Spread of Covid-19 in India: The First Report [29.3.20; 3 pm]

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Our First Report analyses the stock of Novel Coronavirus infections in India (that opened its account with the first patient in Thrissur, Kerala on January 30) as it existed at 3 pm on 29 March 2020. At that point in time, 1045 cases of Covid-19 had been recorded all over India.

The following table – Table 1 – presents information on the distribution of this "Covid infection stock" across different districts in India. Before presenting the table, we describe the different heads under which the data is presented.

Districts in different States/Union Territories: Currently, there are 736 districts in all of the States and Union Territories of India. Of these, Covid infection stock was positive in 170 districts. In our tables, however, we have aggregated the following districts and have reported our data for the aggregate geographical entity: all districts of Delhi/Puducherry/Goa/ Mumbai/Bangalore have been aggregated into a single entity titled Delhi/Puducherry/Goa/ Mumbai/Bangalore.

Total/Primary/Secondary/Tertiary Cases: Table 1 records the total number of cases of infection in a district as recorded up to 3 pm on 29.3.20. This number is broken up in the subsequent columns as follows. In a district, a case counts as a Primary Case if and only if the following is true: the patient had a recent history of travelling into the district (and then getting detected and treated for Covid within the district) from some other place (domestic or foreign) where there pre-existed documented Covid cases. To the extent that Covid-19 is an "imported disease" in India, one might expect every "infected district" to have at least one Primary Case. This is not true in a few districts for the following reason: in these districts it is documented that an externally-infected agent entered the district, transmitted the disease to one or more people, and then travelled to another district where his/her infection was identified and treated. In a district, a case counts as a Secondary Case if and only if it is documented that the patient is an "immediate relative" of a Primary Case. Finally, a case counts as a Tertiary Case if either it is documented that the patient came in contact with a previously infected patient, or no specific information is available as to how the patient got infected. [This last convention generates a positive bias in the number of Tertiary Cases; that is by intention as we do not want our Transmission Index to be negatively biased (as we explain below).]

Transmission Index : While we recognize the "*R naught*" index to be the accepted measure of disease transmission in epidemics, we are currently not in a position (given data and time limitations) to calculate this index with sufficient degree of accuracy in the Indian districts. Rather, we report a "district-specific average disease transmission index" $\boldsymbol{T}(1)$ that we obtain by calculating the following ratio: $\boldsymbol{T}(1)$ = (total number of secondary and tertiary cases)/(total number of cases). This a is a rather naïve transmission index that would make sense if it is indeed the case that each primary patient in a district (if at least one such patient exists) infects exactly $\{[\boldsymbol{T}(1)]/[1-\boldsymbol{T}(1)]\}$ number of his/her district neighbours.

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Table 1

STATE/Affected Districts	Total Cases	Primary Cases	Secondary Cases	Tertiary Cases	Transmission Index *T*(1)
ANDHRA PRADESH	**19**	**12**	**1**	**6**	
Chittoor	1	1			0.00
East Godavari	1	1			0.00
Kurnool	1	1			0.00
Sri Potti Sriramulu Nellore	1	1			0.00
Prakasam	3	1		2	0.67
Guntur	4	1		3	0.75
Krishna	4	4			0.00
Visakhapatnam	4	2	1	1	0.50
BIHAR	**11**	**5**	**2**	**4**	
Nalanda	1	1			0.00
Siwan	1	1			0.00
Bhagalpur	2			2	1.00
Munger	3	1	2		0.67
Patna	4	2		2	0.50
CHATTISGARH	**7**	**6**		**1**	
Bilaspur	1	1			0.00
Durg	1	1			0.00
Rajnandgaon	1	1			0.00
Raipur	4	3		1	0.25
GOA	**3**	**3**			
Goa	3	3			0.00
GUJARAT	**58****	**21**	**7**	**30****	
Bhavnagar	1			1	1.00
Kutch	1	1			0.00
Mehsana	1	1			0.00
Surat	5	2		3	0.60
Rajkot	8	3		5	0.63
Gandhinagar	9	2	4	3	0.78
Vadodara	9	4	3	2	0.56
Ahmedabad	20	8		12	0.60
HARYANA	**35**	**21**	**1**	**13**	
Ambala	1	1			0.00
Palwal	1	1			0.00
Panchkula	1			1	1.00

STATE/Affected Districts	Total Cases	Primary Cases	Secondary Cases	Tertiary Cases	Transmission Index *T*(1)
Sonipat	1	1			0.00
Faridabad	3	1		2	0.67
Panipat	4	1		3	0.75
Gurgaon	24	16	1	7	0.33
HIMACHAL PRADESH	**3**	**3**			
Kangra	3	3			0.00
KARNATAKA	**81**	**52**	**9**	**20**	
Chitradurga	1	1			0.00
Dharwad	1	1			0.00
Kodagu	1	1			0.00
Tumakuru	1	1			0.00
Udupi	1	1			0.00
Davanagere	2	1		1	0.50
Kalaburagi	3	1	1	1	0.67
Dakshina Kannada	6	5		1	0.17
Mysuru	8	2		6	0.75
Uttara Kannada	8	4	3	1	0.50
Chikkaballapur	9	4		5	0.56
Bangalore	40	30	5	5	0.25
KERALA	**182**	**139**	**6**	**37**	
Wayanad	1	1			0.00
Alappuzha	2	2			0.00
Kollam	2	1		1	0.50
Idukki	3	2	1		0.33
Kottayam	3			3	1.00
Palakkad	4	3		1	0.25
Kozhikode	6	5		1	0.17
Thrissur	6	3	1	2	0.50
Thiruvananthapuram	7	5		2	0.29
Malappuram	9	8		1	0.11
Pathanamthitta	12	6	2	4	0.50
Ernakulam	19	15	2	2	0.21
Kannur	25	25			0.00
Kasaragod	83	63		20	0.24
MADHYA PRADESH	**39****	**12**	**2**	**25****	
Gwalior	1	1			0.00
Shivpuri	2	2			0.00
Bhopal	3	1	1	1	0.67

STATE/Affected Districts	Total Cases	Primary Cases	Secondary Cases	Tertiary Cases	Transmission Index ***T*** (1)
Ujjain	4	1	1	2	0.75
Jabalpur	8	6		2	0.25
Indore	20	1		19	0.95
MAHARASHTRA	**192**	**64**	**6**	**122**	
Aurangabad	1	1			0.00
Gondia	1	1			0.00
Jalgaon	1	1			0.00
Kolhapur	1	1			0.00
Raigad	1	1			0.00
Ratnagiri	1	1			0.00
Sindhudurg	1			1	1.00
Ahmednagar	2	2			0.00
Palghar	2			2	1.00
Satara	2	1		1	0.50
Yavatmal	4	4			0.00
Nagpur	12	2	1	9	0.83
Thane	16	2		14	0.88
Sangli	25	4		21	0.84
Pune	37	15	2	20	0.59
Mumbai	85	28	3	54	0.67
MANIPUR	**1**	**1**			
Imphal West	1	1			0.00
MIZORAM	**1**	**1**			
Aizawl	1	1			0.00
ODISHA	**3**	**2**		**1**	
Khordha	3	2		1	0.33
PUNJAB	**39**	**9**	**8**	**22**	
Ludhiana	1	1			0.00
Amritsar	2	2			0.00
Jalandhar	5	1		4	0.80
Hoshiarpur	6			6	1.00
Sahibzada Ajit Singh Nagar	6	2	1	3	0.67
Shahid Bhagat Singh Nagar	19	3	7	9	0.84
RAJASTHAN	**56**	**14**		**42**	
Ajmer	1	1			0.00
Churu	1			1	1.00

STATE/Affected Districts	Total Cases	Primary Cases	Secondary Cases	Tertiary Cases	Transmission Index ***T*** (1)
Pali	1			1	1.00
Sikar	1			1	1.00
Dungarpur	2			2	1.00
Pratapgarh	2			2	1.00
Jodhpur	6	2		4	0.67
Jhunjhunu	7	5		2	0.29
Jaipur	10	6		4	0.40
Bhilwara	25			25	1.00
TAMIL NADU	**42**	**26**	**2**	**14**	
Coimbatore	1	1			0.00
Kanchipuram	1	1			0.00
Tirupur	1	1			0.00
Tiruchirappalli	1	1			0.00
Tirunelveli	1	1			0.00
Thanjavur	1	1			0.00
Virudhunagar	1			1	1.00
Vellore	2	2			0.00
Madurai	3	1		2	0.67
Erode	5	2		3	0.60
Salem	6	4		2	0.33
Chennai	19	11	2	6	0.42
TELENGANA	**67****	**36**		**31****	
Mahbubnagar	1			1	1.00
Warangal	1			1	1.00
Karimnagar	3	2		1	0.33
Bhadradri Kothagudem	4	1		3	0.75
Medchal-Malkajgiri	4	1		3	0.75
Ranga Reddy	7	2		5	0.71
Hyderabad	36	30		6	0.17
UTTAR PRADESH	**65**	**19**	**15**	**31**	
Bagpat	1	1			0.00
Jaunpur	1	1			0.00
Kanpur Nagar	1	1			0.00
Lakhimpur Kheri	1			1	0.00
Moradabad	1	1			0.00
Muzaffarnagar	2			2	1.00
Pilibhit	2	1		1	0.50
Varanasi	2	1		1	0.50
Ghaziabad	5	2	1	2	0.60
Meerut	5	1	4		0.80
Lucknow	8	4		4	0.50

STATE/Affected Districts	Total Cases	Primary Cases	Secondary Cases	Tertiary Cases	Transmission Index ***T***(1)
Agra	10		7	3	1.00
Gautam Buddh Nagar	26	6	3	17	0.77
UTTARAKHAND	**5**	**5**			
Pauri Garhwal	2	2			0.00
Dehradun	3	3			0.00
WEST BENGAL	**18**	**8**	**7**	**3**	
Kalimpong	1	1			0.00
North 24 Parganas	1	1			0.00
Paschim Medinipur	2			2	1.00
Nadia	5		5		1.00
Kolkata	9	6	2	1	0.33
ANDAMAN & NICOBAR	**9**	**2**		**7**	
North and Middle Andaman	1	1			0.00
South Andaman	8	1		7	0.88
CHANDIGARH	**8**	**3**		**5**	
Chandigarh	8	3		5	0.63
JAMMU & KASHMIR	**38**	**8**	**2**	**28**	
Baramulla	1	1			0.00
Badgam	2			2	1.00
Udhampur	2			2	1.00
Rajouri	3			3	1.00
Jammu	6	2		4	0.67
Bandipora	9	1		8	0.89
Srinagar	15	4	2	9	0.73
LADAKH	**13**	**5**	**1**	**7**	
Kargil	2	1		1	0.50
Leh	11	4	1	6	0.64
DELHI	**49**	**15**	**5**	**29**	
Delhi	49	15	5	29	0.69
PONDICHERRY	**1**	**1**			
Pondicherry	1	1			0.00

** In Table 1, district data for the following cases could not be ascertained: 11 cases in Telangana, 4 cases in Gujarat, and 1 case in Madhya Pradesh. These cases have all been considered to be tertiary cases.

Table 1 indicates the existence of the following kinds of spatial non-uniformity in the spread of Covid-19 in India: heterogeneity in the number of districts affected by the disease, heterogeneity in the number of affected patients across the affected districts, and heterogeneity in the transmission index across the affected districts.

With respect to the crude measure of the spread of Covid-19 by 3 pm on 29th March, note that the 170 affected districts (out of the total of 738 districts in India) contain approximately 36% of India's total population. Regarding heterogeneity in the number of affected patients across the affected districts, we have determined that correlation between the total and primary cases across all affected districts is 0.87. This indicates that it might still be "early days" in the spread of Covid-19 in India, where primary infections – predominantly acquired during foreign travel – largely predict the total infections in a district (in the aggregate, primary infections constitute almost 50% of all infections).

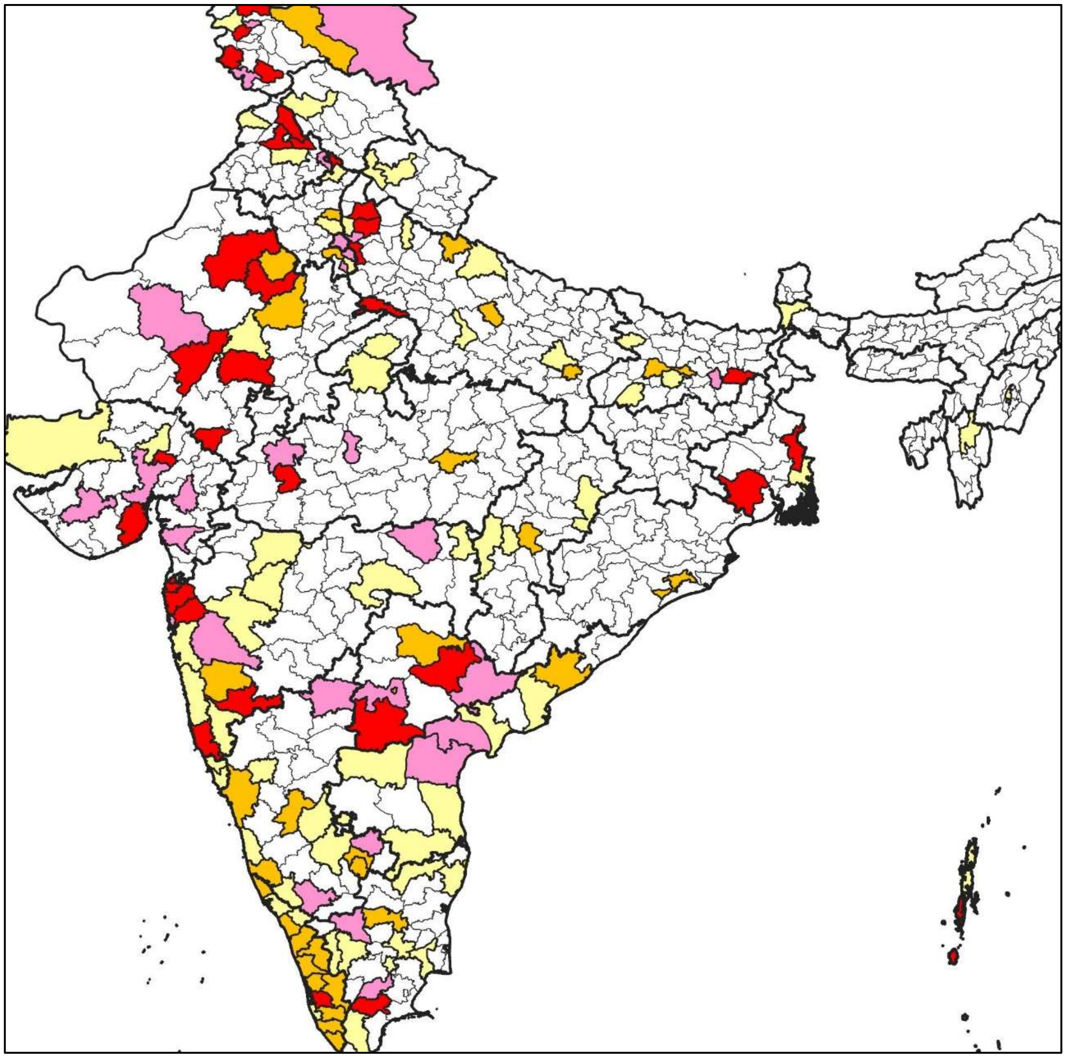
On the other hand, even in these early days, there exists significant variation in our (admittedly naïve) transmission index. Specifically, 38% of all affected districts (containing 33% of the total population of all affected districts) have a transmission index of 0; 27% of all affected districts (containing 28% of the population of all affected districts) have a transmission index greater than 0 and no greater than 0.5 ; 26% of all affected districts (containing 28% of the population of all affected districts) have a transmission index greater than 0.5 and no greater than 0.75; and 9% of all affected districts (containing 11% of the population of all affected districts) have a transmission index greater than 0.75.

Further, Table 1 highlights the following inter-state unevenness in the spread of Covid-19. Maharashtra and Kerala are clearly the worst-affected states, containing a total of 374 cases (36% of all cases in India). But there are also other interesting ways of viewing across-state heterogeneity. In one view, we note that the seven states south of the Vindhyas – Maharashtra, Karnataka, Telangana, Andhra Pradesh, Goa, Kerala, and Tamil Nadu – that contain 32% of India's population, have 56% of all infected patients. In another view, we recognize that all the "western states" that either border Pakistan or the Arabian Sea (or both) – Jammu and Kashmir, Punjab, Rajasthan, Gujarat, Maharashtra, Karnataka, Goa, and Kerala — have 63% of all infected patients while they contain 31% of India's population.

While these facts alert us to the significant lack of uniformity in the spatial spread of Covid-19 across India, we consider it more appropriate to study the spatial heterogeneity of the affliction by looking at more granular data. To that end, the figure overleaf – Figure 1 – colour-codes the various affected districts of India on the basis of the district-level transmission index $\boldsymbol{T}(1)$.

Figure 1 makes it clear that the propagation of Covid-19 in India is creating *clusters of affected districts*. It is true that Kerala is an exception where all districts are affected – possibly due to the return of migrant labour from the Middle East to most districts in the state. It is also true that many of the clusters are located to the west and the south of the country (in fact, the Western Ghats look like a connected chain of affected districts). But once we recognize the existence of clusters of affected districts (not all of which necessarily belong in the same state, as is obvious around the national capital area), we must seek the principal causal factors that explain such clusters. Is it only geographical location that matters, or are there other important determinants as well? To us, the major variables that seem to matter are the following: (*a*) a district's connectivity with the rest of the world, especially with respect to the number of non-resident Indians and their relatives

Figure 1 (yellow) $:= \boldsymbol{T} = 0$; (orange) $:= \boldsymbol{T} \in (0, 0.5]$; (pink) $:= \boldsymbol{T} \in (0.5, 0.75]$ (red) $:= \boldsymbol{T} \in (0.75, 1]$



travelling to and from the district, (*b*) a district's population density in general, and the presence of one or more metropolitan cities in the district in particular, and (*c*) a district's geographical location and associated weather conditions (especially, temperature and humidity).

Of course, the appropriate way to proceed in this context is to pursue rigorous econometric analysis, which we are forced to postpone due to time constraints. Instead, we conclude our first report by presenting some informal/anecdotal evidence regarding the potential determinants of the (clustered) affected districts.

To get a sense of the importance of both global connectivity and population density/urbanization in causing a specific district (and possibly its neighbours) to have a significant number of Covid patients, we focused on the eleven metropolitan areas designated as such by the 74th Amendment to the Indian Constitution (the amendment defines a metropolitan area as "an area having a population of ten lakhs or more, comprised in one or more districts and consisting of two or more Municipalities or Panchayats or other contiguous areas"). Specifically, we looked at the following eleven district clusters: [Delhi + Gurugram + Ghaziabad + Faridabad + Gautam Buddha Nagar], [Mumbai + Thane], [Pune], [Bangalore], [Chennai], [Kolkata], [Hyderabad + Ranga Reddy], [Ahmedabad + Gandhinagar], [Surat], [Jaipur], and [Vishakhapatnam]. Collectively, while these district clusters contain 8% of India's population, they have there are 409 Covid-affected patients (39% of total cases) in them. Apart from these metropolitan district clusters, Table 1 and Figure 1 reveal that other state capitals and important Tier II cities in almost all states have a higher number of total cases than the state-wide district-averages. We believe that the world-connectivity of such places and their population density constitute two important explanations of this phenomenon. In this context, it is relevant to note the case of the district of Shaheed Bhagat Singh Nagar in Punjab which has a high patient load and a high transmission index – while the district does not contain a metropolitan area, it is well known as the "NRI belt of Punjab". [Two exceptions to our explanations should also be noted. Sangli in Maharashtra and Bhilwara in Rajasthan have a significant patient load and a high transmission index. In Sangli, it is reported that a few members of a single family (who travelled from Saudi Arabia) infected all other patients in Sangli, who were their family members. In Bhilwara, it is reported that a single patient from outside the district infected a doctor in a hospital, and from that doctor the disease spread to all other Bhilwara patients, who were all affiliated to that particular hospital.]

We are also struck by the general decrease in the number of afflictions as we move from the South and West of the country to the East and the North-East. It is true that in late March, the day temperatures have risen significantly in Eastern India, and it is also possible that humidity levels are higher in that part of the country. Is it mainly these climatic differences that have slowed Covid propagation to these parts of India? If that is indeed the case, then it is consistent with the findings of the research by Qasim Bukhari and Yusuf Jameel contained in their paper titled "*Will Coronavirus pandemic diminish by summer*?"

We recognize that before we place too much emphasis on the existence of district-clusters of Covid affliction, we must wait to see that whether the new Covid cases that will inevitably arise in the near future *entrench the district-clusters or dilute them.* If the existing clusters are indeed entrenched – and even if a few new clusters emerge – these developments will have significant import for the design of future lock-down policies and treatment approaches in India. We plan to discuss these issues in detail in our future reports.

We conclude our first report by summarizing the following features that we have identified so far regarding the initial spread of Covid-19 in India:

- By the afternoon of 29th March, Covid-19 had spread to 170 of the 736 districts in India (covering 36% of India's population). The total number of patients afflicted by the disease was 1045.
- The disease spread could still be considered to be in its "early phase" in that almost half of all patients were "primary patients" (patients who acquired the disease from an external source – predominantly from a foreign country with a significant patient load), and the number of primary infections largely predicted the total number of infections in a district.
- But even during this early phase of the disease, there was significant variation in the "disease transmission index" across districts in different states, with no transmission in 38% of all affected districts and high transmission in 9% of all affected districts.
- There exists significant state-wide variation in the initial spread of Covid-19. In particular, Kerala and Maharashtra are the worst affected states. In general, southern and western states are worse-affected than eastern and north-eastern states.

- District-level analysis reveals that the propagation of Covid-19 in India is creating clusters of affected districts. Casual empiricism and anecdotal evidence suggest that (*a*) connectedness with the rest of the world, (*b*) population density and urbanization, and (*b*) temperature and humidity conditions might be the principal determinants of a district (or a district cluster) to be afflicted with Covid-19. The following findings are consistent with this hypothesis: 39% of the stock of Covid cases are located in the district-clusters containing the eleven metropolitan areas of India (which contain 8% of India's population). Many other state capitals and Tier II cities have a higher number of total cases than the state-wide district-averages.

In conclusion, we remind the reader that we should all be prepared to see the above picture change significantly over the next few days. While some of these changes will be due to the natural laws of disease progression, it is important to recognize that many other changes will be brought about by our individual and collective responses to the pandemic. And we must be guided by the observed changes in disease propagation (or lack thereof) in designing our public policies to fight Covid-19.