

1 **Demand for hospitalization services for COVID-19 patients in Brazil**

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15

16 **Abstract**

17 COVID-19 is now a pandemic and many of the affected countries face severe shortages of
18 hospital resources. In Brazil, the first case was reported on February 26. As the number of cases
19 grows in the country, there is a concern that the health system may become overwhelmed,
20 resulting in shortages of hospital beds, intensive care unit beds, and mechanical ventilators. The
21 timing of shortage is likely to vary geographically depending on the observed onset and pace of
22 transmission observed, on the availability of resources, and on the actions implemented. Here we
23 consider the daily number of cases reported in municipalities in Brazil to simulate twelve
24 alternative scenarios of the likely timing of shortage, based on parameters consistently reported
25 for China and Italy, on rates of hospital occupancy for other health conditions observed in Brazil
26 in 2019, and on assumptions of allocation of patients in public and private facilities. Results
27 show that hospital services could start to experience shortages of hospital beds, ICU beds, and
28 ventilators in early April, the most critical situation observed for ICU beds. Increasing the
29 allocation of beds for COVID-19 (in lieu of other conditions) or temporarily placing all resources
30 under the administration of the state delays the anticipated start of shortages by a week. This
31 suggests that solutions adopted by the Brazilian government must aim at expanding the available
32 capacity (e.g., makeshift hospitals), and not simply prioritizing the allocation of available
33 resources to COVID-19.

34

35 **Introduction**

36 On March 11 the World Health Organization characterized COVID-19 as a pandemic. Caused by
37 the novel coronavirus SARS-CoV-2, it emerged in China and quickly spread across the country
38 and beyond. As of March 27, it was present in 202 countries and territories, with 509,164 cases
39 and 23,335 deaths reported.¹ The clinical course of COVID-19 poses serious challenges to the
40 health system and may call for drastic rationing decisions.^{2,3} Specifically, allocating hospital
41 beds, intensive care unit (ICU) beds, and mechanical ventilators to COVID-19 patients, besides
42 the ongoing demand driven by other conditions, is a real or soon to be a real problem.⁴⁻⁶

43 Brazil recorded the first COVID-19 case on February 26 and the first death on March 17, both in
44 São Paulo. In 24 days, the disease had spread to every federal unit. As of March 27, 3,417 cases
45 and 92 deaths had been reported. As the numbers increase across the country, so does the
46 demand for hospital services, raising concerns of hospital capacity to cope with that demand.

47 Brazil has a hybrid health system.^{7,8} On the one hand, every citizen has free access to the Unified
48 Health System (SUS). On the other hand, the private sector offers services covered by out of
49 pocket payments and private insurance plans. About 80% of the Brazilian population relies
50 solely on SUS, but this number varies widely across the country reflecting striking inequalities.⁹
51 The offer of hospital services is also unequal. As of December 2019, 67% and 48% of the total
52 available hospital beds and ICU beds, respectively, were offered in the public system.

53 Geographically, the distribution was also unequal, with 9 and 21 beds per 100,000 people in the
54 North and Southeast regions, respectively.¹⁰

55 Here we address this concern and simulate the time it would take for hospitals to operate at
56 capacity, given the current trajectory of COVID-19 in Brazil. We considered different scenarios
57 of supply and demand and detailed the simulations by day and health macro-region. Since not all

58 services are available in each municipality, the Ministry of Health (MoH) considers the macro-
59 region to guide the regionalization of health services.

60

61 **Methods**

62 DATA SOURCES

63 Population by age group and the number of confirmed COVID-19 cases were obtained from the
64 MoH.¹¹ Information on available hospital beds, ICU beds, and mechanical ventilators as of
65 December of 2019 was extracted from the National Registry of Health Establishments (CNES,
66 <http://cnes.datasus.gov.br/>). We excluded pediatric and obstetric beds, and pediatric, neonatal,
67 and burn recovery ICU beds. We distinguished hospital beds and ICU beds by type of service
68 (private and public); this classification was not available for mechanical ventilators. Average
69 public hospital occupancy in 2019 (detailed by hospital beds and ICU beds) was obtained from
70 the hospitalization system of the MoH (<http://sihd.datasus.gov.br/>). There was no information on
71 the occupancy rate for private hospitals (here we assumed the same rate obtained for public
72 hospitals). Lastly, access to private health insurance in December 2019 was extracted from the
73 Brazilian Regulatory Agency ([http://www.ans.gov.br/perfil-do-setor/dados-e-indicadores-do-](http://www.ans.gov.br/perfil-do-setor/dados-e-indicadores-do-setor)
74 [setor](http://www.ans.gov.br/perfil-do-setor/dados-e-indicadores-do-setor)).

75

76 STATISTICAL ANALYSIS

77 We conducted forward simulations of the demand for hospital beds, ICU beds, and mechanical
78 ventilators by health macro-region in Brazil. In the initial phase of a new infectious disease
79 outbreak, the number of cases grows exponentially.^{12,13} Using the number of cases reported to

80 date and estimates of doubling times from the outbreak in China,¹⁴⁻¹⁶ we estimated the number of
81 future cases each day. As the outbreak spreads, the exponential model becomes less realistic,¹³ so
82 we stopped the simulations once 10% of the population was estimated to be infected.
83 We used the age structure of each macro-region combined with age-specific attack and severity
84 rates drawn from the literature. We used attack rates by age from the outbreak in China,¹⁷
85 considering a range of $\pm 3\%$, and considered that 86% of all infections were undocumented.¹⁸
86 Demand for hospitalization was calculated using the severity of cases by age from China.¹⁷ Time
87 from illness to hospitalization was 3-7 days,^{19,20} and length of hospitalization ranged from 7-15
88 days;²¹ for ICU hospitalizations these parameters were 8-15,^{19,20} and 7-15,^{21,22} respectively. We
89 considered that 5% of the cases needed ICU admission^{21,23} and half of those in ICU needed
90 mechanical ventilation^{20,21} for an average of 5 days.²⁴ We also simulated an alternative scenario
91 based on Italy and assumed that 12% of the cases needed ICU admission.^{4,6} These parameters
92 were combined with assumptions of hospital occupancy and type of service to produce twelve
93 scenarios, summarized in Table 1. We performed 1,000 runs for each scenario, drawing from the
94 $\pm 3\%$ uncertainty around attack rates, and considered the results that represented the median of
95 the distribution. All analyses were performed with the use of R software, version 3.6.3, and
96 Rstudio, version 1.2.5033 (R Foundation for Statistical Computing).

97

98 **Table 1. Parameters considered for simulated scenarios**

Scenarios	Assumptions		
	Hospital occupancy	Demand for ICU beds	Public x Private Services
1	Beds, ICU beds, and ventilators available for COVID-19 constrained by average occupancy in 2019	5% of cases	Demand for public/private services apportioned by access to private health insurance in 2019

2	Beds, ICU beds, and ventilators available for COVID-19 constrained by average occupancy in 2019	5% of cases	80% of the demand is for public services
3	Beds, ICU beds, and ventilators available for COVID-19 constrained by average occupancy in 2019	5% of cases	Private hospitals temporarily under the control of the state
4	Beds, ICU beds, and ventilators available for COVID-19 constrained by average occupancy in 2019	12% of cases	Demand for public/private services apportioned by access to private health insurance in 2019
5	Beds, ICU beds, and ventilators available for COVID-19 constrained by average occupancy in 2019	12% of cases	80% of the demand is for public services
6	Beds, ICU beds, and ventilators available for COVID-19 constrained by average occupancy in 2019	12% of cases	Private hospitals temporarily under the control of the state
7	2019 occupancy reduced by 50%, and services allocated to COVID-19	5% of cases	Demand for public/private services apportioned by access to private health insurance in 2019
8	2019 occupancy reduced by 50%, and services allocated to COVID-19	5% of cases	80% of the demand is for public services
9	2019 occupancy reduced by 50%, and services allocated to COVID-19	5% of cases	Private hospitals temporarily under the control of the state
10	2019 occupancy reduced by 50%, and services allocated to COVID-19	12% of cases	Demand for public/private services apportioned by access to private health insurance in 2019
11	2019 occupancy reduced by 50%, and services allocated to COVID-19	12% of cases	80% of the demand is for public services
12	2019 occupancy reduced by 50%, and services allocated to COVID-19	12% of cases	Private hospitals temporarily under the control of the state

99

100 **Results**

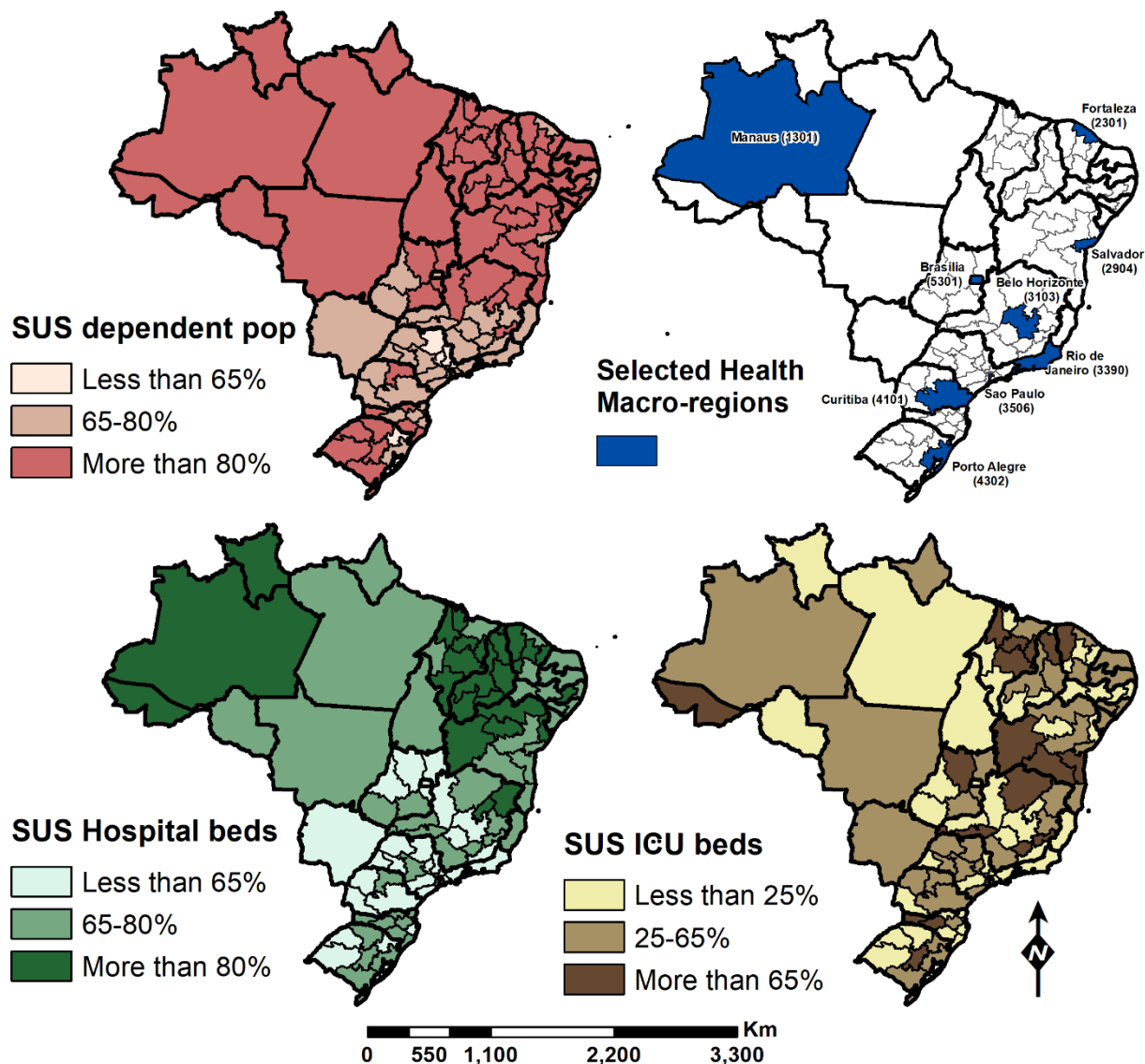
101 Figure 1 shows the fraction of public hospital beds and ICU beds in each health micro-region, as
 102 well as the percentage of the population in those units that rely solely on the SUS. Inequities in
 103 supply and demand exist, and mirror regional inequalities commonly found in social and health
 104 indicators.⁹

105 As of March 27, 3,417 cases were confirmed in Brazil, 70% concentrated in nine cities: São
106 Paulo, Rio de Janeiro, Fortaleza, Brasília, Porto Alegre, Salvador, Belo Horizonte, Curitiba, and
107 Manaus. The growth pattern of the epidemic is not the same across the country. Therefore, we
108 chose to simulate scenarios for the nine health macro-regions associated with those cities;
109 combined these macro-regions represent 79.6% of reported cases. In the case of São Paulo and
110 Brasília, the macro-region includes only the municipality itself. Rio de Janeiro and Manaus have
111 only one macro-region for the entire state. Fortaleza, Porto Alegre, Belo Horizonte, Salvador,
112 and Curitiba are in macro-regions that comprise 44, 89, 103, 48, and 93 municipalities,
113 respectively.

114 Our simulated scenarios indicate that hospital services could start to experience shortages of
115 hospital beds, ICU beds, and ventilators across macro-regions as early as April (Figure 2). ICU
116 beds are, by far, the most pressing need. The supply of hospital beds is likely to face shortages
117 after April 21 and of mechanical ventilators just a few days afterward. The two scenarios for ICU
118 admission (5% and 12% of the total cases) resulted in about 4-6 days difference. With a 12%
119 assumption, Brasília would face a shortage of ICU beds by the end of March. Making 50% of
120 usual occupancy dedicated to COVID-19 postpones shortages for less than a week, and placing
121 all resources under state control shifts the capacity threshold by up to one week for hospital beds
122 and mechanical ventilators, and by up to four days for ICU beds. Considering alternative
123 hypothesis of access to public resources, scenarios 2, 5, 8, and 11 assumed that 80% of the
124 demand would come from individuals that solely rely on SUS. Since the offer of SUS services
125 presents regional inequities (Figure 1), the timing of shortage depends both on the share public x
126 private in each area.

127

128 **Figure 1. Percentage of the population that relies solely on the SUS, percentage of beds**
129 **available in each health macro-region that are allocated to, and location of the simulated**
130 **micro-regions.** Thicker black lines define the boundaries of the federal units. Selected health
131 macro-regions are named after the capital city, and the ID code is also provided.



132
133

134 The timing of shortage varied by health macro-region. It depends on the observed onset and pace
135 of transmission. For example, although the first case in Fortaleza was reported on March 15, 18
136 days after the first case was reported in the country, it took eight days to reach to 100 cases. In
137 São Paulo, where the first case was reported, the first 100 cases were recorded in 19 days.

138 **Figure 2. Date when hospital services will be at capacity in each simulated scenario.**
 139 Numbers on the left represent each of the 12 simulated scenarios described in Table 1. Names on
 140 top indicate the municipality of reference to the health macro-region. HB = hospital beds. ICUB
 141 = ICU beds. MV = mechanical ventilators. Numbers on the table refer to day of the month, and
 142 cell colors indicate the month. Results reflect the median after 1,000 runs of the model.
 143

	São Paulo	Rio de Janeiro	Brasília	Fortaleza	Belo Horizonte	Porto Alegre	Curitiba	Salvador	Manaus	
1	15	20	13	16	27	20	23	26	26	HB
	12	15	3	8	6	13	13	13	12	ICUB
	26	29	20	20	24	24	24	29	1	MV
2	13	19	12	16	27	20	22	27	27	HB
	10	14	3	9	6	13	13	13	13	ICUB
	24	28	19	21	24	23	23	29	2	MV
3	17	21	14	17	29	21	23	27	27	HB
	17	21	11	11	11	15	13	18	16	ICUB
	26	30	21	21	25	23	27	30	2	MV
4	14	20	13	16	27	20	23	27	27	HB
	7	10	29	5	1	8	8	8	8	ICUB
	20	24	15	16	19	19	18	24	26	MV
5	12	19	12	16	27	20	22	27	27	HB
	5	10	29	5	1	7	7	8	8	ICUB
	18	23	14	17	18	18	17	24	26	MV
6	16	21	14	17	29	21	23	28	27	HB
	11	16	6	7	6	10	8	13	11	ICUB
	21	25	16	17	19	18	21	25	26	MV
7	17	22	16	22	30	22	25	29	30	HB
	14	17	5	13	7	15	15	14	14	ICUB
	28	1	22	26	27	26	26	1	4	MV
8	15	21	15	18	29	22	25	29	30	HB
	12	16	4	10	7	15	14	15	14	ICUB
	26	30	21	22	26	25	25	1	4	MV
9	19	23	16	19	1	23	26	30	30	HB
	19	23	13	13	13	17	15	20	18	ICUB
	29	2	23	23	28	25	29	2	4	MV
10	17	22	16	22	30	22	25	29	30	HB
	9	13	31	9	1	10	9	9	9	ICUB
	23	26	17	22	21	21	20	26	28	MV
11	16	21	15	18	29	22	25	29	30	HB
	7	12	30	6	1	9	9	10	9	ICUB
	21	25	16	18	21	20	20	27	29	MV
12	19	23	16	19	1	23	26	30	30	HB
	14	18	8	9	7	12	10	15	13	ICUB
	23	27	18	19	22	21	23	27	29	MV

March
 Apr 1-15
 April 19-30
 May

144

145 **Discussion**

146 Our simulated scenarios show that, if no change in trajectory is observed, around early April
147 Brazil would start to face shortages of hospital beds, ICU beds, and ventilators, with ICU beds
148 being the most immediate problem. The timing of shortages across the country depends on the
149 onset and the intensity of transmission. Also, the population that relies solely on SUS may bear
150 the largest burden, further exacerbating the existing inequalities, which calls for a reflection
151 around equity and ethics in service allocation. Avoiding this scenario is the paramount task of the
152 MoH.

153 It is unreasonable to expect that all hospital resources could be entirely dedicated to COVID-19.
154 Although elective procedures can be postponed, other health emergencies compete for resources.
155 For example, dengue transmission is presently intense and increasing; until March 14 there were
156 390,684 cases and 106 deaths (60.4% of them among individuals aged 60 or more). In 2019,
157 with more than 1.5 million cases of dengue reported, 4% (n=55,235) required hospitalization.
158 Most importantly, 45% of the dengue hospitalizations occurred between March and May (21%
159 just in May, the month when most likely the hospitals will be operating at capacity because of
160 COVID-19). In addition, the influenza season is starting, and in 2019 the peak of hospitalizations
161 occurred in May. Besides beds and ventilators, the stress imposed on the health system
162 compromises the overall care, which may result in deterioration of the treatment of other
163 conditions followed by increases in incidence. This scenario was observed during the 2013-14
164 Ebola outbreak.²⁵

165 Shifts in the current trajectory of the epidemic in Brazil may anticipate or postpone the stress on
166 health services. Importantly, our results are sensitive to assumptions about key parameters in the

167 model, including the doubling time, underreporting rate, age-specific attack and severity rates,
168 time from illness to hospitalization and ICU, and length of stay estimates. By drawing on
169 available evidence of how COVID-19 has and is evolving across the globe, our results rely on
170 and reflect the limitations of the parameters observed in China and on unique patterns reported in
171 Italy. Given the significant uncertainty in parameter estimates at this phase of the epidemic and
172 the simplifying assumptions of an exponential model, results from our simulated scenarios
173 should not be used as precise estimates for the exact timing and extent of capacity thresholds
174 being reached. Instead, they aim to inform planning and prompt response and do send three
175 important messages.

176 First, the epidemic of COVID-19 is likely to exacerbate existing inequalities if those that solely
177 rely on the SUS are hit the hardest. In communities with high population density and poor
178 infrastructure, it is unfeasible to practice social isolation. In those areas, the transmission is likely
179 to occur fast and the population mostly relies only on the SUS, quickly overwhelming the health
180 system. One alternative to alleviate the is to temporarily put all private hospitals under the
181 control of the state, a measure adopted by Spain.²⁶ Yet, our results show that this would postpone
182 shortages by about a week. In fact, solutions that do not involve the opening of new facilities will
183 have a very short effect on the timing of shortage.

184 Second, there is a short window of opportunity to prepare. The response must be immediate, and
185 it will demand a concerted effort from society. Repurposing large spaces (e.g., arenas,
186 convention centers) to build makeshift hospitals for additional beds is critical. Calling on the
187 industry to produce the necessary equipment (e.g., ventilators, masks, gloves, protective gown,
188 etc) and to provide it to hospitals at minimum or no cost would also contribute to mitigating the
189 stress on the system, and to safeguarding the working conditions of health care professionals.

190 Mobilizing community leaders, artists, athletes, and local role models would help to convey a
191 unique message to the population, and to gather support from the wealthy that could provide
192 resources to expand the production of medical equipment.

193 Third, additional actions to contain the transmission and to change the current trajectory of the
194 epidemic must be taken. Partial shutdown has been initiated in many Brazilian cities, but
195 compliance is far from ideal. Increasing the availability of tests would allow the government to
196 comprehensively trace and test all contacts of positive cases, a strategy successfully adopted by
197 South Korea.²⁷ Without intensified actions, or even worse, if current actions are loosened, Brazil
198 may face the need to implement guidelines for rationing health resources,² which invariantly call
199 for difficult decisions.

200

201 **Conclusion**

202 Brazil is, in theory, uniquely equipped to respond to the COVID-19 epidemic. It has a free and
203 universal health system,⁷ it has one of largest community-based primary care delivery programs
204 that serves 74·8% of the population,²⁸ it can learn from the mistakes and success that other
205 countries hit by COVID-19 have made, and it has a history of responding to health threats by
206 implementing governmental action and by generating high-quality scientific evidence, such as
207 was done when Zika virus hit the country.²⁹ Yet, the current moment is unique. It requires a
208 unified message from the country's leadership at various levels: federal, state, and municipal. It
209 requires the industry to work in solidarity to produce needed inputs without aiming profit but the
210 collective wellbeing. It requires the population to realize the importance and the urgency to
211 comply. We hope our results will help to move forward this agenda.

212

213 **Contributors**

214 MCC conceived the original, was responsible for data analysis, data interpretation, data
215 visualization, and wrote the manuscript. LRC was responsible for data curation, data analysis,
216 programming, and contributed to writing. RK and TC were responsible for programming and
217 contributed to writing. GVAF, EMM, and WKO were responsible for data curation and
218 interpretation. All authors approved the final version of the manuscript.

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