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Prudent public health intervention strategies to control the coronavirus disease 2019 transmission in India: A mathematical model-based approach

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***Background & objectives*: Coronavirus disease 2019 (COVID-19) has raised urgent questions about containment and mitigation, particularly in countries where the virus has not yet established human-to-human transmission. The objectives of this study were to find out if it was possible to prevent, or delay, the local outbreaks of COVID-19 through restrictions on travel from abroad and if the virus has already established in-country transmission, to what extent would its impact be mitigated through quarantine of symptomatic patients?**

***Methods*: These questions were addressed in the context of India, using simple mathematical models of infectious disease transmission. While there remained important uncertainties in the natural history of COVID-19, using hypothetical epidemic curves, some key findings were illustrated that appeared insensitive to model assumptions, as well as highlighting critical data gaps.**

***Results*: It was assumed that symptomatic quarantine would identify and quarantine 50 per cent of symptomatic individuals within three days of developing symptoms. In an optimistic scenario of the basic reproduction number (R_0) being 1.5, and asymptomatic infections lacking any infectiousness, such measures would reduce the cumulative incidence by 62 per cent. In the pessimistic scenario of R_0=4, and asymptomatic infections being half as infectious as symptomatic, this projected impact falls to two per cent.**

***Interpretation & conclusions*: Port-of-entry-based entry screening of travellers with suggestive clinical features and from COVID-19-affected countries, would achieve modest delays in the introduction of the virus into the community. Acting alone, however, such measures would be insufficient to delay the outbreak by weeks or longer. Once the virus establishes transmission within the community, quarantine of symptomatics may have a meaningful impact on disease burden. Model projections are subject to substantial uncertainty and can be further refined as more is understood about the natural history of infection of this novel virus. As a public health measure, health system and community preparedness would be critical to control any impending spread of COVID-19 in the country.**

Key words Airport screening - COVID-19 - deterministic model - mathematical model - mitigation - quarantine - transmission

As per the World Health Organization (WHO), 85,403 cases of coronavirus disease 2019 (COVID-19) were reported globally, as of February 29, 2020, including 79,394 cases (2838 deaths) from China and 6009 cases (86 deaths) from 53 other countries/territories/areas[1]. Initially, all of the cases detected in countries other than China were linked to infected cases from China, with subsequent generation of cases in some of the countries, the latest being Japan, South Korea and Italy. Considering the high population mobility through air travel and the documented person-to-person transmission, the WHO provided an advisory on exit screening in countries with the ongoing transmission of COVID-19 and entry screening in countries without transmission, including screening for the signs and symptoms of respiratory infection with focus on temperature screening to detect potential suspects who would require further laboratory tests for the confirmation of infection[2]. As per a stochastic, worldwide, air transportation network dynamic model, India ranks 17th among the countries at the highest risk of importation of COVID-19 through air travel[3]. The probability of an infected air traveller to come to India as the final destination was 0.209 per cent, with the highest relative import risk in Delhi (0.064%) followed by Mumbai, Kolkata, Bengaluru, Chennai, Hyderabad and Kochi[3]. This in the context of an epidemic that has already set in and travel from infected areas continues.

The Ministry of Health and Family Welfare (MoHFW) of India had initially advised to refrain from travelling to China and quarantine of those coming from China[4]. Those returning from Wuhan, China, after January 15, 2020 were to be tested for COVID-19. Those feeling sick within a month of return from China were advised to report to the nearest health facility in addition to maintaining self-isolation at home[5]. Initially, thermal entry screening of passengers from China was established at 21 airports across the country with universal screening for all flights from China, Hong Kong, Singapore, Thailand, Japan, South Korea, Iran and Italy. Symptomatic passengers were advised to volunteer for screening. Similar screening was in place at international seaports[6]. Till February 29, 2020, three cases were reported from India[7].

In the absence of a licensed vaccine or effective therapeutics for COVID-19, in addition to the non-pharmaceutical measures of hand hygiene and cough etiquettes, quarantine becomes a critical strategic containment and mitigation intervention towards the early detection and isolation of cases to break the chain of transmission and slow down the spread of the outbreak. This analysis was done with the following objectives: (*i*) is it feasible to prevent, or delay, the local outbreaks in India through restrictions on travel from countries with COVID-19 transmission; and (*ii*) in the event that COVID-19 transmission becomes established in India, the extent to which its impact could be mitigated through quarantine.

Material & Methods

This analysis was based on a simple Susceptible-Exposed-Infectious-Recovered (SEIR) model to capture the natural history of COVID-19 and its transmission dynamics. The model structure is summarised in Fig. 1, with the following governing equations:

$$\frac{dS}{dt} = -\lambda S$$

$$\frac{dE}{dt} = \lambda S - rE$$

$$\frac{dI}{dt} = rE - \gamma I - \mu I$$

$$\lambda = \frac{\beta I}{N} + \frac{k\beta E}{N}$$

where the compartments are as follows: susceptible (*S*); exposed and infectious but not yet symptomatic (*E*); infected and symptomatic (*I*) and recovered (*R*). Model parameters are as follows: among those

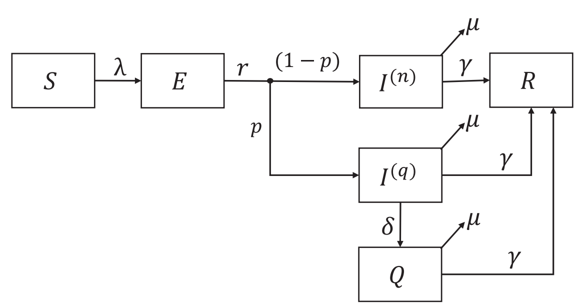

Fig. 1. Summary of the model structure used to represent coronavirus disease 2019 transmission and control in Indian cities. The population in each metropolitan area is divided into different compartments, representing states of disease, with flows between compartments given by the rates shown in the diagram. Thus, susceptible individuals (*S*), upon acquiring infection, enter a state of asymptomatic infection (*E*) and with some delay develop symptomatic disease (*I*). It is assumed that a proportion *p* of symptomatic cases is subject to quarantine [$I^{(q)}$] and the remainder [$I^{(n)}$] is not. The relative size of these two populations (*p*) reflects the coverage of quarantine efforts. Individuals in $I^{(q)}$ are quarantined with an average quarantine delay (1/δ). Finally, individuals may be cured (*R*) or die as per recovery rate (γ) or mortality rate (μ), respectively. Those people who are successfully quarantined (*Q*) do not contribute to onward infection.

Table I. Model parameters for optimistic and pessimistic scenarios of coronavirus disease-19 transmission in India

Parameters	Optimistic scenario	Pessimistic scenario
Basic reproduction number (R_0)	1.5	4
Infectiousness of asymptomatic cases, relative to symptomatic case (k)	0	0.5

exposed, per-capita rate of developing symptoms (r); among symptomatics, per-capita rates of recovery and death (γ and μ, respectively) and the average number of infections caused per day per symptomatic case (β) and the infectiousness of exposed/asymptomatic cases, relative to symptomatic (k).

With the evolving understanding of the natural history of COVID-19 infection, it was assumed that all infections would go through an asymptomatic stage lasting three days on an average, followed by a symptomatic stage, also lasting three days on an average. Previous work has shown that the extent of transmission that occurs before symptoms develop can be an important factor in the feasibility of control[8]. The estimates for the basic reproduction number (R_0) range between 1.5 and 4.9[8-16]. In the current study, we sought to capture a wide range of possible scenarios by adopting two contrasting scenarios, as listed in Table I.

Containment: Port-of-entry screening model: First, a deterministic epidemic was simulated in Wuhan, China, governed by the equations above, to inform projections for the daily introductions of COVID-19 that would arrive on Indian airports. This simulation provided estimates for the prevalence of infection in China, denoted by $E^{(source)}(t)$ and $I^{(source)}(t)$, for the proportion of the population having asymptomatic and symptomatic infection, respectively, at time t.

Then the following stochastic process was simulated for transmission in India: (*i*) A transmission process governed by the equations above, using a simple Gillespie algorithm[17] to translate these to stochastic dynamics, assuming that infection events are independent of one another; and (*ii*) Initial conditions being zero prevalence and universal susceptibility, but with a time series of $M_E(\tau)$, $M_I(\tau)$, introductions of cases of E and I on day τ into the community, for all $\tau > 0$ (these being arrivals from China who have not been stopped at the airport).

To calculate the latter, it was assumed that each day, there were a total of A arrivals from the source region into Indian airports, ignoring seasonality or secular temporal trends. Recalling that $E^{(source)}(t)$ and $I^{(source)}(t)$ are proportions, then on any given day, the proportion of airport arrivals that is infected and asymptomatic is $E^{(source)}(t)$. If we assume that symptomatic cases are m times less likely to travel than those without symptoms, then the proportion of arrivals being infected and symptomatic is $I^{(source)}(t)/m$. Further, assuming that as a result of airport screening, a proportion pE of infected and asymptomatic cases is stopped at the airport before entering the community, and likewise for a proportion pI of infected and symptomatic cases.

Putting these factors together, the number of cases of E being introduced into the community in India, per day would be calculated as:

Introductions of E on day $\tau \sim Bin(A, q[\tau])$

where 'Bin' denotes a binomial distribution, and $q(\tau) = \int_{\tau} E^{(d)}(t)\,dt$

We modelled similarly for the number of introductions of I on day τ, but with the adjustment m described above.

For traveller demographics, we assume conservatively that A=500, meaning that on an average, 500 passengers are arriving per day in Indian airports, from areas in China where COVID-19 transmission is established; the prevalence of asymptomatic infection in international arrivals is the same as in their city of origin and the prevalence of symptomatic infection is half as much (m=½), assuming that symptomatics are half as likely to travel. Airline transportation data suggested that, on an average, there were 3565 passengers arriving from the entire China per day, in Indian airports, during the period from October 2018 to March 2019[18]. We expect this number to have been reduced substantially following recent travel restrictions, but the relevant data are not yet publicly available. Thus, we expect our assumption to be an underestimate.

Under the given scenarios for the proportion of asymptomatic and symptomatic cases that would go undetected by screening, we simulated the stochastic epidemic that would occur in India as a result of the daily introductions and estimated the average 'time to epidemic' as the number of days to reach a prevalence of 1000 cases. This threshold, although arbitrary, represents a level at which it is clear that transmission has been established in India.

Mitigation: Within-country model: In the event that COVID-19 started spreading in India, we developed a mathematical model to simulate the transmission dynamics in the four most populated metropolitan areas (Delhi, Mumbai, Kolkata and Bengaluru metropolitan areas) in India, as well as their population connectivity. We chose to focus on these population centres on the assumption that the introduction of COVID-19 was most likely to occur in international transportation hubs, and thus that these cities were most likely to be the focal points of initial COVID-19 transmission in the country.

As an intervention, we modelled a 'quarantine of symptomatics' scenario wherein a proportion p of symptomatic cases was quarantined within an average of d days of developing symptoms. To incorporate this intervention, we adapted the model equations above, as follows:

$$\frac{dS_i}{dt} = -\lambda_i S_i$$

$$\frac{dE_i}{dt} = \lambda_i S_i - rE_i$$

$$\frac{dI_i^{(q)}}{dt} = rpE_i - \gamma I_i^{(q)} - \mu I_i^{(q)} - \delta I_i^{(q)}$$

$$\frac{dI_i^{(n)}}{dt} = r(1-p)E_i - \gamma I_i^{(n)} - \mu I_i^{(n)}$$

$$\frac{dQ_i}{dt} = \delta I_i^{(q)} - \gamma Q_i - \mu Q_i$$

$$\frac{dR_i}{dt} = \gamma I_i^{(q)} + \gamma I_i^{(n)} + \gamma Q_i$$

$$\lambda_i = \frac{\beta I}{N} + \frac{k\beta E}{N}$$

$$\lambda_i = \sum_{ij} \beta c_{ij} \left[\left(I_j^{(q)} + I_j^{(n)} \right) + kE_j \right] / N_j$$

where the subscript i represents city i; $I^{(q)}$ is the number with symptomatic infection who will self-quarantine after an average delay of d days; $I^{(n)}$ is the number who are symptomatic yet do not quarantine and the rate parameter δ is the inverse of the average quarantine delay, d. The infectiousness of exposed/asymptomatic cases, relative to symptomatic cases, is termed as relative infectiousness (k).

Finally, c_{ij} is the connectivity between cities i and j. We used domestic airline transportation data[18] as a proxy for c_{ij}, while also conducting a sensitivity analysis to address intercity travel through other means, including rail and road. These coefficients (c_{ij}) were estimated as a proxy for the frequency of daily population movement between cities as a proportion of the population of those cities. In sensitivity analysis, we assumed ten times the rates shown in Table II, to address the potential contributions from the lack of rail and road travel data.

Table II. Model coefficient for connectivity between cities

C_{ij}	Delhi	Mumbai	Kolkata	Bengaluru
Delhi	1	0.00045	0.00029	0.00058
Mumbai	0.00048	1	0.00019	0.00052
Kolkata	0.00032	0.00018	1	0.00025
Bengaluru	0.00058	0.00052	0.00025	1

C_{ij}, connectivity between cities i and j

Using this deterministic model, as summarized in Fig. 1, we simulated the introduction of COVID-19 and the resulting epidemic in one of the metropolitan areas. We simulated the epidemic in various scenarios for the proportion of symptomatics being quarantined; the delay to quarantine and the natural history scenarios are shown in Table I.

We present the hypothetical scenario for COVID-19 transmission and interventional effects in Delhi metropolitan area, as an illustration. We estimated the time to hypothetical peak epidemic in days. As an intervention, we modelled a scenario where a given proportion of symptomatic cases (50% at most) could self-quarantine, within a given delay after developing symptoms (at least two days). The indicators for the impact of intervention on the hypothetical epidemic scenario were reduction in cumulative incidence, peak prevalence mitigation (proportional reduction in the highest number of prevalent cases) and attack rate mitigation (proportional reduction in cumulative incidence).

Results

Containment: Airport screening: Fig. 2 shows the delays that could be achieved in the introduction of infection within India, as a result of screening airport arrivals. If symptomatic arrivals alone were screened (blue curve), the model projections for the time to epidemic ranged from 45 to 47.7 days. For illustration, we also examined the impact of screening among asymptomatic individuals (red curve). Results showed

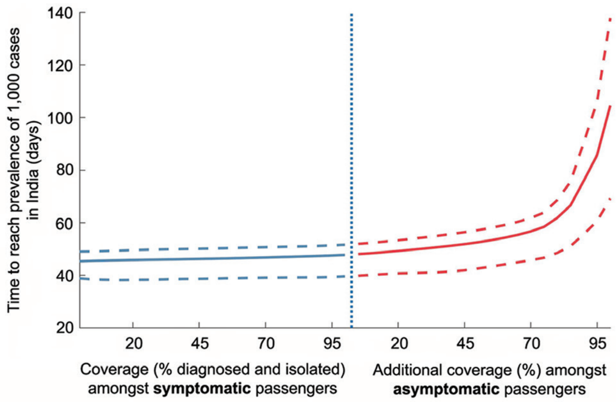

Fig. 2. Model projections for the time to epidemic in India (the time to reach a prevalence of 1000 cases), under different scenarios for the intensity of port-of-entry screening. The left half of the figure illustrates the effect, on epidemic timing, of screening symptomatic passengers alone; the right half illustrates the additional effect of diagnosing coronavirus disease-19 amongst asymptomatic passengers, assuming full screening of symptomatic passengers (infeasible, but illustrative). Solid lines show central estimates, whereas dashed lines span 95 per cent of simulated uncertainty intervals.

that identifying at least 75 per cent of the asymptomatic individuals was needed, in order to delay the within-country outbreak by an appreciable amount. Additional detection of 90 per cent asymptomatic individuals would delay the average time to epidemic by 20 days (Table III). These levels of coverage among asymptomatic cases are practically infeasible, requiring almost all passengers from the identified flights to be screened. However, this hypothetical scenario offers a helpful approach for explaining the lack of impact from addressing symptomatic cases alone (Fig. 2, blue curve). Any containment strategy focused on symptomatic infections, no matter how comprehensively tends to be negated by the asymptomatic infections that escape detection and can go on to cause onward transmission in the community.

Mitigation: Within-country interventions: Fig. 3 illustrates the hypothetical epidemic dynamics that would result in the four metropolitan areas, from an outbreak beginning in Delhi metropolitan area, and under an 'optimistic' scenario for transmission. The Figure illustrates the seeding of transmission in other cities that could arise, as a result of air transportation between these populations. The Figure also illustrates the impact of a hypothetical intervention, wherein 50 per cent of symptomatic cases are quarantined (whether voluntarily or through screening and testing), within an average of three days of developing symptoms. Such measures could reduce the peak prevalence substantially, thus minimizing the pressure on public health services. As a consequence, the intervention has the effect of 'flattening' the epidemic curve, distributing cases over a longer duration than in the absence of intervention. The intervention could reduce the cumulative incidence by 62 per cent. We next illustrate how these impacts may vary, under different transmission and intervention scenarios.

Impact of quarantine of symptomatics: In the 'optimistic' scenario, quarantining 50 per cent of symptomatic cases within three days of developing symptoms would reduce the cumulative incidence by 62 per cent and the peak prevalence by 89 per cent. By contrast in a 'pessimistic' scenario, the projected impact on the cumulative incidence falls to two per cent and the peak prevalence by eight per cent. The corresponding impact on peak prevalence is similarly low, as shown in Fig. 4.

Fig. 5 shows that the duration of the outbreak would be much lower in the scenario of 'no intervention' compared to 'intervention'. As illustrated in Fig. 3, the overall effect of symptomatic quarantine is to flatten the outbreak and increase the duration of the outbreak.

Table III. Alternate scenarios for the effect of airport entry screening of symptomatic and asymptomatic passengers on the delay in average time to epidemic (days to reach a prevalence of 1000 cases) in India by R_0 and relative infectiousness of asymptomatics

Parameters		Delay in average time to epidemic (days)		
R_0	Relative infectiousness, asymptomatic versus symptomatic	All symptomatic COVID-19 identified, but zero diagnosis in asymptomatics	All symptomatic COVID-19 identified, with 50 per cent diagnosis in asymptomatics	All symptomatic COVID-19 identified, with 90 per cent diagnosis in asymptomatics
2	0.5	1.2	5.7	16
2	0.1	2.9	7.4	20
4	0.5	0.5	1.9	5.7
4	0.1	0.8	2.9	7.9

COVID-19, coronavirus disease 19

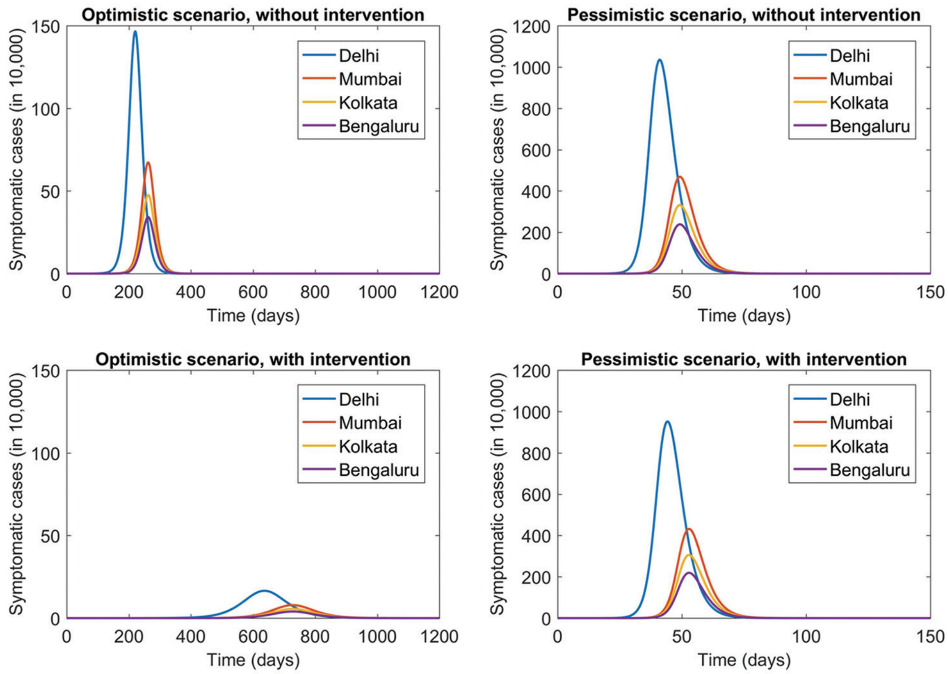

Fig. 3. Model projections for the hypothetical epidemic dynamics (symptomatic prevalence over time) with and without intervention under different scenarios for epidemiologic parameters considering an intervention, in which 50 per cent of the symptomatic cases are isolated within three days of developing symptoms.

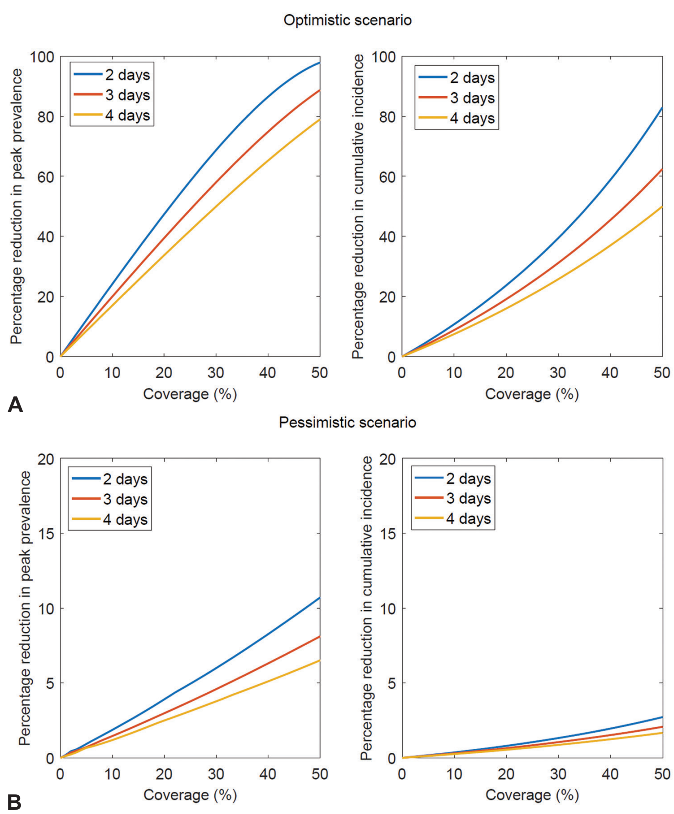

Fig. 4. Model projections for the per cent reduction in hypothetical peak prevalence and per cent reduction in hypothetical cumulative incidence by initiation of quarantine of symptomatics within two, three and four days under the 'optimistic' (**A**) and 'pessimistic' (**B**) scenarios described in the main text.

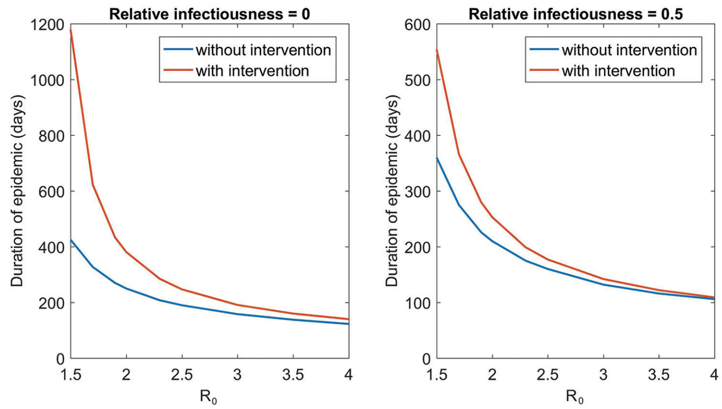

Fig. 5. Projected duration of epidemic (days) for the scenarios with and without symptomatic quarantine at 50 per cent coverage in three days by R_0 and relative infectiousness of asymptomatic cases. Here, the 'epidemic duration' is measured as the duration (in days) over which the prevalence of symptomatic infection is >1 case.

Discussion

The focus of our analysis was not towards predicting the burden of COVID-19 cases but to identify rational intervention strategies that might work towards control of the outbreak in India. We modelled the potential impact of containment strategy of point-of-entry screening and a mitigation response through symptomatic screening on hypothetical COVID-19 transmission scenario in India. Our results suggest that in order to have an appreciable effect on delaying the establishment of transmission of COVID-19 in India, airport arrival screening will need to have near-complete capture of incoming COVID-19 cases, including asymptomatic cases. Although not practically feasible using the currently available tools, our results provide a hypothetical illustration of the additional benefit of identifying asymptomatic cases: if they escape any containment effort, they would tend to negate the effects of that effort, by the onward transmission that they can cause. Presently, there is no accurate, rapid test for COVID-19 that could be deployed in this setting, to reach the required levels of detection among asymptomatic cases; the only way to reach 90 per cent diagnosis among asymptomatic arrivals may be through isolation and quarantine of all arrivals from specified origin airports. Resources may be better spent on the mitigation of infection in the community.

Recent studies indicate that airport screening may not be able to sufficiently detect COVID-19-infected travellers. Quilty *et al*[19] estimated that 46 per cent (95% confidence interval: 36 to 58) of infected travellers would not be detected by thermal screening at airport exit and entry, depending on incubation period, sensitivity of exit and entry screening and proportion of asymptomatic cases. Gostic *et al*[20] estimated that travel screening would miss more than half of the infected travellers on account of being asymptomatic and being unaware of exposure, emphasizing the need for post-travel symptom tracking among them. Our study adds to this by considering the population implications of such leakages in arrival screening. Our analysis shows that, even if symptomatic cases are comprehensively identified and quarantined, the delay in epidemic timing within India would be in days and not weeks. According to the data shared by the Delhi Health Department[21], till February 13, 2020, 17 of 5700 (0.3%) passengers, who had arrived from China and other COVID-19-affected countries prior to the beginning of airport screening from January 15, 2020, were found symptomatic and hospitalized, while the rest were advised for home isolation. The status of another 885 passengers remains unknown[21]. Entry screening or travel restrictions may be beneficial in reducing the risk of outbreak in countries with relatively low connectivity to China, and our study illustrates the critical importance of community-based measures to detect potential cases and prevent transmission.

We also examined the potential impact of quarantine of symptomatics, in controlling transmission within India, with a focus on four major metropolitan areas. Our results suggest that it may be possible to interrupt the transmission of COVID-19 in India, but only in the most optimistic scenarios (for R_0 and for coverage). Even with high R_0 and suboptimal coverage, symptomatic quarantine can still achieve meaningful reductions in peak prevalence, resulting in 'spreading out' of the outbreak. This would make it easier to cope with the peak demand on health services. However, such measures would have very little effect on the overall epidemic size. The actual numerical impact will be highly sensitive to the natural history of COVID-19, the parameters for which are very uncertain at present.

The WHO Scientific and Technical Advisory Group for Infectious Hazards has recommended continuation of the containment strategy and monitoring for the community transmission of COVID-19[22]. It recommends close monitoring of the effectiveness and social acceptance of public health strategies to control COVID-19 transmission in the light of its evolving epidemiological understanding, including engagement of vulnerable populations, and intensified active surveillance[22].

Continuous follow up of passengers returning from COVID-19-affected countries and their contact tracing for the emergence of suggestive symptoms would put a high strain on the healthcare system, more so in the eventuality of the introduction of community transmission. The increasing numbers would make it impractical to use laboratory testing to confirm each case, and therefore, use of symptomatic surveillance should become the primary public health strategy to detect and respond in the most effective and timely manner. We could draw examples from the syndromic surveillance approach for influenza-like illness in the context of H1N1[23]. In practice, this could be achieved either through public advisories for sick individuals to self-quarantine, along with active engagement with the community, or through intensive surveillance for symptoms, followed by testing and quarantine. A combination of both approaches is likely to be needed, although promoting self-quarantine is likely to be more sustainable in the event that transmission becomes widespread. Engagement of local volunteers and community-based organizations can provide the much-needed boost to the efforts of the public health system. Considering the widespread use of mobile phones in the country, mobile applications can be used to self-monitoring and sharing of symptom information on a real-time basis. The same was done for monitoring the passengers on the cruise ship off the Japanese coast[24].

With the evolving understanding of COVID-19 epidemiology, especially the proportion of asymptomatic infected cases, it is difficult to predict the number of beds required or ventilators necessary for COVID-19 cases at this stage. As per reports from other affected countries, we may expect eight to ten severe and 40-50 non-severe COVID-19 cases for every death[25,26]. In a closed setting of similar nature as that on the cruise ship 'Diamond Princess,' we may expect 26 per cent of the entire population to get infected and one in 450 infected individuals to die[27]. We deduce that around five per cent of the infected patients will require intensive care and half of those admitted in the intensive care unit will require mechanical ventilation. Over time, once the model is validated, appropriate numbers can be generated for healthcare planning.

It is pertinent that frontline healthcare workers are identified and trained before the outbreak sets in. Health and life insurance should be announced for healthcare workers if they contract COVID-19. Considering the reports of a high number of infected healthcare workers, measures should be taken to build biosecurity wards and prepare for the outbreak in earnest. Resources should be earmarked; adequate supplies should be procured before the outbreak gains momentum. Healthcare workers should be trained in the use of personal protective equipment, screening of asymptomatic contacts, isolation measures and management of COVID-19 cases. Public health measures should be initiated at multiple levels, including but not limited to public messaging, and community health worker-based education.

Limitations of the model: As with any modelling study, our analysis has some limitations to note. The mean duration of asymptomatic and symptomatic stages is very much uncertain. Some infections may be subclinical and never develop symptoms. In the port-of-entry screening model, we adopted simple assumptions on the number of daily arrivals from non-coronavirus-affected areas due to lack of data. However, considering that we have only used data for airport arrivals and in particular from China, these assumptions are likely to be underestimates in the current situation where people are travelling from many other countries that are now reporting COVID-19 cases, and are thus conservative with respect to our conclusions; higher numbers of daily arrivals would tend to narrow the gap in epidemic timing, between baseline and interventional scenarios. Other important uncertainties include natural history parameters, for example, the average duration of infection; the incubation period and the case fatality rate. Though we have tried to address some of these uncertainties through examining different scenarios for transmission, yet we caution that our model findings may also be sensitive to these other parameters. As more data become available about this new virus, subsequent modelling work can be refined accordingly.

For the country-level model, for simplicity, we created hypothetical scenarios only in four metropolitan areas that have the highest population density. These areas cover only about seven per cent of the total population of India. We ignored the rural population surrounded by these areas and their connectivity. Future work to address this gap will benefit from more systematic information on the rates of population flow between these different settings, data that were not available for our current study. We have simplified our meta-population model by considering constant connectivity between different cities, ignoring age-dependent mobility among the population. How seasonality will change the endemicity of COVID-19 is still unknown and hence not considered in the model. Although there appear to be differences in the immune responses of children compared to adults, for simplicity, this model has not accounted the disease prevalence with age structure.

Comparison of our projected figures with data from countries such as Japan, the Republic of Korea and Iran can help to validate our model, assuming similar transmission dynamics in India. It may be noted that our analysis is based on the available global epidemiological parameters from the initial phase of the outbreak. However, we believe that the predicted direction of the model-based impact of the proposed interventions would remain unaffected, although the onset, magnitude and timing of the simulated epidemic may change, even with the use of updated parameter values from the evolving global situation of COVID-19 epidemic. Validation of mathematical models using real-time data is important to gauge the accuracy of predicted transmission dynamics of infectious diseases. While some models for Ebola virus disease[27] provided fairly reasonable estimates, recent COVID-19 models[28] were inconsistent in their prediction.

Public health implications: At present, it is not clear to what extent the COVID-19 epidemic would establish itself in India. As the introduction of cases may take anywhere from a minimum of 20 days to a few months to be visible, we need to enhance surveillance and prepare the community in a proportionate way that is neither alarmist nor complacent. The critical concerns are the efficiency and timeliness of quarantine and isolation and the challenges of detection of COVID-19 with symptoms similar to many other lower respiratory tract infections. There is a need to engage community-based organizations that can take up the work of symptomatic surveillance, as well as raising awareness of the need for self-quarantine where possible, and referral to hospital where necessary, till infection is confirmed. Till that time, assurance of food and supplies should be given following examples of such practices in Kerala[29]. It is pertinent to engage with the media on a proactive basis with the provision of facts promptly such that reporting of these events does not create a picture of the overwhelming burden of COVID-19 in the country and lead to undue anxiety among the population that may negatively influence self-quarantine. Health authorities need to be on alert and be prepared to closely monitor the situation with the establishment of an intensified surveillance. We advocate for a rational, flexible and resilient approach that is sensitive to the outbreak stage as the health system prepares for the control of COVID-19 transmission in India.

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Conflicts of Interest: None.

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