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COVID-19 Morbidity and Mortality Factors: An International Comparison

Yuval Arbel[1], Chaim Fialkoff[2], Amichai Kerner[3], Miryam Kerner[4]

[1] Western Galilee College, Acre, Israel
[2] Hebrew University of Jerusalem, Jerusalem, Israel
[3] Netanya Academic College, Netanya, Israel
[4] Technion, Israel Institute of Technology, Haifa, Israel and HaEmek Medical Center, Afula, Israel

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Abstract. This study investigates the scope of morbidity and mortality from SARS-COV2 virus at a country-wide level based on three central risk factors: population density, median age, and per capita hospital beds. Given that the relative weight following a change in equal units of measurement has not been examined on a country-wide level, we use empirical models with standardized coefficients. Information for this study was obtained from the World Health Organization (WHO) data base, which encompasses 162 countries, and spans five continents from January 22, 2020, to January 21, 2022. Referring to projected COVID-19 infection and mortality rates, and following a one standard deviation increase, the influence of these independent variables may be ranked as follows: Infection – 1) the median age of the country's population; 2) number of hospital beds per thousand persons; 3) population density. Mortality – 1) the median age of the country's population; 2) population density; 3) number of hospital beds per thousand persons. Findings may be of assistance to public policy planners. Given the dominance of the age variable in the context of the COVID-19 pandemic, on the one hand, the allocation of resources for future pandemics should grow in countries with older population profiles (European countries). On the other hand, the emphasis in countries with younger populations (African countries) should be on better medical infrastructure in sparser regions.

Key words: COVID-19, Morbidity, Mortality, Population density, Median age Per-capita hospital beds

1 Introduction

The COVID-19 pandemic is an interesting subject matter for investigation in an effort to control the spread of the pandemic and to address future world pandemics. Three central risk factors associated with the spread of the COVID-19 pandemic and mortality from the SARS-COV2 virus are densely populated regions (an important issue in regional studies), older population distributions, and low per capita levels of beds in hospitals. The literature demonstrates the importance of these variables, where some findings are surprising. One would expect, for instance, that densely populated regions would encourage the spread of the COVID-19 pandemics. Yet, referring to denser vs. sparser regions, and based on 1,165 US metropolitan areas, after controlling for metropolitan size and other confounding variables, Hamidi et al. (2020) found significantly lower COVID-19 infection rates and lower death rates with higher county density. The authors explained this outcome on the grounds of two opposing forces, in which one overpowers the other. On the one hand, denser regions facilitate human interactions. This, in turn, *raises* anticipated infection rates and the scope of morbidity. On the other hand, the agglomeration forces associated with denser cities allow for, inter alia, better health infrastructure, associated medical literacy, and shorter response times in emergency cases.

Referring to the median age of a country's population (the second explanatory variable in our empirical model), Bauer et al. (2021) investigated the impact of the age variable in Europe and USA. The authors found stronger age dependency for COVID-19 compared to all-cause mortality. Pijls et al. (2021) provided meta-analysis of 59 studies comprising 36,470 patients. Findings showed that men and patients aged 70 and above have a higher risk for COVID-19 infection, severe disease, intensive care units (ICU) admission and death. Zhang et al. (2022) explored the impact of the age variable on COVID-19 morbidity and mortality in Wuhan City, China and found disproportionate age effect in clinical manifestations, risk factors, complications, and COVID-19 outcomes. Finally, referring to 48 European countries, Wang et al. (2020) suggest positive association between COVID-19 mortality and ageing population, median age, and life expectancy at birth. Lulbadda et al. (2021) suggest that the temperature, population size, and median age are positively associated with the spreading rate of COVID-19. There is no evidence supporting that case counts of COVID-19 could decline in countries with better health care facilities.

Referring to the number of hospital beds per thousand persons (the third explanatory variable in our empirical model), this variable provides a proxy for income level, vaccination rates and medical literacy. Brant et al., 2021 investigated the impact of the COVID-19 pandemic on all-causes hospitalization in Brazil. During the studied period, there were 54,722 hospitalizations by non-COVID-19 natural causes, representing a 28% decline compared to the previous five years. Presanis et al. (2021) examined the risk factors associated with hospital burden of COVID-19 and executed an observational cohort study, using data on all PCR-confirmed cases of COVID-19 in Regione Lombardia, Italy, during the first wave of infection from February-June 2020. The authors found decreased risks of severe outcomes such as Intensive Care Units (ICU) admission and mortality within a month of admission. This demonstrates a learning effect of the Italian health system.[1]

Following Arbel et al. (2020, 2021), the objective of the current study is to investigate the scope of morbidity and mortality from SARS-COV2 virus at a country-wide level based on three important risk factors: population density, median age, and the per capita hospital beds. The use of country-level rather than city-level datasets during the COVID-19 pandemic may be justified based on two important considerations: 1) COVID-19 regulation is typically formulated at the national level. 2) Compared to international migration, intra-national mobility among cities is much simpler. The approach employed in this study is the standard parametric procedure (OLS) where the incorporation of each explanatory variable should be justified. Another possible approach – machine learning – is implemented in Manousiadis, Gaki (2023). The authors investigated the resilience of US regions in terms of economic recovery from the pandemic.

The inherent problem associated with standard empirical regression (OLS) model is the different units of measurement of the independent variables. Consequently, in addition to the standard regression model, we estimate a model where all the variables are standardized to the normal distribution function (the beta coefficient model). This permits estimation in terms of one standard deviation of each of the independent variable, and thus the magnitude of effect on the dependent variable. The coefficients of this empirical model measure the change in the standard deviation of the dependent variable (either the scope or morbidity or mortality per 1 million persons) following a one standard deviation change of each independent variable.

Results show negative Pearson correlations among population densities (in line with Hamidi et al. 2020 – at a global level); number of hospital beds per thousand persons and

[1] See also Castagna et al. (2022), Fakih et al. (2022), and Hobohm et al. (2022).

the scope of morbidity and mortality (as anticipated – higher level of health investment yields better outcomes at a global level); and positive Pearson correlations between the median age of the country and the scope of morbidity and mortality (as anticipated and in line with the existing literature at a global level).

Referring to projected COVID-19 infection (mortality) rates, and following a one standard deviation increase, these independent variables may be ranked as follows: infection – 1) the median age of the country's population; 2) number of hospital beds per thousand persons; 3) population density, and mortality – 1) the median age of the country's population; 2) population density; 3) number of hospital beds per thousand persons).

Public policy repercussions of the study may be summarized as follows. Given the dominance of the age variable in the context of the COVID-19 pandemic, on the one hand, the allocation of resources for future pandemics should grow in countries with older population profiles (European countries). On the other hand, the emphasis in countries with younger populations (African countries) should be on better medical infrastructure in sparser regions. The latter finding is supported by Souris, Gonzalez (2020). The authors mostly found low hospitalization with high case-fatality rates in French districts with low population densities and attributed this phenomenon to the limitations of access to local healthcare services.

Our study has three relative advantages, which improve the limitations of previous studies. First, the study is at a global level and encompasses all the countries in the world. The conventional approach is to focus on one country only. Second, in previous studies standardized beta coefficients were not used. Consequently, each explanatory variable had different units of measurement and the magnitude of explanatory power could not be compared. Third, the results show that when the population density increases, the infection actually decreases. This finding is unique at the global level (existing at the municipal level in Hamidi et al. 2020 and partially in Arbel et al. 2022).

The remainder of this article is organized as follows. Section 2 gives the literature review. Section 3 describes the methodology and Section 4 provides the results. Finally, Section 5 concludes and summarizes.

2 Literature Review

COVID-19 is a global pandemic with multiple risk factors. The maps in Figure 1 and Figure 2 demonstrate the scope of morbidity and mortality on April 5, 2023. Globally, as of 10:14am CEST, April 5, 2023, there have been 762,201,169 confirmed cases of COVID-19, including 6,889,743 deaths, reported to WHO, a 0.09645% (less than 0.1%) of the world's population of 7.143 billion persons. Compared to other documented pandemics, such as, the 1918-1920 Spanish Influenza, the death toll is much smaller. According to Barro et al. (2020) the death toll of the Spanish flu is 2.1% of the world's population implying 150 million deaths when applied to current population. The decreased death toll may be attributed to better health infrastructure and technology. As of April 1, 2023, a total of 13,321,840,096 vaccine doses have been globally administered.

There is a significant correlation between COVID-19 and healthcare infrastructure and public health policies. Figure 3 demonstrates the negative correlation between the COVID-19 death rate and the number of hospital beds in the UK and the OECD countries (Figure 5). The authors conclude that: "Countries with higher capacity had fewer COVID-19 deaths, particularly for beds and surgical specialists." ESPON (2022, page 49).

The severity of the pandemic in different regions of the world has been influenced by the quality and capacity of healthcare infrastructure, as well as the effectiveness of public health policies implemented to control the spread of the virus.

In regions with strong healthcare systems and sufficient resources, such as advanced medical equipment, adequate numbers of healthcare workers, and available hospital beds, the impact of COVID-19 has generally been less severe than in regions with weaker healthcare infrastructure. Additionally, public health policies, such as lockdowns, mask mandates, and social distancing measures, have been effective in reducing the spread of

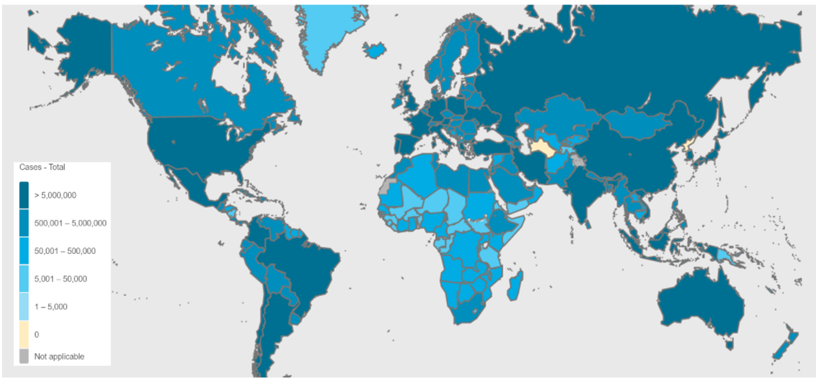


Figure 1: World Health Organization: World Map of COVID-19 Cases

Source: World Health Organization Dashboard. Available at: https://covid19.who.int/ (Last accessed on April 5, 2023).
Note: Globally, as of 10:14am CEST, 5 April 2023, there have been 762,201,169 confirmed cases of COVID-19, including 6,889,743 deaths, reported to WHO. As of 1 April 2023, a total of 13,321,840,096 vaccine doses have been administered.

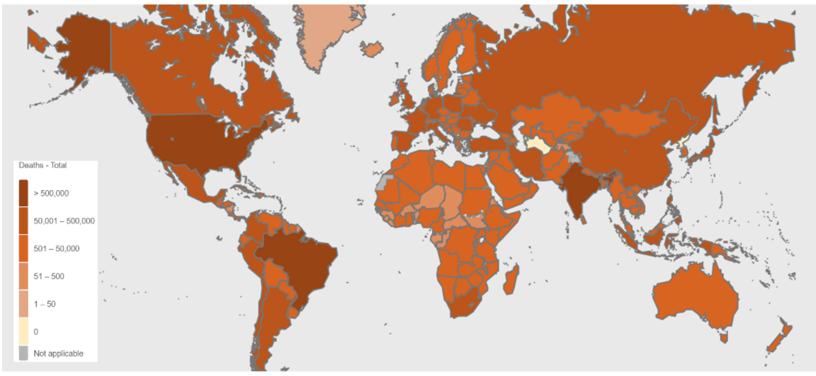


Figure 2: World Health Organization: World Map of COVID-19 Deaths

Source: World Health Organization Dashboard. Available at: https://covid19.who.int/ (Last accessed on April 5, 2023).
Note: Globally, as of 10:14am CEST, 5 April 2023, there have been 762,201,169 confirmed cases of COVID-19, including 6,889,743 deaths, reported to WHO. As of 1 April 2023, a total of 13,321,840,096 vaccine doses have been administered.

the virus in some areas.

On the other hand, in regions with weaker healthcare infrastructure, such as developing countries with limited resources, the impact of COVID-19 has been more severe due to a lack of medical equipment, healthcare workers, and hospital beds. Moreover, public health policies in these regions have been less effective due to various reasons such as lack of implementation or adherence by the population.

Overall, the correlation between COVID-19 and healthcare infrastructure and public health policies highlights the importance of investing in robust healthcare infrastructure and implementing effective public health policies to combat pandemics and protect public health.

There are several countries around the world where the impact of COVID-19 on morbidity and mortality has been closely linked to the strength of their healthcare infrastructure. For instance, the US has experienced one of the highest numbers of COVID-19 cases and deaths in the world. The quality of healthcare infrastructure has played a significant role in determining the impact of the pandemic in different regions of the country. Areas with more advanced healthcare systems, such as New York City, were better equipped to handle the surge in COVID-19 cases, while areas with weaker healthcare systems, such as rural areas, were more vulnerable to the virus. Figure 4 demonstrates that the United States has the highest global number of COVID-19 hospitalized patients – above 120,000

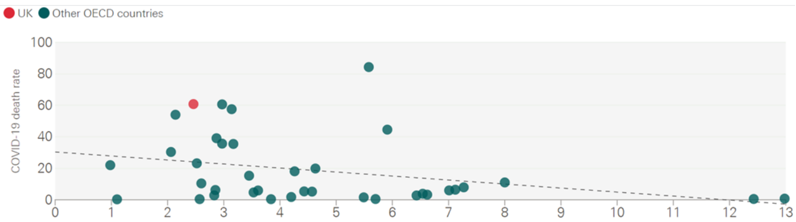


Figure 3: Hospital capacity compared to COVID-19 death rate, deaths as of 30 June 2020

Source: Rocks, Idriss (2020)

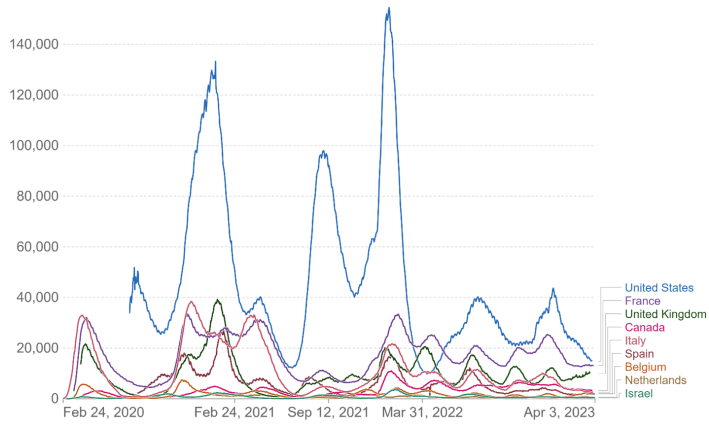


Figure 4: Number of COVID-19 Patients in Hospitals

Source: Our World in Data (2023)

persons – between December 28, 2021 - January 18, 2021 and above 140,000 persons between January 10, 2022 – January 26, 2022 (Our World in Data 2023). Referring to July 2020–July 2021, French et al. (2021) predicted that 100% full intensive care units bed capacity, would result in 80,000 excess deaths two weeks later. Janke et al. (2021) suggest that US geographic areas with fewer intensive care unit beds, nurses, and general medicine/surgical beds per COVID-19 case were statistically significantly associated with an increased incidence rate of death in April 2020. Italy was one of the first countries to experience a major outbreak of COVID-19 outside of China. The country's healthcare system was quickly overwhelmed, leading to high mortality rates. The Italian government was forced to implement strict lockdowns to slow the spread of the virus. Ferrara et al. (2022) suggest that the Italian regions with a lower number of general practitioners showed a higher number of deaths. India has also experienced a devastating impact from COVID-19, with a high number of cases and deaths. The country's healthcare infrastructure has been stretched to its limits, with shortages of medical oxygen, hospital beds, and other critical resources. The government has been working to increase capacity and resources, but the situation remains challenging. Brazil has also struggled with a high number of COVID-19 cases and deaths. The country's healthcare system has been strained due to a lack of resources and funding, leading to shortages of critical medical supplies and equipment. In France, the COVID-19 pandemic unevenly affected different regions of the country. Specifically, three regions in France were affected most, representing 75% of deaths due to the COVID-19 pandemic during the first wave. During the second wave, the highest death rates was recorded in previously low-impact regions. According to model 1 in Tchicaya et al. (2021), in the first wave, there was a statistically significant negative association between the number of resuscitation beds and the COVID-19 mortality rate. Yet this decrease comes at the expense of patients suffering from other pathologies for which care and surgical procedures have been postponed.

Overall, these examples demonstrate the critical importance of healthcare infrastruc-

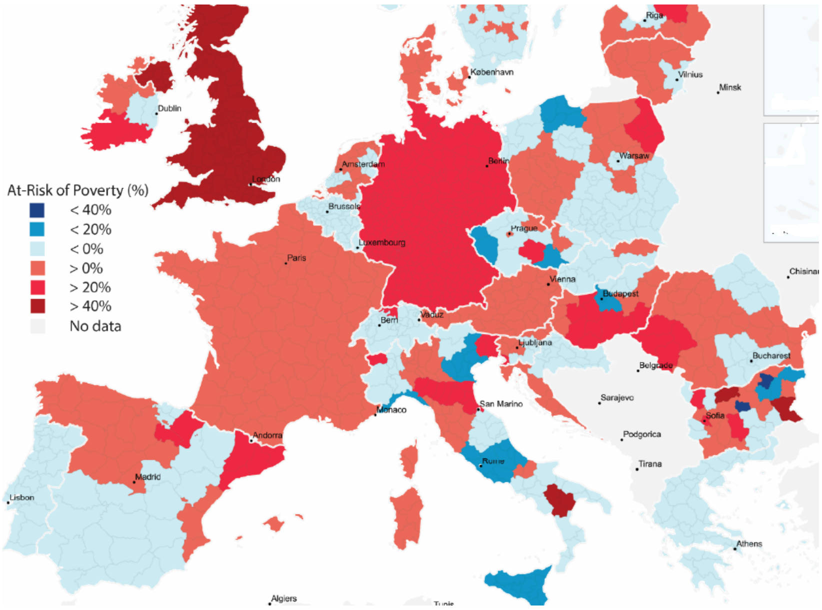


Figure 5: COVID-19 social consequences: Growth rates of At Risk of Poverty (%) from before (2019) and during the pandemic (2020) in European Countries

Source: ESPON (2022, page 49)

ture in responding to a pandemic like COVID-19. Countries with strong healthcare systems and sufficient resources have generally been better equipped to handle the pandemic and protect public health.

Another aspect of the COVID-19 is the growth of at-risk poverty following the pandemic. Figure 5 reports this change in the European countries. Overall, the evolution of people's at risk of poverty across the EU regions decreased by 1.21% on average compared to the pre-COVID-19 period. The UK had the highest change of people living in households with income below the risk-of-poverty threshold (with a growth rate estimated at 85.4%), followed by Iceland (32.6%), Germany (25%) and Latvia (9.9%). In these countries, the COVID-19 pandemic has led to an increase in poverty. On the other hand, about half of the EU member states do not show particular differences compared with 2019.

This can be explained by the fact that, in many countries, regions have the administrative competence to manage social aspects. Some regions have thus put in place specific regional and local policies to help the poorest households cushion the crisis, notably through direct financial aid to maintain or increase their purchasing power.

3 Methodology

Derived from this motivation, and particularly from beneficial public policy tools, we would like to investigate the extent to which hospital capacities, proxied by the number of hospital beds, influence COVID-19 cases and mortality around the world. Given that health investment is the only controlled public policy tool to promote future pandemics, the influence of this variable might prove to be important.

Given that countries around the world differ in population size, the dependent variables in our empirical models (the number of COVID-19 cases and deaths) have to be standardized. This is done by calculating the Cases-Population and Deaths-population ratio. The outcomes are multiplied by a factor of 1 million, so that the dependent variable would become cases/deaths per 1 million persons in the population. Our control variables are *Population_density* (persons per square kilometers) and *Median_age* (Median age of the country in years).

Table 1: Definition of variables

Variable	Description
Total_cases_p.mill.	The ratio between COVID-19 cases and the population of the country multiplied by 1 million
Total_deaths_p.mill.	The ratio between COVID-19 deaths and the population of the country multiplied by 1 million
Population_density	Population density measured as persons per square kilometers
Median_age	Median age of the country in years
Hospital_beds_p.th.	The ratio between the number of beds and the population of the country multiplied by 1,000

Table 2: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max	99% CI
A. Total Cases per 1 Million Persons						
Total_cases_p.mill.	109,813	25,371.9	39,671.99	0.001	347,457.3	[25,063.53, 25,680.28]
Population_density	109,813	204.4703	674.1418	1.98	7,915.73	[199.23, 209.71]
Median_age	109,813	31.43817	8.869181	15.1	48.2	[31.37, 31.51]
Hospital_beds_p.th.	109,813	2.959307	2.355282	0.1	13.05	[2.94, 2.98]
B. Total Deaths per 1 Million Persons						
Total_deaths_p.mill.	102,399	491.422	766.664	0.001	6,115.04	[485.25, 497.59]
Population_density	102,399	204.875	671.5761	1.98	7,915.73	[199.462, 210.281]
Median_age	102,399	31.6389	8.90458	15.1	48.2	[31.57, 31.71]
Hospital_beds_p.th.	102,399	2.97657	2.368613	0.1	13.05	[2.958, 2.996]

Note: The data refer to information regarding 162 countries provided by the World Health Organization (WHO), and spans from January 22, 2020, to January 21, 2022.

3.1 Description of the Data

Information for this study was obtained from the World Health Organization (WHO). The data base encompasses 162 countries,[2] and spans five continents from January 22, 2020, to January 21, 2022. This yields 109,813 (109,322) observations with availability of information on the total COVID-19 cases (deaths) per 1 million persons. Yet only these two variables vary across both time and space. The other variables vary across space (from one country to another), but not across time.

3.2 Descriptive Statistics

Table 2 reports the descriptive statistics of the variables, which are subsequently incorporated in the empirical model. The table is divided into two parts. The upper (lower) part includes the descriptive statistics of observations for which information on total COVID-19 cases (deaths) per 1 million persons is available. The sample mean of COVID-19 cases (deaths) is 25,371.90 (491.42) per million persons and the 99% confidence interval is [25,063.53, 25,680.28] ([485.25, 497.59]). One standard deviation increase (decrease) equals 39,671.99 additional (less) COVID-19 cases and 766.664 additional (less) COVID-19 deaths per 1 million persons. The maximum scope of morbidity (mortality) is obtained in Seychelles Islands, Africa (Peru, South America) with 347,457.30 cases (6,115.035 deaths) per 1 million persons.

3.3 The Empirical Model

Consider the following empirical models:

$$\begin{aligned} Total\_cases\_per\_million \quad &= \quad \alpha_1 + \alpha_2 Population\_density + \alpha_3 Median\_age + \\ & \quad\quad \alpha_4 Hospital\_beds\_per\_thousand + \mu_1 \end{aligned} \tag{1}$$

[2] A full list of countries may be provided upon request from the corresponding author.

$$Total\_deaths\_per\_million = \beta_1 + \beta_2 Population\_density + \beta_3 Median\_age + \beta_4 Hospital\_beds\_per\_thousand + \mu_2 \quad (2)$$

Where the dependent variables are *Total_cases_per_million* and *Total_deaths_per_million*; the independent variables are: *Population_density*, *Median_age* and *Hospital_beds_per_thousand*. $\alpha_1 \ldots \alpha_4$ and $\beta_1 \ldots \beta_4$ are parameters, μ_1 and μ_2 are the random disturbance terms, which satisfy all the classical assumptions of the regression model.

The inherent problem associated with this empirical model is the different units of measurement of the independent variables.[3] To address this problem, we re-estimate the following model:

$$Z(Total\_cases\_per\_million) = \alpha_1^{'} + \alpha_2^{'} Z(Population\_density) + \alpha_3^{'} Z(Median\_age) + \alpha_4^{'} Z(Hospital\_beds\_per\_thousand) + \mu_3^{'} \quad (3)$$

$$Z(Total\_deaths\_per\_million) = \beta_1^{'} + \beta_2^{'} Z(Population\_density) + \beta_3^{'} Z(Median\_age) + \beta_4^{'} Z(Hospital\_beds\_per\_thousand) + \mu_4^{'} \quad (4)$$

$Z(X_i) = \frac{X_i - \bar{X}}{\sigma_X}$ where $\bar{X}$ is the average and σ_X is the standard deviation of X_i. While the constant terms $\alpha_1^{'}$, $\beta_1^{'}$ are the normalized sample means (which equal zero under this formulation of the model), the parameters $\alpha_2^{'}$, $\alpha_3^{'}$, $\alpha_4^{'}$ and $\beta_2^{'}$, $\beta_3^{'}$, $\beta_4^{'}$ reflect the respective change in the dependent variable in standard deviation terms following a one standard deviation increase in the independent variable.

Another version of this model is given by the following equations:

$$Total\_cases\_per\_million = \alpha_1^{''} + \alpha_2^{''} Z(Population\_density) + \alpha_3^{''} Z(Median\_age) + \alpha_4^{''} Z(Hospital\_beds\_per\_thousand) + \mu_3^{''} \quad (5)$$

$$Total\_deaths\_per\_million = \beta_1^{''} + \beta_2^{''} Z(Population\_density) + \beta_3^{''} Z(Median\_age) + \beta_4^{''} Z(Hospital\_beds\_per\_thousand) + \mu_4^{''} \quad (6)$$

Once again, the constant terms $\alpha_1^{''}$, $\beta_1^{''}$ are the sample means, but in their original units of measurement (number of cases or deaths per 1 million persons). The parameters $\alpha_2^{''}$, $\alpha_3^{''}$, $\alpha_4^{''}$ and $\beta_2^{''}$, $\beta_3^{''}$, $\beta_4^{''}$ reflect the respective change in the dependent variable in the original units of measurements (number of cases or deaths per 1 million persons) following a one standard deviation increase in the independent variable.

4 Results

Table 3 reports the regression outcomes based on equations (1) and (3), where the dependent variable is *Total_cases_p.mill.*. Table 4 gives the corresponding results for equations (2) and (4) with *Total_deaths_p.mill.* as dependent variable. Table 5 gives the estimation outcomes of equations (5) and (6). Interestingly, in all tables, projected scope of

[3] According to Kmenta (1997, page 422): "The coefficients of a regression model – but not the tests or R^2 – are affected by the units in which the variables are measured. For this reason, a comparison of magnitudes of individual regression coefficients is not very revealing. To overcome this problem, applied statisticians have at time been using a transformation in the regression coefficients resulting in "standardized" or "beta" coefficients, which yield values whose comparison is supposed to be more meaningful. The idea behind the transformation is to measure all variables in terms of their respective sample standard deviations. The resulting "beta" coefficients then measure the change in the dependent variable corresponding to a unit change in the respective explanatory variable, holding other explanatory variables constant and measuring all changes in standard deviation units.".

Table 3: Regression Analysis Total Cases per 1 Million Persons with Normalized Variables

Variables	(1) Total_cases_p.mill.	Variables	(2) Z(Total_cases_p.mill.)
Constant	-32,307***	Constant	1.62×10^{-9}
	(437.9)		(0.00278)
Population density	-3.481***	Z(Population density)	-0.0592***
	(0.166)		(0.00282)
Median age	1,982***	Z(Median age)	0.443***
	(16.84)		(0.00377)
Hospital_beds_p.th.	-1,321***	Z(Hospital_beds_p.th.)	-0.0784***
	(62.86)		(0.00373)
Observations	109,813	Observations	109,813
R-squared	0.153	R-squared	0.153
F (3, 109,809)	6,607.78***	F (3, 109,809)	6,607.78***
1% Critical F	3.782	1% Critical F	3.782
H0: coef (Z(population density)) = coef		F (1,109,809)	19.23***
(Z(Hospital_beds_p.th.)); H1: Otherwise.		1% Critical F	6.635

Notes: Column (2) reports the regression outcomes where each variable (both dependent and independent) is standardized by $Z(X_i) = \frac{X_i - \bar{X}}{\sigma_X}$ where $\bar{X}$ is the average and σ_X is the standard deviation of X_i. The calculated F (3, 109,809) clearly rejects the joint null hypothesis that all $(k-1) = 3$ coefficients of the explanatory variables are equal to zero. The F-values and critical F-values at the bottom of the table refer to the null hypothesis that coef (Z(population_density)) = coef (Z(Hospital_beds_p.th)). Standard errors are given in parentheses. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

morbidity (mortality) *drops* with higher population density by 3.481 cases (1.45×10^{-7} deaths) for each 1 unit *increase* in the population density of the country. This outcome is consistent with the results presented by Hamidi et al. (2020). Based on 1,165 US metropolitan areas, and after controlling for metropolitan size and other confounding variables, the authors found significantly lower infection rates and lower death rates with higher county density.

Referring to the explanatory variables *Median_age* and *Hospital_beds_p.th.*, the signs of their coefficients are as anticipated. Projected scope of morbidity (mortality) *rises* by 1,982 cases (3.72×10^{-5} deaths) per 1 million persons with a 1 unit increase in the median age of the country's population. Projected scope of morbidity (mortality) *drops* by 1,321 cases (2.98×10^{-5} deaths) per 1 million persons with 1 unit increase in the hospital beds per thousand persons in the country. Indeed, the literature defines age (e.g. Bauer et al. 2021, Pijls et al. 2021, Zhang et al. 2022) and hospital beds per thousand persons (e.g. Brant et al. 2021, Presanis et al. 2021, Castagna et al. 2022, Fakih et al. 2022, Hobohm et al. 2022) as risk factors for COVID-19 morbidity and mortality.[4]

Given that the units of measurements of the explanatory variables are not identical, columns (2) in Tables 3 and 4, we present the outcomes after standardization. This transformation permits ranking the contributions of the three variables following an identical change (one standard deviation of each independent variable). Figure 6 gives the relative contribution of each of the three variables, and Table 5 provides comparable contributions in terms of cases (deaths) per 1 million persons.

Referring to the scope of morbidity, the most influential explanatory variable is the median age of the country's population. A one standard deviation *increase* in the median age (by 8.9 years) is associated with a 0.443 rise in the anticipated standard deviation of COVID-19 cases per 1 million persons (17,576 cases per 1 million persons – see Table 5).[5] The second influential explanatory variable is the per capita rate of hospital beds. A one standard deviation *rise* in the number of hospital beds of the country (by 2.355

[4]In fact, referring to the latter variable, and like population density (e.g. Hamidi et al. 2020), one should consider two opposing forces. On the one hand, more hospital beds are associated with better medical infrastructure and increased prospects of COVID-19 recovery. On the other hand, congestion in hospitals and healthcare centers may be a source for elevated infection (Sampeth Jayaweera, Reyes 2019, Ngandu et al. 2022). This, in turn, might increase morbidity and mortality particularly during periods with high occupancy rates.

[5]This may also be demonstrated as follows. Based on Table 3, one standard deviation of *Total_cases_p.mill.* equals 39,671.99. Multiplication by 0.443 yields $39,671.99 \times 0.443 = 17,574.69$, which is approximately 17,576 cases per 1 million persons.

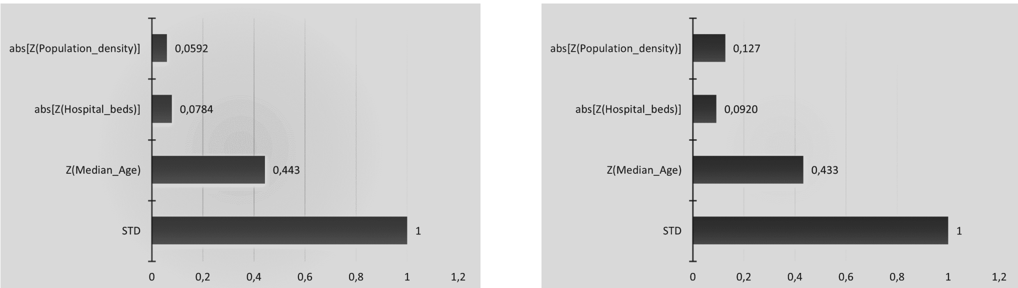
Table 4: Regression Analysis Total Deaths per 1 Million Persons with Normalized Variables

Variables	(1) Total_deaths_p.mill.	Variables	(2) Z(Total_deaths_p.mill.)
Constant	-0.000569***	Constant	1.06×10^{-10}
	(8.91×10^{-6})		(0.00289)
Population density	-1.45×10^{-7}***	Z(Population density)	-0.127***
	(3.35×10^{-9})		(0.00294)
Median age	3.72×10^{-5}***	Z(Median age)	0.433***
	(3.43×10^{-7})		(0.00398)
Hospital_beds_p.th.	-2.98×10^{-5}***	Z(Hospital_beds_p.th.)	-0.0920***
	(1.28×10^{-6})		(0.00395)
Observations	102,399	Observations	102,399
R-squared	0.144	R-squared	0.144
F (3, 102,395)	5,730.19***	F (3, 102,395)	5,730.19***
1% Critical F	3.782	1% Critical F	3.782
H0: coef (Z(population density)) = coef		F (1,102,395)	56.05***
(Z(Hospital_beds_p.th.)); H1: Otherwise.		1% Critical F	6.635

Notes: Column (2) reports the regression outcomes where each variable (both dependent and independent) is standardized by $Z(X_i) = \frac{X_i - \bar{X}}{\sigma_X}$ where $\bar{X}$ is the average and σ_X is the standard deviation of X_i. The calculated F (3, 109,809) clearly rejects the joint null hypothesis that all $(k-1) = 3$ coefficients of the explanatory variables are equal to zero. The F-values and critical F-values at the bottom of the table refer to the null hypothesis that coef (Z(population_density)) = coef (Z(Hospital_beds_p.th)). Standard errors are given in parentheses. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

hospital beds per thousand persons) is associated with a 0.0784 *drop* in the anticipated standard deviation of COVID-19 cases per 1 million persons (3,112 cases per 1 million persons – see Table 5). Finally, the least influential explanatory variable is population density. A one standard deviation *rise* in the population density of the country (by 674.14 persons per square kilometer) is associated with a 0.0592 *drop* in the anticipated standard deviation of COVID-19 cases per 1 million persons (2,347 cases per 1 million persons – see Table 5). As the right side of Figure 6 demonstrates, to offset the positive contribution of the median age to morbidity scope, population density must grow by a factor of $\frac{0.4430307}{0.0591514} = 7.4898$ standard deviations with 99% confidence interval of (6.584, 8.396).

Referring to the scope of mortality, once again the most influential explanatory variable is the median age of the country's population. A one standard deviation *increase* in the median age (by 8.9 years) is associated with a 0.433 rise in the anticipated standard deviation of COVID-19 deaths per 1 million persons (331.6 deaths per 1 million persons



(a) Covid-19 Cases Per 1 Million Persons (b) Covid-19 Deaths Per 1 Million Persons

Figure 6: Beta Coefficients

Notes: $\text{abs}(x) = -x \,\forall\, x < 0,\ x \,\forall\, x \geq 0$. To offset the positive contribution of the median age to morbidity scope, population density must grow by a factor of 0.4430307/0.0591514 = 7.4898 standard deviations with 99% confidence interval of (6.584, 8.396). To offset the positive contribution of the median age to mortality scope, population density must grow by a factor of 0.425423/0.1266079 = 3.416 standard deviations with 99% confidence interval of (3.210, 3.622).

Table 5: Robustness Test

Variables	(1) Total_cases_p.mill.	(2) Total_deaths_p.mill.
Constant	25,372***	491.4***
	(110.2)	(2.217)
Z (Population density)	-2,347***	-97.07***
	(112.0)	(2.252)
Z (Median age)	17,576***	331.6***
	(149.4)	(3.052)
Z(Hospital_beds_p.th.)	-3,112***	-70.51***
	(148.1)	(3.027)
N	109,813	102,399
R-squared	0.153	0.144
F (3, $N-4$)	6,607.78***	5,730.19***

Notes: The table reports the regression outcomes where each independent variable is standardized by $Z(X_i) = \frac{X_i - \bar{X}}{\sigma_X}$ where $\bar{X}$ is the average and σ_X is the standard deviation of X_i. The constant term reflects the sample mean of the dependent variable, and the coefficients reflect the change in the total cases or deaths per 1 million persons following a one standard deviation increase. Standard errors are given in parentheses. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

– see Table 5). Unlike the scope of morbidity, the second influential explanatory variable is the population density. A one standard deviation *rise* in the population density of the country (by 671.58 persons per square kilometer) is associated with a 0.127 *drop* in the anticipated standard deviation of COVID-19 deaths per 1 million persons (97.07 deaths per 1 million persons – see Table 5). Finally, the least influential explanatory variable is the per capita rate of hospital beds. A one standard deviation *rise* in the number of hospital beds of the country (by 2.37 hospital beds per thousand persons) is associated with a 0.0920 *drop* in the anticipated standard deviation of COVID-19 deaths per 1 million persons (70.51 deaths per 1 million persons – see Table 5). As the right part of Figure 6 demonstrates, to offset the positive contribution of the median age to mortality scope, population density must grow by a factor of $\frac{0.425423}{0.1266079} = 3.416$ standard deviations with 99% confidence interval of (3.210, 3.622).

5 Conclusions

The objective of the current study is to investigate the weight given to three risk factors associated with the scope of COVID-19 mortality and morbidity at a country level: population density, median age, and per capita rate of hospital beds per thousand persons. All of these variables have been identified in the literature as important risk factors (e.g., Hamidi et al. 2020 – population density; Bauer et al. 2021, Pijls et al. 2021, Zhang et al. 2022 – age; Brant et al. 2021, Presanis et al. 2021, Castagna et al. 2022, Fakih et al. 2022, Hobohm et al. 2022 – per capita hospital beds). Yet, their relative weights following a change in equal units of measurement have not been examined in a country level around the world. Consequently, we use empirical models with standardized coefficients, which measure the change in the standard deviation of the dependent variable (either the scope or morbidity or mortality per 1 million persons) following a one standard deviation change of each independent variable.

Referring to projected COVID-19 infection rates, and following a one standard deviation increase, these independent variables may be ranked as follows: 1) the median age of the country (a 0.443 standard deviation increase in the dependent variable); 2) per capita hospital beds (a 0.0784 standard deviation decrease in the dependent variable); 3) population density (a 0.0592 standard deviation decrease in the dependent variable).

A possible interpretation to the higher weight of the number of hospital beds compared to population density is the fact they proxy socioeconomic status and better medical literacy, which, in turn, may reduce the prospects of infection from SARS-COV2 virus. The implication of a better medical literacy is elevated awareness to the need to wash hands and wear masks. Combined with better water and sewerage infrastructure,[6] these

[6] In that context Tietenberg, Lewis (2012, p. 4) state that: "According to U.N. data, Africa and

factors might prove to be more important than population density in terms of the scope of COVID-19 morbidity.

Referring to projected COVID-19 mortality rates, and following a one standard deviation increase, these independent variables may be ranked as follows: 1) the median age of the country's population (a 0.433 standard deviation increase in the dependent variable); 2) population density (a 0.127 standard deviation decrease in the dependent variable). 3) per capita rate of hospital beds (a 0.0920 standard deviation decrease in the dependent variable).

A possible interpretation to the higher weight of the population density compared to the per capita rate of hospital beds is the fact that higher population density is associated with more human interactions, which, in turn, increase the infection rates of vulnerable population groups. The mortality prospects among these particular populations are higher (e.g., the delta compared to the omicron variants. The latter increased both infection and mortality rates).

Finally, note that for different dependent variables (i.e., scope of morbidity and mortality) one standard deviation of the independent variables are very similar. Yet, the impact of the same one standard deviation of population density on the scope of mortality is a higher *drop* compared to the scope of morbidity. This attenuation in the *drop* with higher population density may be explained on the grounds that while infection rates are direct derivatives of elevated human interactions proxied by population density, mortality rates are only indirect derivatives of population density. COVID-19 mortality follows infection. Other factors that may influence mortality are percent of vaccinated persons, and accessibility to medical services (intensive care hospital beds and equipment, anti-viral medicines, such as, Paxlovid). Other components, such as, vaccination rates or medical literacy are derivatives of the per capita rate of hospital beds. Consequently, the negative impact of population density on projected morbidity rate is attenuated compared to mortality rate.

Public policy repercussions of the study may be summarized as follows. Given the dominance of the age variable in the context of the COVID-19 pandemic, the allocation of resources for future pandemics should grow in countries with older population profiles (European countries). On the other hand, the emphasis in countries with younger populations (African countries) should be on better medical infrastructure in sparser regions. The latter finding is supported by Souris, Gonzalez (2020). The authors mostly found low hospitalization with high case-fatality rates in French districts with low population densities and attributed this phenomenon to the limitations of access to local healthcare services.

Our study is not without limitations. Every country in the world has its own regulations and in-depth research should be done with reference to each and every country. This article does not consider the scope of the health investment made (investment per inhabitant). For further investigation, we suggest doing follow-up studies on the division between men and women and by religion and by income.

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Asia suffer the most from the lack of access to sufficient clean water. Up to 50 percent of Africa's urban residents and 75 percent of Asians lack adequate access to a safe water supply. The availability of potable water is further limited by human activities that contaminate the finite supplies. According to the United Nations, 90 percent of sewage and 70 percent of industrial wastes in developing countries are discharged without treatment."

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