Effect of socioeconomic inequalities and vulnerabilities on health-system preparedness and response to COVID-19 in Brazil: a comprehensive analysis

Rudi Rocha, Rifat Atun, Adriano Massuda, Beatriz Rache, Paula Spinola, Letícia Nunes, Miguel Lago, Marcia C Castro

Summary

Background COVID-19 spread rapidly in Brazil despite the country's well established health and social protection systems. Understanding the relationships between health-system preparedness, responses to COVID-19, and the pattern of spread of the epidemic is particularly important in a country marked by wide inequalities in socioeconomic characteristics (eg, housing and employment status) and other health risks (age structure and burden of chronic disease).

Methods From several publicly available sources in Brazil, we obtained data on health risk factors for severe COVID-19 (proportion of the population with chronic disease and proportion aged ≥60 years), socioeconomic vulnerability (proportions of the population with housing vulnerability or without formal work), health-system capacity (numbers of intensive care unit beds and physicians), coverage of health and social assistance, deaths from COVID-19, and state-level responses of government in terms of physical distancing policies. We also obtained data on the proportion of the population staying at home, based on locational data, as a measure of physical distancing adherence. We developed a socioeconomic vulnerability index (SVI) based on household characteristics and the Human Development Index. Data were analysed at the state and municipal levels. Descriptive statistics and correlations between state-level indicators were used to characterise the relationship between the availability of health-care resources and socioeconomic characteristics and the spread of the epidemic and the response of governments and populations in terms of new investments, legislation, and physical distancing. We used linear regressions on a municipality-by-month dataset from February to October, 2020, to characterise the dynamics of COVID-19 deaths and response to the epidemic across municipalities.

Findings The initial spread of COVID-19 was mostly affected by patterns of socioeconomic vulnerability as measured by the SVI rather than population age structure and prevalence of health risk factors. The states with a high (greater than median) SVI were able to expand hospital capacity, to enact stringent COVID-19-related legislation, and to increase physical distancing adherence in the population, although not sufficiently to prevent higher COVID-19 mortality during the initial phase of the epidemic compared with states with a low SVI. Death rates accelerated until June, 2020, particularly in municipalities with the highest socioeconomic vulnerability. Throughout the following months, however, differences in policy response converged in municipalities with lower and higher SVIs, while physical distancing remained relatively higher and death rates became relatively lower in the municipalities with the highest SVIs compared with those with lower SVIs.

Interpretation In Brazil, existing socioeconomic inequalities, rather than age, health status, and other risk factors for COVID-19, have affected the course of the epidemic, with a disproportionate adverse burden on states and municipalities with high socioeconomic vulnerability. Local government responses and population behaviour in the states and municipalities with higher socioeconomic vulnerability have helped to contain the effects of the epidemic. Targeted policies and actions are needed to protect those with the greatest socioeconomic vulnerability. This experience could be relevant in other low-income and middle-income countries where socioeconomic vulnerability varies greatly.

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Introduction

The newly emerged virus SARS-CoV-2 was initially reported in China in December, 2019. On March 11, 2020, WHO declared the SARS-CoV-2 outbreak a pandemic. By April, 2020, western Europe had become the epicentre of the pandemic,[1,2] and by late May, the epicentre had shifted to Latin America, a region that includes low-income and middle-income countries (LMICs) with precarious welfare systems and persistent wide socioeconomic inequalities in the distribution of health-system resources, access to health services, and health outcomes.[2–4]

COVID-19, the disease resulting from SARS-CoV-2 infection, led to 2·8 million deaths worldwide by the end of March, 2021,[5] and has affected countries in different ways.[6] In east and southeast Asia, lessons from previous

Research in context

Evidence before this study

The spread, response, and impact of COVID-19 in Brazil have been widely discussed in the Brazilian media and documented in academic articles. However, there are few quantitative studies and, where they exist, they have focused on a particular aspect of the response and have not examined in a systematic way overall patterns, over time and across regions, for the entire country. We used the search terms "COVID-19", "Brazil", "response", "health system preparedness", "inequalities", and synonyms to search Google Scholar, PubMed, and EconLit up to Nov 24, 2020, to identify relevant studies published in English or Portuguese. These studies have focused on a limited range of indicators (for response and outcome) or on specific regions, states, or populations.

Added value of this study

Our study contributes new comprehensive evidence on the determinants and outcomes of the spread of COVID-19, particularly in contexts of wide socioeconomic and geographical inequalities. By combining data on an extensive set of state-level indicators, municipal-level panels of monthly data, and robust econometric techniques, we produced a wide-ranging characterisation of the spread of COVID-19 in Brazil and identified patterns that could be relevant to informing responses in Brazil and elsewhere. In particular, we found that existing socioeconomic inequalities, rather than age and health status, determined the initial course of the epidemic and deaths from COVID-19, with a disproportionate burden on states and municipalities with high socioeconomic vulnerability, despite their efforts to contain the epidemic. These results revealed the need for targeted policies and actions to protect the most vulnerable groups. The Brazilian experience also reveals that local response and population behaviour in locations with high socioeconomic vulnerability might be instrumental for containing the epidemic, especially in contexts with central government inertia.

Implications of all the available evidence

A similar pattern of the epidemic observed in Brazil has emerged in other countries, particularly in low-income and middle-income countries with wide inequalities, where socioeconomically vulnerable areas and populations are the least protected and face the greatest risk from COVID-19. In addition to risk factors for adverse COVID-19 outcomes, such as older age and chronic disease, policies aimed at fighting COVID-19 should consider socioeconomic vulnerability.

epidemics—such as severe acute respiratory syndrome in 2003 and Middle East respiratory syndrome in 2015—enabled governments to take rapid and efficient health-systems responses to control SARS-CoV-2 transmission.[7] For example, South Korea has implemented an effective mass testing strategy to identify and isolate infected cases.[8] In Singapore, the outbreak was quickly contained by a combination of public health actions, economic support for vulnerable groups, and digital interventions to effect social and behavioural changes in the population.[9]

In western Europe, which has an older population than that of Latin America, the response to the COVID-19 pandemic has varied. Although countries such as France, Italy, Spain, and the UK saw major increases in COVID-19 cases and deaths,[10] the ability of health systems to expand hospital capacity (especially intensive care units [ICUs]), the rapid scale-up of testing for SARS-CoV-2, the presence of social welfare systems, and the state capacity to introduce economic interventions to support businesses and unemployed citizens have helped to cushion the adverse health, economic, and social consequences of COVID-19.[10,11] By contrast, the response in Latin America has been hampered by inadequately resourced health systems,[12] widespread health and socioeconomic inequalities,[13] and weak state capacity to mount comprehensive health, social, and economic responses to the pandemic.[14] In LMICs, health-system preparedness,[15] population behaviour,[16] and local responses to COVID-19[17] have varied.

Since the 1990s, Latin American countries have implemented social policies and health-system reforms that have helped to reduce poverty and expand access to health-care services.[18,19] However, the region remains the most unequal in the world, with large income gaps between the rich and the poor, disparities in social determinants of health, and differences in access to and quality of public and private health services.[18] Brazil, the largest and the most populous country in Latin America, and socioeconomically one of the most unequal, had a rapid and continued rise in the number of cases and deaths from COVID-19 since the first case was recorded on Feb 25, 2020. By Nov 24, 2020, there were 6 020 164 confirmed cases and 168 613 reported deaths,[2] the worst counts in Latin America.

In 1988, Brazil established a unified health system, *Sistema Único de Saúde* (SUS), with the aims of achieving universal health coverage and reducing disparities in access to health-care services and health outcomes.[20] Despite chronic underfunding and complex governance mechanisms, the SUS has helped to successfully expand access to health services throughout Brazil, improve health outcomes, and reduce health inequalities.[21] It has also established a comprehensive health information system in which data on health-service capacity and use, as well as multiple nationally representative surveys, are publicly available. However, multiple layers of geographical and socioeconomic inequalities in health-care access and health outcomes persist.[22] These disparities have worsened after a prolonged economic crisis and fiscal austerity policies introduced since 2016.[23]

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Earlier studies that have examined COVID-19 in Brazil have focused on specific indicators, such as antibody prevalence, poverty, and how mortality from COVID-19 varies by ethnicity and by region.[24–27] In this Article, we present a comprehensive analysis of health-system preparedness and response to COVID-19 in Brazil. We examine the relationship between the availability of health-care resources in different parts of the country, the socioeconomic characteristics of the population (eg, income, housing, and employment status), risk factors for adverse COVID-19 outcomes (age and burden of chronic disease), and socioeconomic vulnerability, with the pattern of spread, response, and outcomes of the epidemic, as measured by the number of deaths by state and municipality.

Methods

Data sources

We used several publicly available data sources (appendix 2 p 1). Recent research and empirical findings, both on a global scale and specifically for Brazil, have reinforced the importance of accounting for overlapping deprivations and multidimensional poverty in the assessment of the capacity that people have to prevent infection and to recover from COVID-19.[27–29] We obtained state-level indicators for socioeconomic and health characteristics of the population from the 2013 National Health Survey (*Pesquisa Nacional de Saúde* [PNS])—the last year with publicly available microdata on chronic conditions—and from the 2019 Continuous National Household Sample Survey (*Pesquisa Nacional por Amostra de Domicílios Contínua* [PNADC], fourth quarter). The combination of these two datasets allowed us to characterise the health, economic, and household characteristics of the Brazilian population specifically related to vulnerability to adverse outcomes with COVID-19.

Data on health vulnerability

From PNS data, we calculated the share of adults (aged ≥18 years) with chronic diseases—those who reported hypertension, diabetes, kidney failure, or lung diseases (such as emphysema, chronic bronchitis, or chronic obstructive pulmonary disease), those with obesity (body-mass index ≥30 kg/m²), or those with a past or current smoking habit. These characteristics are risk factors for adverse outcomes from COVID-19.[30] In addition, we calculated the percentage of households whose physical and environmental conditions might increase vulnerability to COVID-19, including poor walls (uncoated masonry, uncoated rammed earth, and reclaimed wood or straw), no sewage or septic tank, no running water, or no waste collection.

Data on socioeconomic vulnerability

Using PNADC data, we computed the percentage of the population aged 60 years or older and the percentage of the population who were informal workers (those without a formal labour contract and those who were self-employed). We combined the share of households in vulnerable conditions and the share of informal workers with the income and education subcomponents of the state-level Human Development Index (HDI) that is available for Brazil to create a socioeconomic vulnerability index (SVI) by using principal component analysis. The state-level HDI for income and education was computed as a population-weighted average of municipality-level HDI for each subcomponent, obtained from the Atlas of Human Development in Brazil (see appendix 2 p 1) based on data from the 2010 population census. The essential goal of principal component analysis is to reduce a complex set of many correlated variables into a set of fewer, uncorrelated components. Details on how the SVI was constructed and the weights obtained in the principal component decomposition are provided in appendix 2 (p 2). The SVI ranges from 0 to 1, with 0 being the least vulnerable state and 1 the most vulnerable.

See Online for appendix 2

Data on pre-existing hospital services

To assess pre-existing hospital services at the state and municipal levels, we used the National Register of Health Establishments (*Cadastro Nacional dos Estabelecimentos de Saúde* [CNES]) to quantify the number of SUS and private adult ICU beds in January, 2020, and the 2018 Medical Demography in Brazil to obtain the number of ICU physicians, anaesthesiologists, and cardiologists (necessary specialties to treat severe COVID-19 cases in the ICU). Estimates of population by state in 2019 were obtained from the Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatistica*) and used to compute the number of ICU beds per 100 000 residents, and the number of physicians per 100 000 people.

Two measures of pre-existing primary care services in January, 2020, were extracted from the Ministry of Health's e-Gestor *Atenção Básica* database: population coverage of the family health strategy (*Estratégia Saúde da Família*) and of community health agents. Brazil's family health strategy focuses on prevention and provision of essential health-care services, which are delivered by multidisciplinary teams comprising a physician, a nurse, a nurse assistant, and community health agents. Brazil had 44 716 family health teams and 269 921 community health agents in April, 2020. We used the share of the population covered in 2019 by the *Bolsa Família* programme, a conditional cash transfer programme for low-income families in Brazil, as a proxy for social assistance.

Data on response and outcomes

We tracked government responses to COVID-19 both in the executive and legislative branches. From ordinances issued by the Ministry of Health, we obtained the number of new adult ICU beds added to SUS hospital infrastructure for the treatment of COVID-19 at the state level as of June 29, 2020, and Oct 28, 2020. We used a daily composite stringency index at the state level, computed by the COVID-19 Government Response Tracker for the Brazilian Federation, University of São Paulo,[31] to measure the strictness of physical distancing policies based on official regulation of school and work activities, as well as public and private gathering closures along with their duration.

Regarding population behaviour, we tracked adherence to physical distancing policies using data from In Loco, a Brazilian technology company that uses data generated by cellphone applications on user movements, which provided daily averages of the percentage of individuals staying at home, based on locational data from more than 60 million mobile devices. Finally, we obtained the daily number of confirmed deaths at the state and the municipality levels, published by state health secretariats, until Oct 31, 2020.

Statistical analysis

We did analyses at the state and municipal levels. First, we used descriptive statistics and estimated Pearson coefficients for bilateral correlations between state-level indicators to characterise the relationships of the availability of health-care resources and the socioeconomic characteristics of the population with the spread of the epidemic and the response of state governments and populations, in terms of new investments, legislation, and physical distancing. Second, we used panel regression models to characterise the dynamics of COVID-19 death rates, policy responses, and population behaviour across municipalities. More specifically, we relied on a municipality-by-month longitudinal dataset from Feb 1 to Oct 31, 2020, containing COVID-19 death rates (with variation across municipalities and months) and the municipality's income and education subcomponents of HDI (with variation across municipalities, measured in 2010, and henceforth referred to as HDI_{ie}). In the regression analysis, we used a dummy variable indicating whether the municipality had HDI_{ie} below the median as a proxy for local socioeconomic vulnerability (henceforth referred to as SV_m). The panel regressions followed the equation

$$Death_{mst} = \alpha + \sum_{t=3}^{10} \beta_t D_t \times SV_m + \theta SV_m + D_t + \varepsilon_{mst}$$

in which $Death_{mst}$ denotes the COVID-19 standardised death rate in municipality (m), located in state (s), and month (t). We analogously used as outcomes our measures of physical distancing (averaged at the month and municipality level), and the stringency index (averaged at the month and state level). The coefficients β_t capture the relationship between socioeconomic vulnerability (SV_m) and outcome variables over month dummies (D_t, for the months between March and October in comparison to February, the omitted category). The term ε_{mst} is the error. We estimated standard errors clustered at the municipality level to allow for serial correlation within municipalities over time. This specification enables us to test whether the COVID-19 death rate (or the physical distancing and stringency indices) dynamics have been differentially related to socioeconomic vulnerability over time. More specifically, we report the coefficients β_t, which measure the difference in outcomes between more versus less socioeconomically vulnerable municipalities, as measured by the SVI, over time.

We used standardised death rates to account for differences in age structure across states and municipalities. We multiplied crude COVID-19 death rates (number of confirmed deaths per 100 000 inhabitants) by total deaths in region (r, municipality or state) divided by a factor defined by

$$\sum_a \left(Pop_{a,r} \times \frac{Deaths_{a,Brazil}}{Pop_{a,Brazil}}\right)$$

where $Pop_{a,r}$ denotes population size within age bracket (a) in region (r, municipality or state). We considered quinquennial age groups up to 79 years, and a final age group of 80 years and older. The term $Deaths_{a,Brazil}$ denotes the total number of deaths in Brazil in 2018 and $Pop_{a,Brazil}$ denotes the population by age (a) in 2017 (the last years available).

Role of the funding source

There was no funding source for this study.

Results

The table shows summary statistics on inequalities in Brazil and by region (North, Northeast, Centre-west, Southeast, and South). The standardised COVID-19 death rate was highest in the North region, where, according to the SVI, some of the most vulnerable states are located. Although these were not the states where the typical COVID-19-related health risks (older age groups and burden of chronic disease) were the greatest, we observed greater scarcity in hospital resources, both in the public and private sectors. The number of ICU beds per capita was roughly twice as high in the South region as in the North region, not only in the private sector but also in the SUS. The inequality was even wider for human resources, as measured by the number of ICU physicians per capita, whose supply is typically inelastic in the short term as it requires several years of training to qualify as an ICU physician.

Rankings of socioeconomic, health-system indicators, physical distancing, and governmental responses by state are shown in appendix 2 (p 3). The most vulnerable states in terms of SVI were also the ones where the SUS provided greater coverage of primary health-care services, in particular when measured by the share of the population covered by community health agents. These states also have greater coverage of the *Bolsa Família* programme.

SVI and health risk factors (age and chronic disease), hospital capacity, and death rates followed a distinct

	Brazil	Average by region					Correlation with COVID-19 deaths	
		North	Northeast	Centre-west	Southeast	South	Coefficient*	p value
COVID-19 deaths per 100 000 people, age-adjusted (as of Oct 31, 2020)	76·2	99·9	79·4	90·2	85·9	45·4	1·0	<0·0001
Socioeconomic vulnerability								
Socioeconomic vulnerability index	0·62	0·79	0·80	0·44	0·33	0·31	0·1	0·76
Housing vulnerability (%)	44·5	56·8	50·1	44·6	19·8	32·0	–0·1	0·61
Informal workers (%)	25·7	29·8	26·9	24·4	22·4	19·0	0·3	0·09
Health vulnerability								
Population with health risk factors (%)	47·0	43·2	45·7	49·0	50·3	52·9	–0·2	0·25
Population aged ≥60 years (%)	16·1	12·7	17·2	15·4	19·2	18·0	–0·3	0·08
Pre-existing hospital services								
SUS ICU beds per 100 000 people	6·1	4·3	5·7	6·5	8·0	8·9	–0·5	0·02
Private ICU beds per 100 000 people	9·0	2·8	4·4	31·6	10·1	5·5	0·1	0·51
ICU physicians per 100 000 people	15·2	7·2	11·4	22·9	24·0	23·1	–0·1	0·64
Pre-existing primary health care and social assistance								
Community health agents coverage (%)	72·4	78·1	86·0	59·7	56·0	56·7	–0·2	0·36
Family health strategy coverage (%)	72·1	69·9	84·7	63·0	59·3	68·7	–0·3	0·12
Bolsa Familia coverage (%)	8·0	8·7	12·6	4·1	4·5	2·8	0·1	0·58
Response and outcomes as of June, 2020								
New ICU beds (per 100 000 people)	4·4	3·6	4·7	4·8	3·7	5·2	–0·1	0·76
New ICU beds (% of pre-existing)	82·9	108·2	88·5	77·3	48·7	60·2	0·2	0·28
Policy stringency index	53·4	54·0	57·5	40·6	57·8	50·9	0·2	0·39
Change in physical distancing adherence since February, 2020 (percentage points)	10·8	11·0	12·0	9·4	10·2	9·8	0·2	0·31
COVID-19 deaths per 100 000 people, age-adjusted	31·8	50·2	34·2	11·3	34·5	5·1	0·8	<0·0001
Response and outcomes as of October, 2020								
New ICU beds (per 100 000 people)	7·3	5·3	7·1	9·3	8·3	9·2	–0·2	0·24
New ICU beds (% of pre-existing)	130·2	142·2	131·3	147·6	105·1	108·9	0·2	0·33
Policy stringency index	37·0	40·0	33·6	43·8	27·7	43·2	0·2	0·29
Change in physical distancing adherence since February, 2020 (percentage points)	6·5	5·8	8·2	5·5	5·9	4·9	0·0	0·86

SUS=*Sistema Único de Saúde*. ICU=intensive care unit. *Pearson coefficients for bilateral correlations between state-level indicators and COVID-19 deaths.

Table: **Inequalities in socioeconomic characteristics, health-system resources, and governmental response, for Brazil and its regions**

spatial pattern (figure 1). Although the state of São Paulo, in the Southeast region, had the first confirmed case in the country, COVID-19 death rates soon became higher in the North and Northeast regions, where SVI and scarcity of hospital capacity were highest, and where the risk factors for severe COVID-19 (advanced age and chronic disease burden) were lowest. COVID-19 deaths were positively correlated with socioeconomic vulnerabilities and negatively associated with the level of hospital resources (table, figure 1; appendix 2 p 3).

Considering state-level correlations (figure 2), socioeconomic vulnerabilities were positively correlated among them, and negatively correlated with the health risk factors of age and chronic disease burden, and with hospital resources. Health risk factors were positively correlated with hospital capacity and negatively correlated with health-system resources devoted to primary health care, as well as with social assistance coverage. Correlations between response indicators and outcomes as well as the remaining variables were weaker, but we found generally positive associations between socioeconomic vulnerabilities, physical distancing, and access to primary health care and social assistance coverage.

Pearson coefficients for bilateral correlations between pre-existing hospital capacity, as measured by ICU beds available in the SUS per 100 000 people, and the remainder indicators of socioeconomic vulnerability and COVID-19 response are shown in figure 3A. Pre-existing hospital capacity is negatively correlated with SVI, housing vulnerability, and the share of informal workers, but positively correlated with health risk factors and age. The response has been relatively more active in states where hospital resources were low. In particular, we found a negative correlation between pre-existing hospital capacity and physical distancing adherence (–0·27 to June, 2020, and –0·26 to October, 2020), although this correlation was not statistically significant in either month (p=0·18). The correlation between the

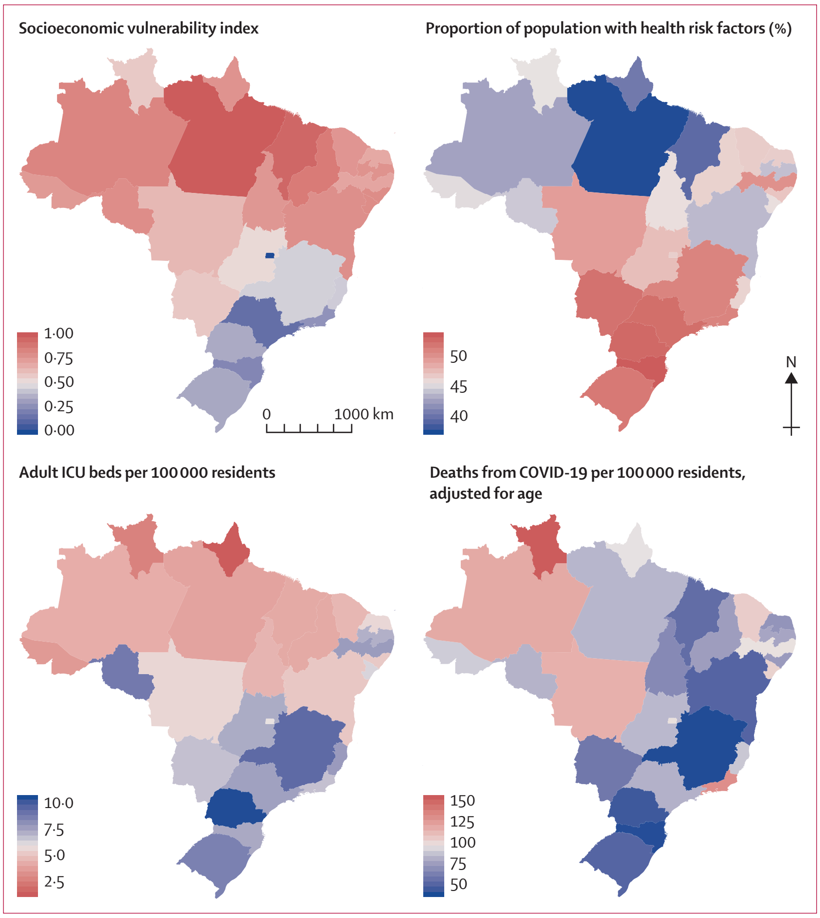

Figure 1: **Spatial distribution of socioeconomic vulnerabilities, COVID-19 health risks, hospital capacity, and COVID-19 death rates**

Maps show state-level indicators. A socioeconomic vulnerability index of 0 indicates the least vulnerable and 1 the most vulnerable. ICU=intensive care unit.

policy stringency index and number of ICU beds was negative to June, 2020 (–0·07, p=0·73), but positive to October, 2020. Although we observed a positive and significant correlation between the number of pre-existing and new SUS ICU beds per capita by the end of October, 2020 (0·42, p=0·03), hospital capacity increased significantly more in relative terms (when measured as a percentage change of pre-existing capacity) in states with lower pre-existing capacity (–0·63, p=0·0005).

Scatterplots of state-level data show that responses to COVID-19, as measured in terms of physical distancing adherence, state-related COVID-19 legislation (policy stringency index), and investments in hospital ICU capacity, have not been particularly weaker in the most socioeconomically vulnerable states (figure 3B). Despite the lack of coordination at the executive branch of the federal government, the allocation of new ICU beds was correlated with higher SVI. These socioeconomically vulnerable states have been able to produce stringent COVID-19-related legislation to introduce protective public health measures (eg, to increase physical distancing). This response was particularly clear during the initial spread of the epidemic, up to June, 2020. The most socioeconomically vulnerable states also achieved, and still have, relatively greater physical distancing. The patterns of policy and population responses were consistent with patterns in death rates, which initially (to June, 2020) increased rapidly among states with a high SVI. However, while physical distancing adherence remained relatively higher among the most socioeconomically vulnerable states, the correlation between SVI and death rates flattened and converged to zero by October, 2020.

The dynamics of death rates from February to October, 2020, across municipalities are shown in figure 4A, which reports the difference in outcomes between more and less socioeconomically vulnerable municipalities as proxied by the dummy variable SV_m. The number of deaths per 100 000 people accelerated until June, 2020, particularly in the most socioeconomically vulnerable municipalities, but that pattern was reverted from July onwards when the difference between the more and less socioeconomically vulnerable municipalities decreased to zero and soon became negative (indicating a higher death rate in the less vulnerable municipalities between July and October).

For physical distancing and policy stringency outcomes, both variables increased relatively more in the most socioeconomically vulnerable municipalities until June (figure 4B). In July, the difference in policy stringency decreased to zero and remained around zero until September, becoming significantly negative in October, while physical distancing remained relatively higher in the most socioeconomically vulnerable places. Therefore, convergence in death rates occurred in tandem with continuously higher levels of physical distancing in the most socioeconomically vulnerable municipalities. These patterns were remarkably stable in regressions that adjusted for baseline characteristics (appendix 2 p 4). All point estimates and standard errors are also reported in appendix 2 (p 5).

Discussion

Our results indicate that the initial spread of COVID-19 infections and deaths in Brazil was mostly affected by patterns of socioeconomic vulnerability rather than population age structure and prevalence of existing chronic disease morbidity. Although COVID-19 was first recorded in São Paulo and Rio de Janeiro, in the Southeast region, death rates increased quickly in states with marked socioeconomic vulnerabilities, particularly in the North and Northeast regions.

Pre-existing hospital resources, in particular ICU capacity, were positively correlated with vulnerabilities in population health. However, we observed negative correlations between pre-existing hospital capacity and vulnerability in terms of other socioeconomic markers, such as housing conditions and informality in the labour

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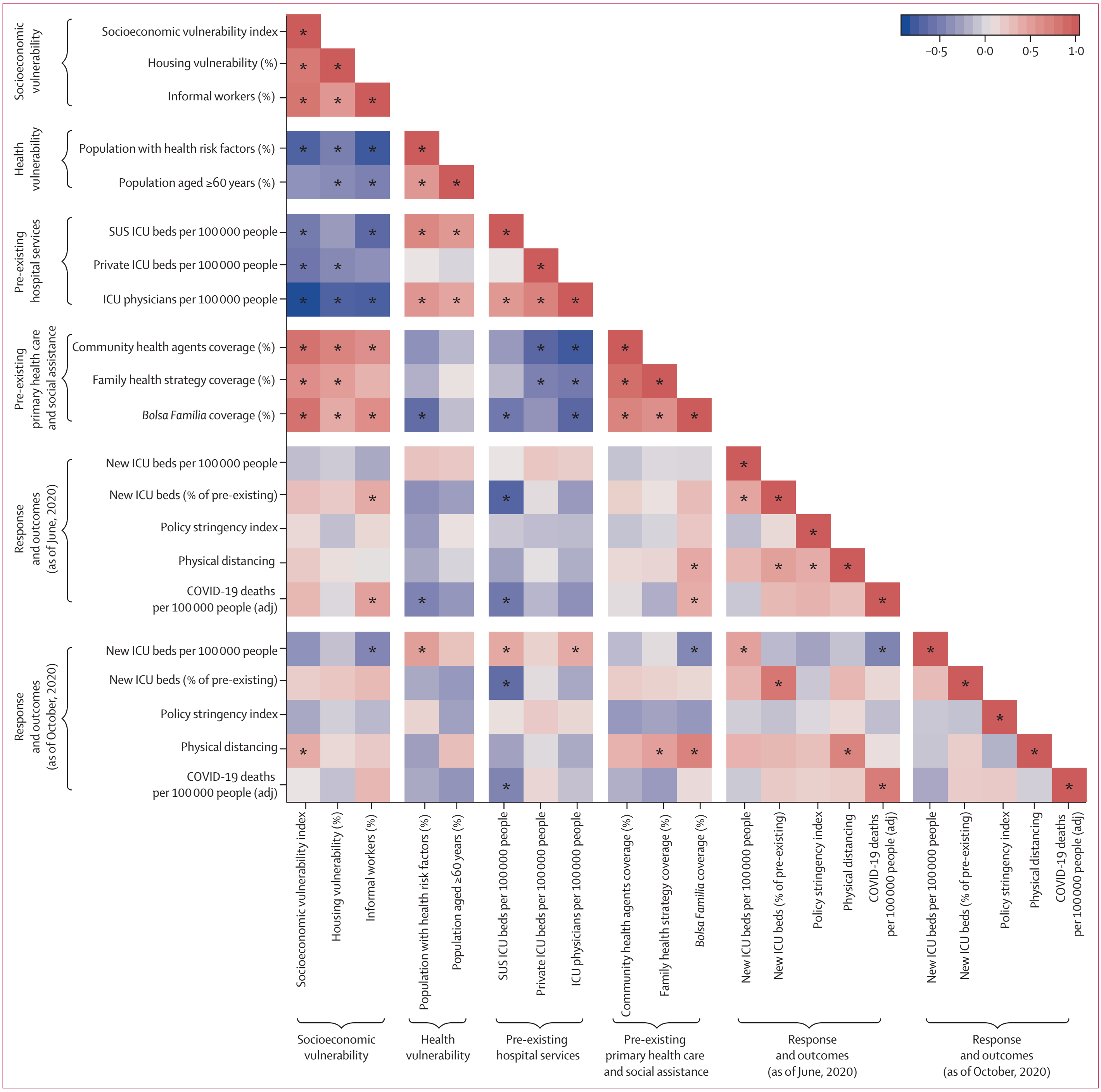

Figure 2: **Correlation matrix of indicators of socioeconomic vulnerability, health risk factors, pre-existing health-system resources, and responses to COVID-19**
Correlations are expressed as Pearson coefficients for bilateral associations across all pairs of indicators, in the range of –1 to +1. adj=age-adjusted. ICU=intensive care unit. SUS=*Sistema Único de Saúde*. *Significant at the 5% level.

market. This socioeconomic vulnerability is counterbalanced by greater coverage of social assistance and primary health-care programmes, as well as by a timely response from policy and population behaviour, which had important roles in the containment of COVID-19 spread and its effects. Despite the political turmoil and absence of overall coordination at the executive branch of the federal government, the most socioeconomically vulnerable states were able to expand hospital capacity and to enact stringent COVID-19-related legislation in an

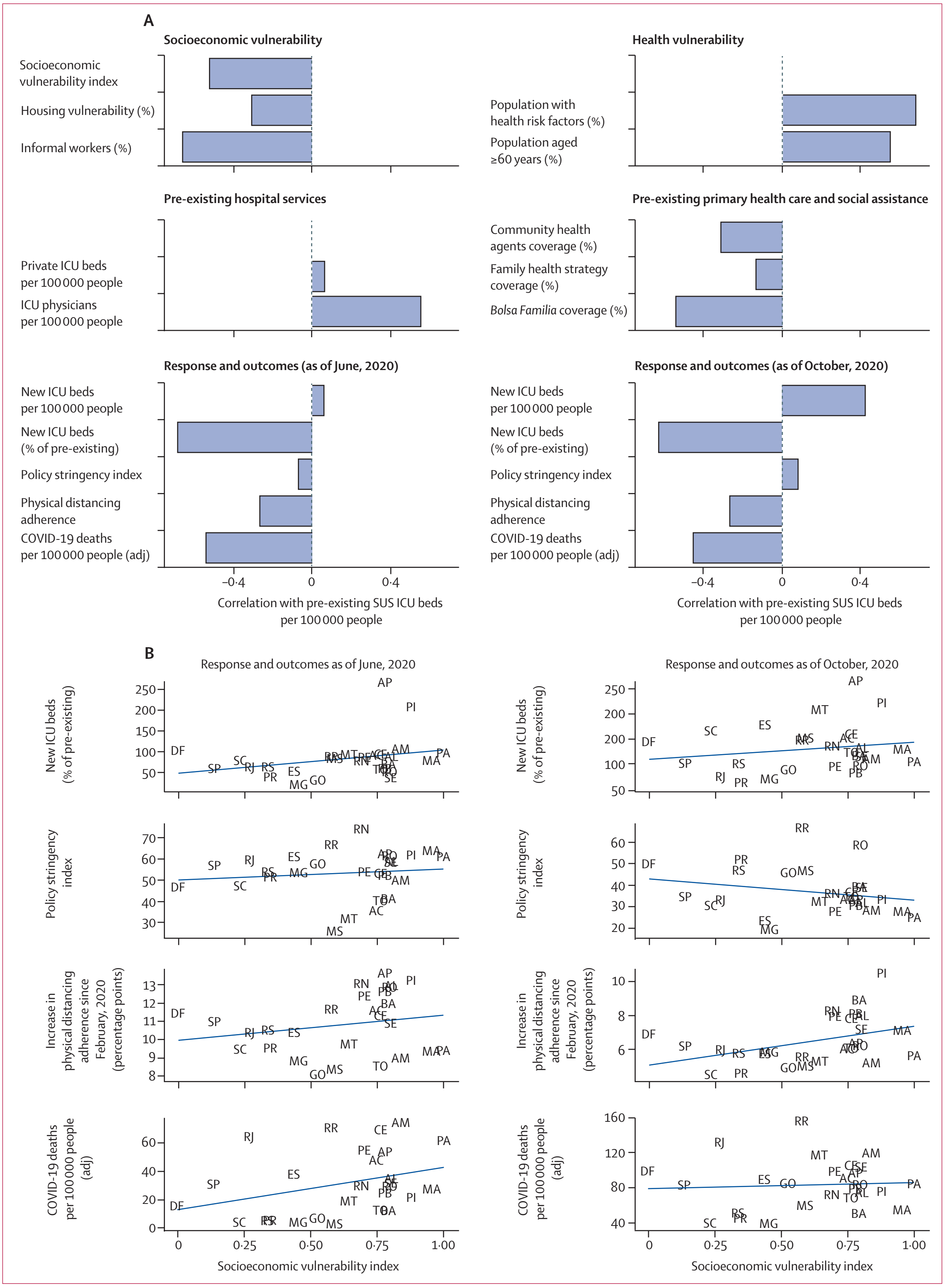

Figure 3: **Correlations between pre-existing hospital capacity, socioeconomic vulnerability, age and chronic disease burden, response, and COVID-19 death rates**
(A) Pearson coefficients for state-level bilateral correlations between selected indicators and pre-existing SUS ICU beds per 100 000 people. (B) State-level bilateral correlations between selected indicators and the socioeconomic vulnerability index. Scatterplots show linear associations at the state level. States are represented by their two-letter ISO 3166-2 codes. adj=age-adjusted. ICU=intensive care unit. SUS=*Sistema Único de Saúde*.

attempt to increase physical distancing. These measures, however, were not sufficient to prevent the most socioeconomically vulnerable states from having higher COVID-19 death rates during the initial spread of the disease. Yet, the association between SVI and death rates flattened in the longer term as physical distancing remained relatively higher in the most vulnerable places.

In Brazil, multiple layers of vulnerability and risk have overlapped and amplified existing structural inequalities to produce worse outcomes in socioeconomically vulnerable regions, states, and municipalities during the initial phase of the epidemic compared with less vulnerable areas. These poor outcomes could have been mitigated through a governmental response adapted to local inequalities, but two factors prevented this from happening.

First, frequent changes in health leadership have generated administrative instability—one minister was fired by the president in April, 2020, the successor resigned in less than a month, and the Ministry of Health had an interim minister from May 15 to Sept 16, 2020. The Ministry of Health's technical ability to promptly respond to the pandemic was suboptimal, and 23·1% of the emergency funds of R$ 44·2 billion (US$ 8·26 billion) authorised by the federal government in February and March had not yet been spent up to October, 2020.[32] However, as the health system in Brazil is decentralised, and local governments have the autonomy to implement local laws, public health interventions, and physical distancing policies, they were able to adopt measures to reduce transmission and to expand hospital capacity. Although the type and timing of those responses were heterogeneous across Brazil, the unequal burden of COVID-19 would have been even higher without the SUS and local responses.

Second, the political context posed a major challenge to the response. The consistency of communication by leadership affects citizens' behaviour.[33–35] The risk of the virus has been downplayed by the current political leadership in Brazil and messages from the federal government have been mixed with regard to physical distancing restrictions, use of face masks, and reopening plans, among other aspects. During a pandemic, especially one of a completely new pathogen, coherent and consistent communication from leaders is crucial to foster adherence to control policies implemented by states and municipalities in order to mount a whole-of-society response.[36] Physical distancing behaviour was less evident in municipalities with stronger electoral support for the current political leadership, especially after public events and presidential speeches in which the leadership directly referred to and advised against it.[37,38]

Our study has limitations. First, COVID-19 data might have measurement errors. These errors are especially salient worldwide with regard to confirmed deaths. However, if confirmed COVID-19 deaths are biased downwards in most vulnerable states, our findings are conservative. Nevertheless, overall trends are unlikely to change once more complete information is made available. Second, administrative data might have weaknesses, particularly in the case of proxies for COVID-19-related legislation and for measures of pre-existing hospital capacity that rely on CNES data, which have been criticised because of errors in administrative records.[39] We accounted for possible measurement errors in the data by aggregating indicators at the regional and state levels, at which much of the noise is expected to cancel out. Third, bilateral correlations were based on small samples at the state level and statistical significance was expected to be underpowered. Together with the measurement error in COVID-19 deaths and in measures of pre-existing hospital capacity, this limitation makes our findings conservative. Coefficient estimates of linear regressions should not be interpreted as causal but as revealing patterns of spread in COVID-19 deaths differentially along with reasonable proxies for socioeconomic conditions related to education and income. Fourth, although we considered an extensive set of variables on health resources and hospital capacity,

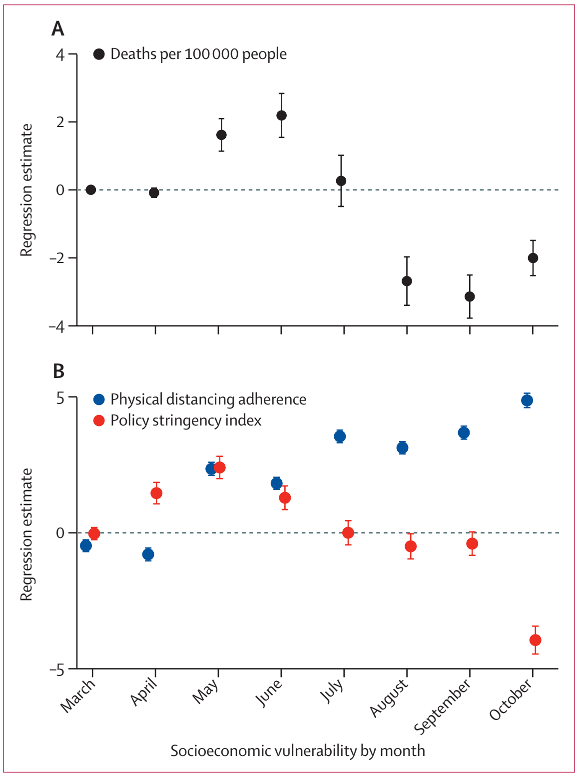

Figure 4: **Differentials on outcome variables by socioeconomic vulnerability and month in 2020**
The plots show coefficients and 95% CIs (error bars) of linear regressions that measure, for each month, the difference in average outcomes between municipalities with HDI below the median and those with HDI above the median (February is the omitted category). (A) Deaths per 100 000 people. (B) Physical distancing adherence and policy stringency indicators. Positive estimates indicate that the respective outcome increased relatively more in municipalities with HDI below the median, and negative estimates indicate that the respective outcome decreased relatively more in municipalities with HDI below the median. HDI=Human Development Index.

proxies for availability of more specific equipment such as masks, sanitiser, gloves, quality and types of care, and pharmacy networks remained missing as data are not systematically available. However, we expect a direct and strong correlation between scarcity in overall health infrastructure and hospital capacity (with proxies included in our analysis) and scarcity in more specific equipment. Finally, an important limitation of our proxy of socioeconomic vulnerability (SVI) relates to the fact that it relied on a principal component analysis over a limited set of socioeconomic indicators, and was used to help us characterise how outcomes have behaved across regions and over time in places typically more versus less socioeconomically vulnerable. In that sense, the SVI does not allow us to disentangle the role of specific socioeconomic deprivations in the spread of the disease, nor to precisely identify more versus less relevant determinants of COVID-19 death rates among specific socioeconomic characteristics. Moreover, it was not our intention to use SVI interchangeably as a vulnerability index for the risk of infection and the risk of deaths. We used death rates as a general but arguably relevant marker for the spread of the epidemic.

There are important lessons from Brazil's experience with COVID-19, especially regarding how existing socioeconomic inequalities, rather than age and level of chronic disease, have affected the initial course of the epidemic and the deaths from COVID-19, with a disproportionate adverse burden on socioeconomically vulnerable regions, states, and municipalities. A similar pattern has emerged in other LMICs, where socioeconomically vulnerable groups were the least protected and faced the greatest risk from COVID-19, further widening unacceptable health and socioeconomic inequalities.[13] Targeted policies and actions would have been crucial to protect the most vulnerable groups from the adverse consequences of COVID-19. A further lesson relates to the organisation and governance of health systems: in decentralised systems, state-level or municipality-level responses might help to counterbalance inertia in central government actions. Efforts should be made to strengthen local-level public health responses to strengthen health-system resilience.

Contributors

RR, AM, MCC, and RA jointly conceived the study and developed the study outline with PS, LN, and BR. BR, LN and PS compiled the data, and BR and RR did the analysis. RR wrote the first draft with input from all authors. All authors contributed to the subsequent drafts and to the final manuscript. All authors had access to all estimates presented in the paper and had final responsibility for the decision to submit for publication. BR and RR accessed and verified the underlying data.

Declaration of interests

We declare no competing interests.

Data sharing

All data used in this study are publicly available, except for those provided by In Loco (percentage of individuals staying at home based on locational data from >60 million mobile devices). Details on source and download can be found in appendix 2 (p 1).

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