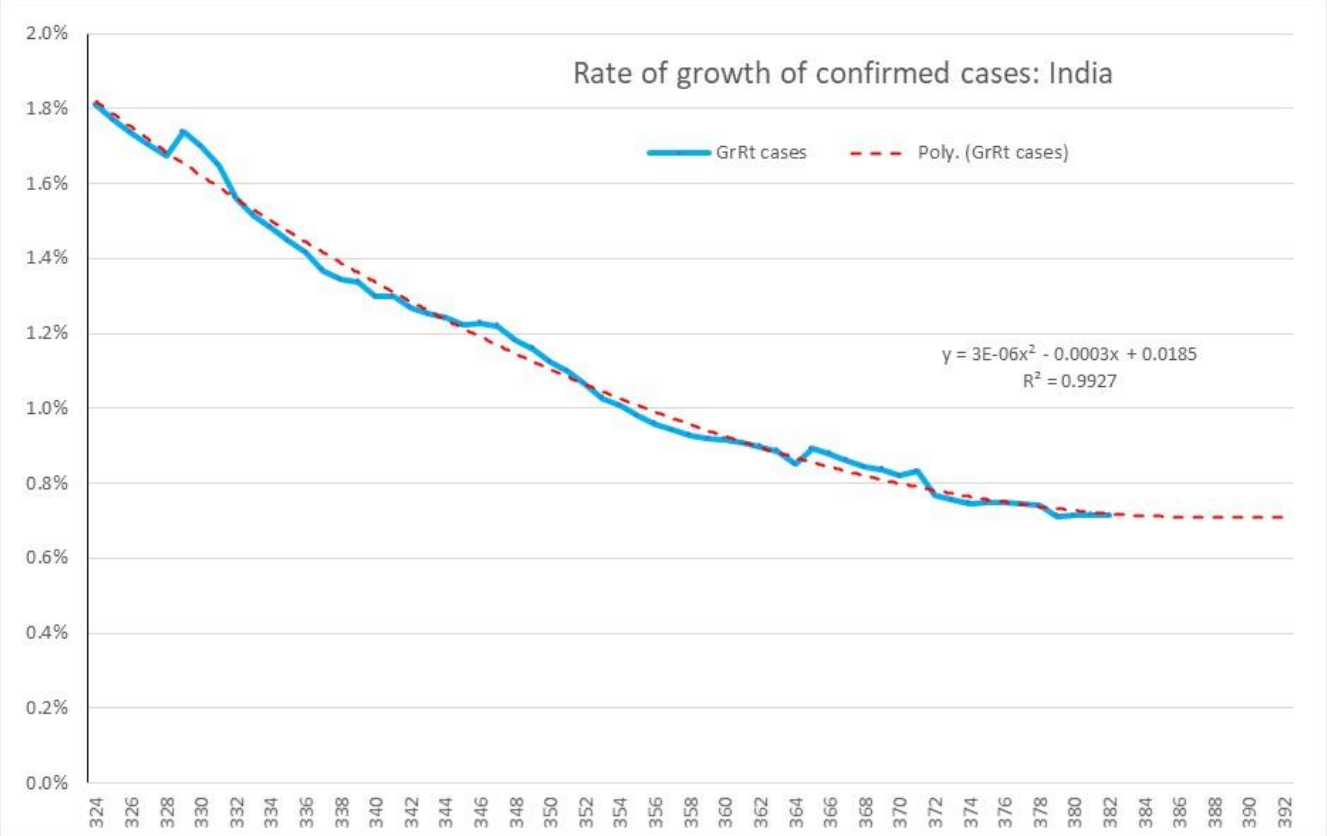
The R square for this fitted curve is 0.998.

Figure 9: Punjab's S-curve of Confirmed cases



The following regression supports our assumption that the region version of the Corona Virus continues to spread at the lowest rate reached.

Figure A1: Rate of Growth of Confirmed cases (cumulative)



10. Appendix Tables

Appendix Table A1: First wave of Covid Cases

	S curve of first wave				End of first wave: Trough			
State	A (cases)	c (days)	b	Rsq	A (%)	Active	Cases	CV Gr Rt
	1	2	3	4	5	6	7	8
Punjab	176,000	195	0.035	0.995	27-Jan-21	2,080	172,406	0.74%
J&K	125,000	198	0.035	0.998	6-Feb-21	631	124,850	0.32%
Haryana	278,000	220	0.029	0.997	8-Feb-21	813	269,498	0.23%
Gujarat	284,000	197	0.020	0.998	10-Feb-21	1,800	264,165	0.67%
Maharashtra	2,000,000	185	0.033	0.999	11-Feb-21	31,437	2,052,905	0.83%
Madhya Prad	273,000	204	0.026	0.998	13-Feb-21	1,829	257,423	0.47%
Delhi	660,000	224	0.027	0.989	13-Feb-21	1,041	636,796	0.14%
India	11,000,000	210	0.035	0.999	14-Feb-21	141,370	10,916,480	0.71%
Chhattisgarh	310,000	215	0.034	0.997	14-Feb-21	3,258	309,099	0.51%
Assam	220,000	153	0.045	0.999	16-Feb-21	1,605	217,309	0.02%
Jharkhand	121,000	166	0.039	0.997	18-Feb-21	469	119,478	0.23%
West Bengal	600,000	207	0.028	0.999	18-Feb-21	3,672	573,193	0.20%
Andhra Prad	910,000	175	0.043	0.998	18-Feb-21	619	889,077	0.04%
Rajesthan	330,000	225	0.030	0.997	21-Feb-21	1,245	319,543	0.19%
Uttar Pradesh	630,000	195	0.029	0.996	22-Feb-21	2,370	602,785	0.09%
Telengana	300,000	195	0.030	0.999	23-Feb-21	1,701	297,712	0.31%
Tamil Nadu	820,000	175	0.035	0.998	23-Feb-21	4,074	849,166	0.37%
Karnataka	939,000	189	0.043	0.999	24-Feb-21	6,096	949,183	0.29%
Uttarakhand	100,000	210	0.028	0.994	25-Feb-21	1,747	96,837	-0.17%
Bihar	270,000	164	0.032	0.994	6-Mar-21	334	262,728	0.08%
Oddisha	340,000	186	0.044	1.000	12-Mar-21	586	338,056	0.13%
Kerala	1,300,000	285	0.021	0.994	18-Mar-21	25,463	1,098,292	1.16%

Source: Authors Calculation based on ICMR Covid data.

Appendix Table A2: Second wave of Covid -Mutations

	Mutation take-off		Second Wave: S curve of mutation spread				Inflection day		Predicted Total Cases	
State	Date	cases	A (cases)	c (days)	b	Rsq	date	cases	31-May-21	30-Jun-21
	1	2	3	4	5	6			7	8
Maharashtra	12-Feb-21	1,965,556	3,750,000	80	0.07	1.00	19-Apr-21	1875000	5,636,131	5,791,438
J&K	13-Feb-21	125,268	216,000	104	0.10	1.00	12-May-21	108000	311,092	338,896
Chhattisgarh	15-Feb-21	304,319	652,000	76	0.11	1.00	24-Apr-21	326000	949,095	960,123
India	16-Feb-21	10,937,158	17,500,000	86	0.09	1.00	1-May-21	8750000	27,226,793	28,303,092
Tamil Nadu	24-Feb-21	842,730	925,000	80	0.10	1.00	6-May-21	462500	1,696,344	1,767,260
Karnataka	25-Feb-21	936,051	1,460,000	75	0.12	1.00	3-May-21	730,000	2,363,700	2,408,558
Gujarat	4-Mar-21	271,725	536,000	84	0.11	1.00	27-Apr-21	268,000	785,281	799,873
Punjab	#	173,674	540,000	108	0.05	1.00	9-May-21	267,975	578,672	676,285
Haryana	14-Mar-21	275,137	530,700	92	0.11	1.00	3-May-21	265,350	774,025	797,876
Madhya Pradesh	14-Mar-21	268,594	540,000	82	0.10	1.00	27-Apr-21	270,000	779,910	796,301
Jharkhand	18-Mar-21	120,951	215,700	76	0.12	1.00	29-Apr-21	107,850	331,099	335,092
Telengana	24-Mar-21	304,298	286,000	75	0.11	1.00	1-May-21	143,000	574,239	582,778
Delhi	25-Mar-21	652,742	790,000	77	0.14	1.00	25-Apr-21	395,000	1,420,843	1,425,726
Rajesthan	25-Mar-21	327,890	572,500	74	0.13	1.00	30-Apr-21	286,250	881,913	891,606
Oddisha	28-Mar-21	340,194	298,500	59	0.13	1.00	4-May-21	149,250	628,346	636,347
Uttar Pradesh	4-Apr-21	1,099,932	1,100,000	68	0.14	1.00	1-May-21	694,994	1,718,600	1,729,661
Andhra Pradesh	6-Apr-21	910,943	725,000	85	0.12	1.00	7-May-21	362,500	1,572,709	1,612,778
West Bengal	6-Apr-21	597,634	556,600	79	0.13	1.00	1-May-21	278,300	1,119,090	1,129,631
Bihar	6-Apr-21	270,392	426,200	61	0.14	1.00	30-Apr-21	213,100	688,833	688,973
Assam	11-Apr-21	220,310	170,000	83	0.14	1.00	10-May-21	85,000	378,776	387,143
Kerala	18-Apr-21	1,239,425	1,106,000	51	0.14	1.00	2-May-21	553,000	2,178,707	2,203,945
Uttarkhand	21-Apr-21	134,012	207,000	72	0.13	1.00	2-May-21	103,500	299,162	303,699

Note # = The formal procedure yields 2nd February 2021 as the take-off date for Punjab. However, a closer examination shows that the take-off occurred much later, in the first week of March (figure 10).

Appendix Table A3: Difference between second & first wave

	Difference in parameters				
State	A(max)	days	speed	Rsq	A(%)
	1	2	3	4	5
Punjab	365,000	-87	0.02	0.00	209%
Maharashtra	1,750,000	-105	0.04	0.00	88%
J&K	91,000	-94	0.06	0.00	73%
Chhattisgarh	342,000	-139	0.08	0.00	110%
India	6,500,000	-124	0.05	0.00	59%
Tamil Nadu	105,000	-95	0.06	0.00	13%
Karnataka	521,000	-114	0.08	0.00	55%
Gujarat	252,000	-113	0.09	0.00	89%
Haryana	252,700	-128	0.08	0.00	91%
Madhya Pradesh	267,000	-122	0.08	0.00	98%
Jharkhand	94,700	-90	0.09	0.00	78%
Telengana	-14,000	-120	0.08	0.00	-5%
Delhi	130,000	-147	0.11	0.01	20%
Rajesthan	242,500	-151	0.10	0.00	73%
Oddisha	-41,500	-127	0.09	0.00	-12%
Uttar Pradesh	470,000	-127	0.11	0.00	75%
Andhra Pradesh	-185,000	-90	0.07	0.00	-20%
West Bengal	-43,400	-128	0.10	0.00	-7%
Bihar	156,200	-103	0.11	0.00	58%
Assam	-50,000	-70	0.10	0.00	-23%
Kerala	-194,000	-234	0.12	0.00	-15%
Uttarkhand	107,000	-138	0.10	0.00	107%