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Original Article/Research

Effects of the COVID-19 pandemic in India: An analysis of policy and technological interventions

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A B S T R A C T

Objectives: Following a surge in cases of coronavirus disease 2019 (COVID-19) in June 2020, India became the third-worst affected country worldwide. This study aims to analyse the underlying epidemiological situation in India and explain possible impacts of policy and technological changes.

Methods: Secondary data were utilized, including recently published literature from government sources, the COVID-19 India website and local media reports. These data were analysed, with a focus on the impact of policy and technological interventions.

Results: The spread of COVID-19 in India was initially characterized by fewer cases and lower case fatality rates compared with numbers in many developed countries, primarily due to a stringent lockdown and a demographic dividend. However, economic constraints forced a staggered lockdown exit strategy, resulting in a spike in COVID-19 cases. This factor, coupled with low spending on health as a percentage of gross domestic product (GDP), created mayhem because of inadequate numbers of hospital beds and ventilators and a lack of medical personnel, especially in the public health sector. Nevertheless, technological advances, supported by a strong research base, helped contain the damage resulting from the pandemic.

Conclusions: Following nationwide lockdown, the Indian economy was hit hard by unemployment and a steep decline in growth. The early implementation of lockdown initially decreased the doubling rate of cases and allowed time to upscale critical medical infrastructure. Measures such as asymptomatic testing, public–private partnerships, and technological advances will be essential until a vaccine can be developed and deployed in India.

Public interest summary: The spread of COVID-19 in India was initially characterized by lower case numbers and fewer deaths compared with numbers in many developed countries. This was mainly due to a stringent lockdown and demographic factors. However, economic constraints forced a staggered lockdown exit strategy, resulting in a spike in COVID-19 cases in June 2020. Subsequently, India became the third-worst affected country worldwide. Low spending on health as a percentage of gross domestic product (GDP) meant there was a shortage of hospital beds and ventilators and a lack of medical personnel, especially in the public health sector. Nevertheless, technological advances, supported by a strong research base, helped contain the health and economic damage resulting from the pandemic. In the future, measures such as asymptomatic testing, public–private partnerships, and technological advances will be essential until a vaccine against COVID-19 can be developed and rolled-out in India.

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Introduction

The coronavirus disease 2019 (COVID-19) pandemic has posed an unprecedented challenge to the people and governments of every country in a very short period since its emergence in Wuhan, China, in December 2019 [1]. The first case of COVID-19 in India was reported on 30 January 2020 in the state of Kerala; this was a student who returned from Wuhan and tested positive for COVID-19, following which aggressive contact tracing followed by 14-day home quarantine for suspected cases were enforced [2]. The state remained on high alert. During March, cases began to be reported across India. Despite the aggressive measures taken by the Indian
government to prevent and contain the epidemic, as of 12 August 2020 there were 652,473 active cases, 1,695,860 recovered cases, and 47,138 deaths due to COVID-19 [3].

India is the world’s second-most populous and the third-worst affected country by COVID-19 to date (in terms of the total number of confirmed COVID-19 cases). Therefore, it is relevant to review how the country has fought the pandemic since its onset. Against this backdrop, the focus of this paper is to assess the impact of public policy and technological interventions on COVID-19 trends in India. First, India’s diverse demographic profile followed by the status of health and hospital infrastructure prior to the COVID-19 pandemic are presented. Second, the impact of the pandemic on India and the measures taken by the government in response are discussed. Third, the technological advances that catalysed the overall recovery process are summarised. Finally, the economic impact of the pandemic is presented, followed by concluding observations with regards to the impact of these measures, their limitations and the way forwards.

**Country description**

**Country and health system overview**

India comprises 28 states and 8 union territories. Table 1 [4–8] shows that despite a huge population, the old-age dependency ratio and life expectancy in India are lower than the Organization for Economic Co-operation and Development (OECD) average of 0.264 and 80.7 years, respectively [9]. The current health expenditure in India as a percentage of gross domestic product (GDP) is one of the lowest in the world, which has left the country with insufficient doctors, nurses and beds to face an unprecedented situation such as a pandemic. Social distancing is a key part of tackling the spread of COVID-19, but a high population density can make social distancing challenging. Furthermore, more than half of the elderly population in India has co-morbidities, e.g. hypertension and diabetes, which could potentially increase these individuals’ risk of contracting COVID-19. However, India’s median age reflects the fact that more than half of the country’s population comprises the young, thereby lowering the anticipated fatality rates from COVID-19.

A health-system overview is critical for tracking the diverse demographic and health indicators across the country (see Table 2) [10–12]. Population density exhibits extreme variations, from 123 individuals per km² in Himachal Pradesh to 1106 individuals per km² in Bihar. The percentage of the population aged 60 years or more varies from 6.7% in Jharkhand to 12.9% in Kerala. Furthermore, the average life expectancy varies from 63.6 to 72.2 years and is higher for females than males. These variations result from the jurisdiction for health being decentralized, with states having the power to allocate health budgets. Health expenditure as a percentage of GDP is as high as 2.21% in Assam and as low as 0.60% in Maharashtra, even though the population of Maharashtra is 3.5 times that of Assam.

Differences in health spending result in major variations in health infrastructure in terms of hospitals, beds, ventilators, etc. across the states. For example, Jharkhand and Kerala have comparable populations but the number of hospitals, beds and ventilators in the public sector varies by almost 3.5 times (see Table 3) [6,13,14]. A visible mismatch between medical infrastructure supply and demand in the public sector will pose a big challenge to deal with the increasing number of cases across the country under the prevailing situation.

Healthcare financing in India is a mix of public and private schemes; however, at least 75% of the population has no kind of insurance cover [15]. Furthermore, the private sector provides 58% of hospitals and 81% of doctors in India [16]. During the early days of the pandemic, public hospitals were involved in the testing and treatment of COVID-19. Insufficient public health infrastructure together with a surge in cases called for a policy revision in terms of participation of the private sector in testing and treatment for COVID-19. The public sector accounts for around 20% of the total healthcare expenditure in India, representing around 1% of GDP, one of the lowest proportions of any country in the world [17]. The remaining 80% contributed by the private sector is targeted towards financing and the creation of infrastructure facilities. While diagnosis and treatment were free for 500 million beneficiaries of the health insurance scheme ‘Ayushman Bharat’ in public hospitals, the costs of tests (USD 44) and treatment were capped at private facilities. For example, the Delhi government capped isolation facilities at USD 160–200 per day for isolation beds, USD 260–350 per day for an ICU bed without a ventilator, and USD 300–360 per day for an ICU bed with a ventilator [18].

**Changes due to COVID-19**

Other changes in India included contingency plans for an anticipated surge in cases. Railway coaches (2,500) were converted to isolation wards, making available an additional capacity of 40,000 beds [19]. Paramedical staff, including volunteers, ex-service people, homeopathic and ayurvedic practitioners, medical students, teachers, doctors (including retired doctors), and others, were identified at municipal, district and state levels to create an online data pool of 15,896,093 human resources for various activities required to fight COVID-19; each person was designated a ‘COVID warrior’, and a surveillance policy of one COVID warrior per 250 citizens was devised [20]. With the increased supply of infrastructure and human resources, it was equally important to match the demand for medical equipment and medicines. With the involvement of private hospitals, the demand for personal protective equipment (PPE) increased.

**Zonal classification**

Geographical areas within a city were classified as red (more than 15 confirmed cases on a given day), orange (up to 15 confirmed cases), or green (no cases) zones, based on levels of infections [21]. Containment zones were geographical areas where a cluster of confirmed cases (more than six) was found, especially in cramped locations where social distancing was not realistically possible. Specific guidelines in these areas include:

- Entry only after a taking COVID-19 preventive drug.
- Designated helpline numbers for the delivery of essential items, sanitisation drives, and health check-ups.
- Restricted movement to other zones, with violators booked under sections of the Disaster Management Act (2005), the Epidemic Diseases Act (1897), and the Indian Penal Code (IPC).
Table 2

| State              | Health expenditure as a percentage of GSDP*(2015–16) | Population in millions (2013) | Population density (individuals/km²) (2011) | Percentage of the population aged ≥ 60 years (2012) | Average life expectancy (years) (2012–2016) |
|--------------------|------------------------------------------------------|-------------------------------|---------------------------------------------|---------------------------------------------------|-------------------------------------------|
| Andhra Pradesh     | 0.76                                                 | 87.0                          | 308                                         | 9.60                                              | 69.7                                      |
| Assam              | 2.21                                                 | 32.2                          | 398                                         | 6.60                                              | 65.6                                      |
| Bihar              | 1.33                                                 | 108.7                         | 1,106                                       | 7.10                                              | 68.7                                      |
| Gujarat            | 0.72                                                 | 61.6                          | 308                                         | 8.50                                              | 69.6                                      |
| Himachal Pradesh   | 1.68                                                 | 7.1                           | 123                                         | 10.60                                             | 72.45                                     |
| Jharkhand          | 1.25                                                 | 34.1                          | 414                                         | 6.70                                              | 67.9                                      |
| Kerala             | 0.93                                                 | 34.4                          | 860                                         | 12.90                                             | 75.05                                     |
| Madhya Pradesh     | 1.04                                                 | 74.4                          | 236                                         | 7.20                                              | 65.45                                     |
| Maharashtra        | 0.60                                                 | 117.0                         | 365                                         | 9.50                                              | 72.25                                     |
| Punjab             | 0.87                                                 | 28.4                          | 551                                         | 9.90                                              | 72.6                                      |
| Rajasthan          | 1.44                                                 | 71.7                          | 200                                         | 7.50                                              | 68.4                                      |
| Tamil Nadu         | 0.74                                                 | 74.0                          | 555                                         | 10.70                                             | 71.45                                     |
| Uttarakhand        | 1.06                                                 | 10.4                          | 189                                         |                                                   |                                           |
| Uttar Pradesh      | 1.42                                                 | 208.7                         | 829                                         |                                                   | 64.75                                     |
| West Bengal        | -                                                    | 93.5                          | 1,028                                       | 8.40                                              | 70.85                                     |

* GSDP – gross state domestic product.

Table 3

| State             | Number of hospitals Public | Number of hospital beds Public | Number of intensive care unit (ICU) beds Public | Number of ventilators Public |
|-------------------|---------------------------|-------------------------------|-----------------------------------------------|------------------------------|
| Andhra Pradesh    | 258                        | 670                           | 23,138                                        | 60,092                       |
| Assam             | 1,226                      | 503                           | 17,142                                        | 7,036                        |
| Bihar             | 1,147                      | 1,887                         | 11,664                                        | 19,193                       |
| Gujarat           | 438                        | 970                           | 20,172                                        | 44,690                       |
| Jharkhand         | 555                        | 809                           | 10,784                                        | 15,712                       |
| Kerala            | 1,280                      | 2,062                         | 38,004                                        | 61,223                       |
| Madhya Pradesh    | 465                        | 506                           | 31,106                                        | 33,833                       |
| Maharashtra       | 711                        | 2,492                         | 51,446                                        | 180,293                      |
| Punjab            | 682                        | 1,638                         | 17,933                                        | 43,064                       |
| Rajasthan         | 2,850                      | 2,794                         | 47,054                                        | 46,122                       |
| Tamil Nadu        | 1,217                      | 1,222                         | 77,532                                        | 77,843                       |
| Uttar Pradesh     | 4,635                      | 12,468                        | 76,260                                        | 205,142                      |
| Uttarakhand       | 460                        | 829                           | 8,512                                         | 15,331                       |
| West Bengal       | 1,566                      | 697                           | 78,566                                        | 34,969                       |

- Zones were reassessed within four weeks from the discharge of the last confirmed case.

This concept of zonal classification was based on the steep learning curve experienced during the 1918 influenza A virus (H1N1) pandemic in India. One of the lessons learned during this earlier pandemic was that even though the spread of a virus among the Indian population could be high, it is unlikely to affect all parts of the country uniformly [22].

COVID-19 trends

Overview of data availability and data transparency

State governments usually report COVID-19 data based on daily numbers of confirmed, deceased, recovered and active cases. The major channels for disseminating official data included the Ministry of Health and Family Welfare (MoHFW), the Aarogya Setu Mobile application, press conferences, and the COVID-19 India website [23], which was developed by a group of volunteers. Table 4 [23] provides an overview of the growth rate of the epidemic during different phases of the mitigation strategies.

Fig. 1 [23] shows the top-ten states with the highest tally of confirmed cases (up to 12 August 2020). Maharashtra emerged as the epicentre of the virus, with clusters of infections in Asia’s biggest slum, ‘Dharavi’. Although Telangana and Gujarat reported a similar percentage of confirmed cases, Gujarat reported a higher percentage of deaths. New Delhi had a lower percentage of confirmed cases than Karnataka but reported a higher percentage of deaths. These differences reflect differences in technological expertise and medical facilities across states.

Table 4

| COVID-19 spread during subsequent lockdowns in 2020. |
|-----------------------------------------------------|
| Lockdown duration | Mitigation strategy | Growth rate (%)(The number of new cases divided by the total number of confirmed cases on the previous date) |
|-------------------|---------------------|-------------------------------------------------|
| 24 March–14 April | Phase 1 (lockdown)  | 15.06 (on 25 March)                             |
| 15 April–3 May    | Phase 2 (lockdown)  | 7.5 (on 25 April)                               |
| 4 May–17 May      | Phase 3 (lockdown)  | 6.4 (on 5 May)                                  |
| 18 May–31 May     | Phase 4 (towards exit strategy) | 4.63 (on 25 May) |
| 1 June–30 June    | Phase 5 (unlock 1.0) | 3.85 (on 25 June)                               |
| 1 July–31 July    | Phase 6 (unlock 2.0) | 3.63 (on 25 July)                               |
Trends in COVID-19 cases, deaths and recoveries

Fig. 2 [3] depicts the impact of various unlock phases on the increase in the number of new cases. It should be noted that until the end of phase 4, the trend was linear. However, during unlock phase 5, the trend resembled an exponentially increasing curve tapering off during unlock phase 6 ($R^2 = 88.57\%$). It was observed that during this time, the recovery rate was constantly increasing (see Fig. 3) [3], with less than 1% of confirmed cases on ventilators, less than 2% in ICUs and less than 3% in oxygen beds [24]. The growth in recovery rates started matching the growth in confirmed cases, possibly due to a better understanding of the nature and treatment of a novel disease from a technological perspective.

The case fatality rate (CFR), when comparing the top-three worst-affected countries (in terms of the total number of confirmed COVID-19 cases) shows that India's CFR (see Fig. 4) [3] was much lower [25]. This could possibly be attributable to demographic factors, such as a relatively young population, the effectiveness of an early lockdown [26], a possible inverse correlation between Bacille Calmette–Guérin (BCG) immunization and COVID-19 incidence and severity [27], missing data from untested deceased patients, or the temperature and humidity [28]. A slight increase in CFR during March 2020 was possibly due to states initiating the process to have their statistics audited by Death Audit Committees (DAC). A written explanation for any delay in reporting COVID-19 fatalities was mandated, to prevent any underreporting of actual numbers.

State-wise evolution of COVID-19

The state-wise evolution of the spread of COVID-19 during the first 100 days of the epidemic is shown in Fig. 5 [23], showing that the evolution of the disease differed across states. Kerala received accolades from the United Nations while leading India’s early response to this pandemic [29]. The curve for Kerala was almost linear until day 40 after an initial spike in cases.

Kerala ranks first in the overall health index [30], where public initiatives in health went hand in hand with private partnerships to fight COVID-19 [31]. A highly responsive and robust healthcare model started systematically preparing to handle a possible outbreak in January 2020. Kerala launched the ‘Break the Chain’ campaign as a means to highlight the importance of hygiene...
(handwashing) and social distancing. Standard operating procedures covered aggressive contact tracing; infection control for ambulances; careful management of biomedical waste and handling the spillage of body fluids; disinfection and sterilisation; management of dead bodies; use of PPE; and sample collection and transportation. Transparency in communication was maintained, in the form of reporting daily confirmed cases, revised guidelines related to quarantine, hospital admissions, and discharged cases. Additionally, the state undertook total financial responsibility for testing and treatment. However, during July, Kerala witnessed a sudden surge in COVID-19 cases, largely due to the easing of lockdown restrictions and an influx of migrants from other states and from abroad [32]. As a result, there was a sharp increase in the percentage of locally transmitted cases (contacts of the imported cases) [33]. During this time, the scale of testing was unable to match the scale of migrants, thereby delaying the contact tracing and treatment protocol. Additionally, the use of rapid antigen tests (with low accuracy) [59] possibly reduced the reliability of results [34].

Age and sex trends

COVID-19 is more likely to infect the male population in India, with the highest percentage of cases in males aged 30 to 39 years (see Fig. 6) [35]. In the absence of specific COVID-19 statistics based on comorbidities, patients with diabetes, chronic kidney disease, hypertension, and heart disease have been considered at risk [36]. The male population aged more than 60 years accounts for the majority of deaths (see Fig. 7) [35].

Policy and technology road map

Policy mandates

For any country to make a rapid recovery from the effects of the pandemic, it is imperative to investigate the role of policy and technological changes. Tables 5a [37], 5b [37] and 5c [38] list government policies across India and by sector.

Table 5b shows that during March and April, schools planned to roll-out online learning, both in terms of formulating online content and upgrading their information technology (IT) infrastructure. The objective of opening liquor shops during phase 3 was to replenish state revenues through excise duty on liquor, which comprises between 10% and 15% of their tax revenue. The resumption of selected economic activities indicated a staggered lockdown exit strategy. From Phase 4 onwards, the responsibility for unlock poli-
cies was transferred to the state level, as the spread of disease varied across states.

India’s pharmaceutical industry, which is third largest in the world by volume, sources the majority of its active pharmaceutical ingredients from China [40]. This supply was affected owing to the virus outbreak in China. Hence, during the initial phases of lockdown, Indian exports were prohibited or restricted to maintain an undisturbed supply chain for the nation, as shown in Table 5c. However, following a tremendous increase in indigenous manufacturing capacity, medical exports began opening up again during July.

**Economic relief measures taken by the Indian government**

Within a month of lockdown, the unemployment rate in India increased dramatically, from 8.7% in March to 23.52% in April 2020 (see Fig. 8) [42]. This resulted in job losses for an estimated 140 million people and an income drop for more than 45% of households [43]. As evident from Fig. 8, the unemployment rate started to decline again after May because of the reopening of industries and other commercial activities and almost reached pre-COVID-19 levels. Relief measures were announced through different modes, via the central bank or existing schemes; however, they had limited social coverage considering the duration of lock-

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**Fig. 5.** Evolution and spread of COVID-19 across states during the first 100 days.
Technological advances

India is among the largest manufacturers of vaccines in the world and was the fifth country to isolate the strain of SARS-CoV-2, the virus that causes COVID-19 [45]. India could play an important role in terms of mass-producing a vaccine at an affordable cost [46]. Out of seven Indian firms racing to develop a vaccine, two had vaccine candidates already in the human trial phase as of August 2020 [46]. Around 12 August, India’s proportion of recovered COVID-19 cases of 70%, shown in Fig. 9 [3], was higher than the average (69%) of the top-five countries (by total number of COVID-19 confirmed cases), representing more than 1.6 million [3] recovered cases in absolute terms. This was testimony to the technological advances applied at scale against the backdrop of lockdown measures. Furthermore, research advances, in the form of scaling-up of convalescent plasma therapy, where blood from individuals who have recovered from COVID-19 is given to other infected individuals to help them recover [47], gave an impetus to the treatment process.

Table 5a
Government policies in response to the COVID-19 pandemic.

| Timeline | Interventions (pre-peak) | Type* |
|----------|--------------------------|-------|
| Phase 1 and 2 | Curb of non-essential activities 1.3 billion people impacted Zonal classification of cities initiated | Medium Imprisonment (6 months– 2 years) or a fine imposed or both |
| Phase 3 (Towards an exit strategy) | Relaxation in all zones except containment zones Opening of stand-alone liquor shops Intrastate movement with a pass Government offices opened with 33% capacity Interstate movement permitted | Minimal |
| Phase 4 | Lockdown regulations indicating an exit strategy Domestic travel resumed The authority for opening commercial activities was decentralized to state level | Medium |
| Phase 5 Unlock 1.0 | Lockdown only in containment zones Metros and other social gathering venues closed | |
| Phase 6 Unlock 2.0 | Additional guidelines to Unlock 1.0 included a night-time curfew from 9 p.m. to 5 a.m. | |
| Phase 7 Unlock 3.0 | Additional guidelines to Unlock 2.0 included revocation of the night-time curfew Gymnasiums and yoga institutes open | |

* Type: Medium – mandated by law (no punishment); Minimal – advisory; Significant – mandated by law (punishable) [39].
### Table 5b
Interventions introduced across industries in response to the COVID-19 pandemic.

| Sector | Timeline (2020) | Intervention (pre-peak)                                           | Type* |
|--------|-----------------|-------------------------------------------------------------------|-------|
| Agriculture | January March, April May | Villages organised awareness meetings Agricultural activities curbed Agricultural activities restarted | Minimal |
| Education | March April May–August | Schools closed (New Delhi) All colleges (except medical) closed Hostels vacated Online learning | Significant |
|          | April May–August | Kits exported to 50 countries worldwide Permitted for medical coveralls, goggles, face shields Upper cap on PPE medical coveralls Permitted for medical coveralls (second-largest manufacturer in the world) and 0.20 million N-95 masks every day, which means better availability of medical coveralls in the future [50]. The launch of the Aarogya Setu app at an all India level for contact tracing was followed by the launch of specialized apps at the state level to fill in the information gap in terms of occupancy and availability of hospital beds, ICUs and ventilators for patients with COVID-19 [51–53]. | Significant |
| Industry | March May July–August | Non-essential activities closed Industries open with limited capacity Seamless operation of industrial units in multiple shifts | Medium |
| Aviation | January February March–August | Screening of travellers from China Avoid non-essential travel to China E-visa for Chinese passport holders suspended International passengers quarantined Existing visas invalided or suspended until April, except for a few categories Flights banned Domestic and non-scheduled international flights for stranded citizens | Minimal |
| Entertainment | March–August June–August | Cinemas, theatres and auditoriums closed Malls opened | Significant, Disease Epidemic Act (1897), Section 188(IPC) Fine imposed 6 months imprisonment |
| Religious | March April June–August May–August | Mass gatherings limited in number Amendment to Disease Epidemic Act, 1897 Acts of violence against health workers registered Religious places opened, with a ban on large religious gatherings Interstate trains and buses operational, metros remain closed | Significant |

* Type: Medium – mandated by law (no punishment); Minimal – advisory; Significant – mandated by law (punishable) [39].

### Table 5c
Amendments in medical export policy.

| Sector | Timeline (2020) | Export interventions                                                                 | Type* |
|--------|-----------------|--------------------------------------------------------------------------------------|-------|
| Active pharmaceutical ingredients (APIs) | April May | Prohibited for paracetamol APIs As an exception, HCQ was exported to 55 countries with COVID-19 | Significant |
| Diagnostic kits | April June | Restricted for certain diagnostic or laboratory reagents Restricted for viral transport medium (VTM) kits and reagents and reverse transcription polymerase chain reaction (RT-PCR) extraction kits and reagents | Significant |
| Ventilators | March August | Prohibited for ventilators and any other breathing device | Minimal |
| PPE | June July | Prohibited for medical coveralls, goggles, face shields Upper cap on PPE medical coveralls Permitted for surgical droapes, isolation aprons, surgical wraps and X-ray gowns, face shields Restricted for medical goggles (upper cap on export volume) | Significant |
| Masks | May July | Permitted for non-medical or non-surgical masks Restricted for surgical masks (upper cap on export volume) | Minimal |
| Sanitisers | May June | Prohibited for alcohol-based sanitisers Prohibited for alcohol-based hand sanitisers with dispenser pump | Minimal |
| Textile raw material | July | Prohibited for fabrics used to make medical masks | Minimal |

* Type: Medium – mandated by law (no punishment); Minimal – advisory; Significant – mandated by law (punishable) [39]
telemedicine units for home-quarantined cases (asymptomatic) provided a digital platform for a COVID-19 treatment [55], thereby reducing the burden on the health infrastructure. Further, the success of policy and technological interventions applied together was evident in the form of a substantial reduction in the number of new COVID-19 infections reported from Asia’s largest slum (Dharavi) in the state of Maharashtra, the financial capital of India [56]. Here, on the technological front, both swab and blood tests of suspected cases were conducted, while on the policy front an ‘Integrated Disease Surveillance Programme’ was activated, which involved healthcare workers going door to door to test suspected cases and their family members.

**Evolution of testing criteria**

Initially, the testing protocol was limited to symptomatic international passengers entering India, contact history with a positive case, and symptomatic healthcare workers. However, from April onwards people in infection hotspots with symptoms of cold, cough and fever; individuals who participated in large gatherings; and patients with severe acute respiratory illness could be tested. It was reported that nearly 80% of confirmed cases were asymptomatic or had mild symptoms [57]. A revised discharge policy (10 days) was recommended compared with the initial 14 days standard from symptom onset and no fever for three days, to reduce the pressure on medical infrastructure [58].

**Evolution of testing methods**

During the early phases of the COVID-19 outbreak, public hospitals used the RT-PCR method, which gave results of high accuracy but with a turnaround time of 24 hours. The scale of testing increased as private laboratories began performing tests and using the antibody blood test, which gave results in less than 30 minutes, but with an accuracy as low as 50%. The Indian Council of Medical Research (ICMR) issued guidelines for unconfirmed cases with negative results from antigen tests to have RT-PCR done; in Delhi alone less than 1% of those with negative antigen results received an RT-PCR test [32]. As of 4 August 2020, 30% of all tests being conducted were antigen tests [59]. The COVID-19 positivity rate may not have given a clear picture of the scale of the outbreak due to large numbers of false negatives. This hindered contact tracing and may have acted as a catalyst for new cases. Furthermore, India’s testing rate continues to be one of the lowest in the world [60]. Despite a manufacturing capacity of 4.87 million test kits per day, the country could only conduct 0.7 million tests per day as of 12 August 2020. This could be attributed to the fact that the state governments paid private laboratories in the range of almost half of the price cap set by ICMR [61]. More tests per million people did not necessarily result in more positive cases being detected (see Table 8) [62]. For example, in Rajasthan and Bihar, more positive cases per 100 tests were found in Bihar than Rajasthan, even though more tests per million people were conducted in Rajasthan.

**Healthcare system response data**

**Demand-side versus supply-side scenario**

With increased testing capacity, infrastructure and human resources, India equipped itself to handle the expected surge in cases during the later phases of lockdown. In addition to public-private partnerships (PPPs) in the health sector, the government augmented health infrastructure through the creation of dedicated COVID-19 facilities. As shown in Fig. 10 [63], admission to a dedicated COVID-19 facility was based on the clinically assessed med-
The fiscal and monetary policies introduced by the Indian government aim to mitigate the adverse economic impact of COVID-19. Table 6 illustrates the measures taken by the Reserve Bank of India (RBI) to supportנוע את רישומי הם מיושרים עם מדיניות מרמאות שונות. שיתוף פעולה עם הרשת של מסגרת הרמה בישארת במרחבי תקופת קורונה-19 הנוגעת ב מידע שהושקע במערכי תקופת קורונה-19. עם זאת, מאמץ ההערכה של процент העלייה במערך-medical infrastructure בתקופת קורונה-19 נותרו שלוקדים,следствие deficit במערך-medical infrastructure בתקופה שלאחר קורונה-19. בעקבות אובדן מידע ש_inds in the event of any shortfall of funds.

### Table 6

| Measure | Mode | Action | Type |
|---------|------|--------|------|
| Fiscal, monetary rates | Reserve Bank of India (RBI) | Slashed repo rate* Extended the loan repayment period | Medium |
| Schemes | Pradhan Mantri Garib Kalyan Yojana | Payment (ex gratia) to poor senior citizens, widows and the disabled Insurance coverage for healthcare workers involved with COVID-19 treatment and care Medical insurance to cover all health workers States to provide cash transfers in installments to farmers | Minimal Medium |
| | Pradhan Mantri Kisan Yojana Jan Dhan accounts Employee Provident Fund (EPF) | Monthly cash transfers to 200 million women Government contribution to EPF (for both employer and employees for companies with less than 100 workers) | Significant |
| | | Covered 800 million people Free liquefied petroleum gas (LPG) for ‘Ujjwala Scheme’ beneficiaries for a specified period of time | Minimal |
| Food security | Scheme | States to use construction worker funds | Medium |
| Construction funds | Scheme | Credit line to small businesses and support to shadow banks Food-grains to stranded workers for two months and credit to farmers Support for agriculture and allied sectors and, structural reforms | Significant |
| Education | Fee | Private schools could not hike fees, could only charge a tuition fee | None |
| Atmanirbhar package | Stimulus package announced 13 May | Credit line to small businesses and support to shadow banks Food-grains to stranded workers for two months and credit to farmers Support for agriculture and allied sectors and, structural reforms | Significant |

* Type: Medium – mandated by law (no punishment); Minimal – advisory; Significant – mandated by law (punishable).
** repo rate – the rate at which RBI lends money to commercial banks in the event of any shortfall of funds.

The fiscal and monetary policies introduced by the Indian government aimed at mitigating the adverse economic impact of COVID-19. Table 6 provides information regarding the medical infrastructure in these facilities. However, estimating the percentage increase in medical infrastructure pre- and post COVID-19 remains a challenge, due to the absence of data regarding new infrastructure that has been built and existing private facilities that were reserved as COVID-19 wards.

### Medicines and medical services

All elective surgeries were curtailed during phases 1 and 2 of the lockdown, with only life-saving surgeries taking place from 21 March 2020 [65]. Patients dealing with other ailments were encouraged to use telemedicine services, as outpatient departments were closed [66]. However, lockdown 4 included the opening of outpatient services for all ailments.

### Economic and financial fluctuations

**Fiscal value of human lives lost to COVID-19**

Subsequent lockdown phases since the start of the pandemic have had an adverse impact on the Indian economy. Table 10 [67] shows an approximation of the total fiscal value (TFV) of human lives lost in India due to COVID-19 as USD 815 million (4% rate) and USD 703 million (6% rate) at the prevailing interest rates in India (to 12 August 2020). As shown in Eq. (1), the discounted fiscal value (DFV) for a particular age group has been calculated as the product of non-health GDP per capita (NGDPC), discounted years of life lost (DISYLL), and the number of deaths in the age group due to COVID-19 [67]. NGDPC has been calculated as the difference between GDP per capita and current health expenditure (CHE). Years of life lost (YLL) for each age group have been estimated as the difference between the life expectancy at birth (LE) and the average age at death from COVID-19 [56]. The discount factor $1/(1+r)^k$ in Eq. (1) has been used to calculate DISYLL, where $r$ is an interest rate that measures the opportunity cost of lost earnings. The summation (Eq. (1)) used $k = 1$ as the first year of life lost and $k = n$ as the final year of the total number of YLL per case of COVID-19 within an age group. The number of deaths due to COVID-19 in a particular age group (N) has been approximated as a percentage of the total number of deaths (TD) due to COVID-19 (see Fig. 7). The fiscal value of life lost across the age groups in Table 10 was summed up, and finally the average monetary value per human life lost was calculated as total fiscal value divided by TD. Also, the average monetary value per human life lost from COVID-19 in India was found to be sensitive to the dis-
Table 7
Technological initiatives initiated in response to COVID-19 (pre-COVID-19 peak).

| Category       | Advance                        | Description                                                                 | Type       |
|----------------|--------------------------------|----------------------------------------------------------------------------|------------|
| Testing        | Indigenous testing kits        | Testing kits at one-fourth the cost of imported kits with results in 2–3 hours Rapid antibody kits were designed The world’s most affordable testing kit (to date) at a base price of USD 8 was developed [54] | Significant|
|                | Immunodiagnostic kits          | Efforts were initiated since they can also detect asymptomatic cases       | Significant|
| Tracing        | Manual process                 | Contact tracing through in-depth interviews                                | Minimal    |
|                | Drones used for surveillance    | Monitoring whether areas in a city were following social distancing via an aerial view | Medium     |
|                | and public announcements       |                                                                             |            |
|                | Aarogya Setu App               | Real-time data update powered by Bluetooth technology and artificial intelligence Risk-assessment, contract tracing for individuals | Significant|
| Treating       | Vaccine                        | Launched phase II human trials                                             | Significant|
|                | Thermal screening              | Temperature checks during international and interstate travel              | Minimal    |
|                | Selected drugs                 | Existing preventive drugs approved for emergency use                        | Medium     |
|                | Convalescent plasma therapy    | Blood transfusion from recovered patients                                   | Medium     |
|                | Tele-health                    | Online applications designed                                               |            |
|                | Laboratory-manufactured PPE    | Designed at a reduced cost. PPE could be taken off without touching the outer surface | Significant|
|                | alcohol sanitisers             | To disinfect people when they walk through it                               | Significant|

* Significant: an innovation; Medium: successful use of an existing technology or therapy; Minimal: manual intervention for results [39].

Table 8
Variation in the scale of testing across states around 12 August 2020.

| State          | Tests per million people | Positive tests per million people | Positive per 100 testspeople |
|----------------|--------------------------|----------------------------------|-----------------------------|
| Bihar          | 8,425                    | 657                              | 7.8                         |
| Delhi          | 59,308                   | 7,235                            | 12.2                        |
| Gujrat         | 14,355                   | 1,033                            | 7.2                         |
| Madhya Pradesh| 10,705                   | 469                              | 3.9                         |
| Maharashtra    | 22,161                   | 4,270                            | 19.3                        |
| Kerala         | 27,803                   | 970                              | 3.5                         |
| Punjab         | 16,328                   | 377                              | 4.4                         |
| Rajasthan      | 22,260                   | 671                              | 3.0                         |
| Tamil Nadu     | 17,814                   | 1,605                            | 9.0                         |
| Uttar Pradesh  | 13,684                   | 538                              | 3.9                         |
| West Bengal    | 11,343                   | 980                              | 8.6                         |

Table 9
Medical infrastructure in dedicated COVID-19 facilities.

| Category                | DCH | DCHC | CCC |
|-------------------------|-----|------|-----|
| Dedicated facilities    | 1,378 | 3,077 | 10,351 |
| Total ICU beds          | 46,487 |      |      |
| Total oxygen support beds | 165,361 |      |      |
| Total ventilators       | 21,738 |      |      |

count rate [67].

\[
DFV = \sum_{k=1}^{K-n} \left[ \frac{1}{(1+r)^k} \right] \times NGDPC \times N;
\]

\[ k = 1 \ldots \text{final year of total YLL within an age group} \]  \tag{1}

International trade and sectoral impact

The World Bank downgraded India’s growth for the fiscal year 2021 [68]. However, the International Monetary Fund’s GDP growth projection (2021–22) for the country (1.9%) was the highest among the G20 nations [69], although the pandemic in India began when its GDP had already been on a downward trajectory since Q2 2018–19 and experienced a new low (4.5%) in Q2 2019–20 (see Fig. 11) [70,71]. The impact of any economic downturn will depend on the duration and severity of the pandemic. In an optimistic scenario, the recovery could be V-shaped, both in GDP growth and inflation, compared with a U-shaped recovery in an extended recovery scenario.

Credit rating agencies have downgraded India’s growth for the fiscal year 2021 [72,73]. Exports and imports form a crucial component of GDP. The effect of the COVID-19 pandemic reduced India’s exports by 34.6% and 60.28% in March and April, respectively. The trade deficit narrowed to USD 9.76 billion in March 2020 [74], which was further aggravated by a sharp depreciation of the rupee against the dollar (INR 75 per USD on 20 March) [70]. Many sectors were expected to experience overall negative growth [73], especially import-driven sectors such as the automotive industry [75]. The Indian aviation industry (the world’s third-largest domestic aviation market) [76] was near to collapse following the travel bans; however, it gradually started to revive with the opening up of domestic flights. Severe liquidity problems were experienced by the hospitality industry (airlines, hotels and restaurants). Amidst this economic uncertainty and a collapsing growth rate, the RBI slashed repo rates to provide stimulus to the economy, increase liquidity in the market and possibly reduce the cost of financing for the corporate sector. Despite these efforts, the growing number of COVID-19 cases casts a shadow on the recovery of the economy in the near future.

Discussion

Understanding the impact of the COVID-19 pandemic on any country and analysing the impact of interventions that were intended to contain it requires several critical considerations at the
present (in addition to a lot more data in the future to substantiate any findings, in the absence of any precedents). One needs to appreciate the size of a nation; consider its population, the socio-economic fabric of which can support or cripple any policy intervention; have a thorough grasp of how good or bad its healthcare system was in the first place; have the right definition of success criteria in line with the extent of the spread of the virus; and possess the ability to identify relevant and useful data.

COVID-19 vis a vis the Indian context

In a developing country such as India, with the world’s second-highest population, fifth-largest economy, the fastest-growing major economy [77], and one of the lowest healthcare expenditures per capita, it is easy to see how a disaster such as the COVID-19 pandemic would be catastrophic for the nation, both in terms of lives and livelihoods. Even the most earnest, massive, and unprecedented policy and technological interventions would be at best limited in their ability to solve the prevailing problems. Despite this, the country has fared much better than many other developing countries in managing the health impact of the crisis so far.

Health impact

Our study found that the high recovery rate from COVID-19 in India was a result of significant technological interventions, effective mitigation policies implemented in a phased manner by the government, complemented by the demographic dividend. However, any initial success of handling the pandemic will not last without continuous and reliable testing followed by contact tracing [78]. For instance, the state of Kerala, which was initially leading the country’s war against the pandemic, later showed a significant drop in recovery rates due to a resurgence in confirmed cases [79]. With stark variations in the numbers of tests as well as COVID-19 trends across the states of India, they were uniquely equipped to handle the pandemic.

While increased testing has been proposed as the most potent solution to COVID-19 globally, it is important to understand country-specific nuances around how testing is being carried out and how it should be done, to arrive at the right solution for India. An increased capacity to manufacture testing kits in India is commendable but will only make a difference to the overall spread of the pandemic if it aligns with the number of tests conducted daily, dependent on the availability of healthcare services. Again, variations in COVID-19 tests conducted to accelerate national level testing should be based on the reliability of results, so as not to slow down contact tracing efforts.

Economic impact

On the economic side, high unemployment during the nationwide lockdown, instead of an initial lockdown policy based on disease spread within states [80], complemented by paid-for testing and expensive treatment for COVID-19 in private facilities, have only exacerbated the existing state of economic inequity [81]. On the surface, while the resumption of economic activity amid the pandemic looks set to lead to economic recovery, the economic modelling used shows that the average monetary value per human life lost from COVID-19 in India translates to 7.09–8.22-fold of the country’s GDP per capita.

Conclusions and policy implications

The spread of COVID-19 in India has tested the country’s pandemic preparedness in terms of its health infrastructure, technological capabilities and policy interventions. The initial impact of a timely and one of the most stringent lockdown policies was observed to slow the spread of the virus. At the same time, it helped the country to prepare critical medical infrastructure, human resources and technological advances. The severity of the COVID-19 pandemic in India has been relatively low compared with many other developing countries in terms of case fatality and recovery rates. However, the crisis has augmented the pre-existing risks of economic slowdown, while the underfunded public healthcare system has played havoc with the pandemic management strategy in the country. Overall, the pandemic has been a wake-up call and India is now consciously thinking about embracing long-term mea-

### Table 10

| (A–B) | NGDPC (USD) | Deaths (N) | YLL (Years) | DISYLL (4%) | DFV (4%) | DISYLL (6%) | DFV (6%) |
|-------|-------------|------------|-------------|-------------|----------|-------------|----------|
| 0–4   | 2,034.81    | 565        | 67.41       | 24.15       | 27,799,376.07 | 17.32     | 19,934,549.17 |
| 5–19  | 2,034.81    | 424        | 57.41       | 23.26       | 20,083,290.86 | 17.04     | 14,713,486.88 |
| 20–29 | 2,034.81    | 989        | 44.91       | 21.53       | 43,374,123.95 | 16.38     | 32,987,048.09 |
| 30–39 | 2,034.81    | 2,168      | 34.91       | 19.39       | 85,544,760.63 | 15.36     | 67,755,154.40 |
| 40–49 | 2,034.81    | 6,457      | 24.91       | 16.21       | 213,046,660.37 | 13.53     | 177,779,597.4 |
| 50–59 | 2,034.81    | 12,255     | 14.91       | 11.51       | 287,099,015.61 | 10.26     | 255,779,462.1 |
| 60–69 | 2,034.81    | 14,989     | 4.91        | 4.55        | 138,917,286.95 | 4.40      | 134,078,523.48 |
| *70–79* | 2,034.81   | 6,929      | –           | –           | –         | –           | –         |
| *80+*  | 2,034.81    | 2,404      | –           | –           | –         | –           | –         |
| TFV (USD) | 815,864,514.44 | –         | –           | –           | –         | –           | –         |
| Average monetary value per human life lost (USD) | 17,308.00 | 703,027,821.52 | 14,914.25 |

Data used: TD around 12 August 2020 = 47,138 [3], GDP per capita (2018) [5], CHE (2017) [5].

The LE in India is 69.41 years [3], therefore the fiscal valuation of deaths due to COVID-19 for age groups beyond 69.41 years was not performed.

Fig. 11. Real GDP growth percentage (constant 2011–12 prices).
sures to develop a responsive, sustainable and robust healthcare system, to which PPPs and the manufacturing sector might make significant contributions.

Limitations of the study and scope of future work

Due to limitations of data relating to existing and augmented infrastructure facilities in terms of hospitals, beds and ventilators, a comparison of pre- and post-COVID-19 infrastructure is missing. Case fatality rate analysis based on co-morbidities is missing due to insufficient availability of secondary data. Future work could include recommendations for possible revisions to the existing population-level policy, taking a cue from other countries. This could help ensure comparable infrastructure and resources to face future pandemics.

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Isha Goel: Conceptualization, Data curation, Formal analysis, Writing - original draft, Writing - review & editing. Seema Sharma: Supervision. Smita Kashiramka: Supervision, Writing - review & editing.

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