Magnitude and Determinants of Mortalities Related to COVID-19: Evidence from 94 Countries Using Regression Techniques

Ashis Kumar Pradhan¹ · Ronny Thomas² · Sandhyarani Rout³ · Alok Kumar Pradhan⁴

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Abstract
This study attempts to investigate the factors determining COVID-19 deaths during the pandemic across countries by employing a rich dataset sourced from 94 countries updated till 6 February, 2022. For empirical analysis, the study makes use of cross-sectional linear regression technique in the first part and after required diagnostic tests use 2SLS regression technique for correcting possible endogeneity bias in the second part. Findings from the study indicate that factors like total reported cases, population size, population over 70 years of age, extreme poverty, and human development index play significant role in determining COVID-19-related death. Further, to check the robustness of the findings the present study employed LASSO regression. Findings from the study highlight the possibility of government intervention to devise appropriate policies to control COVID-related incidence and death.

Keywords COVID-19 deaths · Mortality risks · Infectious diseases · LASSO regression · Pandemic

Ashis Kumar Pradhan
ashiskumarprdhn@gmail.com

Ronny Thomas
ronny@rajagiri.edu

Sandhyarani Rout
sandhyarout1992@gmail.com

Alok Kumar Pradhan
alokeffect1@gmail.com

¹ Department of Humanities and Social Sciences, Maulana Azad National Institute of Technology, Bhopal, Madhya Pradesh, India
² Rajagiri Business School (RBS) and Rajagiri College of Social Sciences (RCSS), Rajagiri Valley Campus, Kakkanad, Kochi, Kerala, India
³ Department of Social Science, Fakir Mohan University, Balasore, Odisha, India
⁴ Indian Institute of Management Nagpur, Dahegaon, India
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1 Introduction

The periodic occurrence of pandemics has tested the vulnerability and resilience of the healthcare system across countries from time to time. The recent history of these pandemics shows large compromise of human casualty across countries at different time periods (Baldwin and Mauro 2020). Hence, an enquiry into the factors causing death in the context of a pandemic is highly relevant knowing its life taking power.

The novel coronavirus pneumonia (or COVID-19) got initially reported towards the late 2019 and has created reverberation across the globe through its destructive impact on health, economic and social wellbeing of the people (Pradhan et al. 2021). COVID-19 is known to be caused by the virus SARS-CoV-2. The World Health Organization (WHO) officially announced that the disease is caused by SARS-CoV-2 on February 12, 2020 and declared this health emergency as a “Pandemic” on March 11, 2020. The COVID-19 pandemic started spreading throughout China and crossed the borders. The first confirmed case identified outside China was reported on January 13, 2020, in Thailand. Within a short period of five months, this disease has spread all over the world causing severe damage to human health. As on, February 12, 2022, around 409,693,562 COVID-19 pandemic cases and 5,823,492 deaths have been registered all over the globe.1

Rapid increase in the COVID-19 cases and associated incidence of death has drawn the attention of researchers and policy makers with high priority. There has been a sudden spurt of academic studies cutting across various domains of knowledge on the factors contributing to the increase of COVID-19 pandemic cases, transmissions and deaths. These studies mainly focus on the following: spatial effects of COVID-19 (Guliyev 2020); effects on temperature and humidity variations in the number of COVID-19 deaths (Ma et al. 2020; Wu et al. 2020; Qi et al. 2020); environmental impacts on COVID-19 transmission (Xu et al. 2020); air pollution and COVID-19 infection (Yongjian et al. 2020; Bontempi 2020); maternal deaths due to COVID-19 (Hantoushzadeh et al. 2020); association between the COVID-19 cases and deaths (Sarkodie and Owusu 2020); COVID-19 and stock market volatility (Sreenu and Pradhan 2022); COVID-19 and microfinance institutions (Sangwan et al. 2021); social distancing and COVID-19 death (Conyon et al. 2020); labour mobility and fatality due to COVID-19 (Wright et al. 2020); nationalism and COVID-19 (Wang 2021; Gülseven 2021; Zhao 2021; Pan and Korolev 2021; Lin 2021; Givens and Mistur 2021; Yang and Chen 2021; Zhao 2021; Boylan et al. 2021; Albertoni and Wise 2021; He and Chen 2021); global politics and COVID-19 (Salvati 2021; Makarychev and Romashko 2021; Chen 2021; Wang and Sun

1 According to WHO situation report-82, COVID 19 related death is defined as “death resulting from a clinically compatible illness in a probable or confirmed COVID 19 case, unless there is a clear alternative case of death that cannot be related to COVID 19”. (This definition of death proposed by WHO for reporting purpose).
2021; Lin 2021; Huang 2021; Chang 2021; Jaworsky and Qiaoan 2021; Caballero-Anthony and Gong 2021); mitigating measures against COVID-19 (Zhang et al. 2021; Ullah et al. 2021).

Compared to these studies, in our study we attempt to empirically examine the factors influencing COVID-19 death with a comprehensive data set using information from 94 countries on total number of cases, population, population density, total smokers, older aged people in the population, extreme poverty, hospital beds per 100,000 populations, and human development index. Our study contributes to the domain of health economics, and public administration in numerous ways. First, departing from the previous studies, we make an attempt to investigate the mortality risks and other factors that cause COVID-19 deaths across the globe. Especially, we combine the data related to demographic pattern, health, economic, personal traits and epidemiological factors from the past literature on a unique and extensive dataset. Second, our study is novel from the methodological viewpoint. To examine the factors determining COVID-related death, we use cross-sectional regression technique correcting for possible endogeneity bias and further validated the robustness of the results by employing Least absolute shrinkage and selection operator (LASSO regression). Third, previous studies were able to identify few environmental, and climatic factors as the most common determinants of death due to this infectious disease. Employing other set of variables categorized as demographic, health infrastructure, smoking habits among other factors which cause these deaths can be a value addition in understanding these mortalities. Fourth, we have incorporated daily data across nations to decipher the factors affecting COVID-19 mortalities which has not been considered in the past studies. Finally, the outcome of this study will assist in taking appropriate policy prescripts related to public health, will be a value addition from the perspective of pandemic management in order to mitigate and contain the virus spread and take necessary preparatory actions related to the upcoming waves of COVID-19.

The remainder of the paper is categorized as follows: In the Sect. 2, we discuss the overview of the recent literature on COVID-19. In the Sect. 3, we briefly describe about the methodology and data. The results and robustness checks of the models are discussed in the Sect. 4 and an elaborate discussion on the results is documented in the Sect. 5. Section 6 concludes the study.

2 Review of Literature

2.1 Past Studies

In this section, we discuss about selected literature on the factors that influence COVID-19 death across countries. Banik et al. (2020) probed on the factors that caused the COVID-19 fatalities among 29 economies by using the cross-sectional regression techniques. The findings of the study explain that variables such as public healthcare system, population age above 65 years, BCD vaccination and poverty rate have better explanatory power in determining the COVID-19 fatality rates. The outcome of the study suggests about the implementation of robust policies pertaining
to the improvement of public healthcare system. Using the dataset of 10 COVID-19 severely hit nations, Sharma et al. (2021) find a strong cross-sectional dependence between the variables namely cases and deaths due to COVID-19 and the meteorological factors such as air pressure, temperature and humidity. The authors also confirm a bidirectional causality among these set of variables under study. The results indicate about the implementation of appropriate policy prescriptions related to pandemic management.

Roy and Ghosh (2020) investigate on the factors that contribute to post-COVID-19 infection and mortalities in 50 states of USA. The authors employ the machine learning techniques to rank the key factors and multiple regression methods to show that variables such as population density, volume of tests, air traffic, and higher age group as significant determinants of COVID-19 spread and fatalities. In a similar study, Roy and Khalse (2020) find the correlation among several epidemiological variables. The results from the Pearson correlation coefficient suggest that the variables namely healthcare expenditure as a ratio of gross domestic product and critical beds per capita have a positive and significant correlation with the case fatality rate of COVID-19 cases and the variable such as population density shows a negative and significant correlation with the case fatality rate of COVID-19 cases.

Among a few studies on mortalities related to COVID-19, Williamson et al. (2020) created a health analytics platform covering 40% of patients from England and examine the reasons of their deaths. The authors find that gender, age, ethnicity, medical conditions of the patients and other clinical factors are a few factors responsible for such deaths. By employing quantile regression, Upadhyaya et al. (2020) purport to show the reasons of COVID-19 deaths across 184 countries by using the data from June 2020. The authors find that population more than 65 years of age, urbanization and obesity are among a few determinants of COVID-19 mortality. There results also show that per capita income has a negative effect on COVID-19 mortalities. Similarly, Jabłońska et al. (2021) probe on the factors of COVID-19 deaths from 34 European countries. The authors find that nations with more people living in urban areas, increasing trends in population migration during the beginning of the pandemic and more infected people when borders were closed were most affected nations. The authors also recommend that increasing the hospital bed capacity might delay in reaching the deaths’ peak due to COVID-19, whereas increase in the visits of foreign travelers to these nations could accelerate the death rate.

The overall review of literature shows that earlier studies are concentrated on developed markets such as USA and Europe. We are able to minimize the research gap by using a voluminous dataset of 94 countries and combining the demographic, health, economic and epidemiological factors by conducting a comprehensive study.

2.2 Theoretical Framework

After claiming approximately fifty-eight lakhs lives due to the COVID-19 spread across the globe as on 12.02.2022, the effect of the pandemic shows no signs of slowing down. While the top COVID-19 affected nations are preparing themselves for the third wave—it is imperative to probe about those factors that contribute
towards the fatalities and cases due to COVID-19. Against the backdrop of the growing trends of COVID-19 infection, we have identified a set of factors from the past literature that has influenced the COVID-19 death across countries. Studies indicate that the incidence of COVID-19 death is higher for countries that reported more number of positive cases (Sohrabi et al. 2020; Yuan et al. 2020). This is mainly, because several hospitals which are overwhelmed with patients are entering rapidly into crises mode around the world. With the rise in the number of total positive cases, it becomes cumbersome to handle the infection when the rate of contact and transmission is rapid. Given, the constraints of health infrastructure, it is likely that the new deaths will increase with a rise in the total increment in new positive COVID-19 cases (Banik et al. 2020). Sohrabi et al. (2020) discuss that compared to SARS in the case of COVID-19 the number of laboratory confirmed cases was higher. Again, the number of reported cases and fatality rates vary across countries. For example, Yuan et al. (2020) have undertaken a real-time tracking of Case Fatality Rates (CFR) and found that death rates in relation to positive confirmed cases are high for Spain and France.

Another key aspect that determines COVID-19-related death is the quality of public health infrastructure. Healthcare service delivery is considered to be the most crucial factor in the assessment of the public health care system of a country. Among all the available indicators, the number of inpatient hospital beds per 10,000 populations is considered to be a good indicator of healthcare service delivery (Banik et al. 2020). Increase in the number of patients to a hospital merits the demand of more hospital infrastructure. Therefore, a rise in the number of hospital beds would increase the likelihood of saving more human lives during an emergency. Furthermore, in align with the international standards every healthcare unit with 100 hospital bed facility must equip a minimum of 5 ICUs (Abdullah 2020). According to the Organisation for Economic Co-operation and Development (OECD), the total number of hospital beds per 10,000 people in South Korea is 123, China possesses 43 hospital beds per 10,000 populations, Italy has 32 hospital bed facility per 10,000 inhabitants, while other developed regions such as Spain, the USA and the UK have 32, 28, 25 hospital beds per 10,000 populations, respectively (Banik et al. 2020). However, better hospital infrastructure only cannot reduce the number of deaths in a situation like COVID-19. Facilitating timely healthcare benefits, availing the COVID-19 testing kits and testing the symptoms on a large scale, emphasizing on social distancing norms, and isolating the infected patients can be remarkably effective (Conyon et al. 2020; Banik et al. 2020). All such actions must be stringently applied and government intervention in containing and mitigation is equally necessary.

2 Yuan et al. (2020) shows that the transmissibility of COVID-19 is high when the laboratory confirmed cases are high. In their study they used real time variant of Case Fatality Rate- Naïve Case Fatality Rate (nCFR) and Adjusted Case Fatality Rate (aCFR). Again, the death rate in relation to confirmed cases may also vary within the country. In a study of Chinese provinces, Leung et al. (2020) found that provinces differ in terms of confirmed cases and CFR. Provinces with high number of confirmed cases are also the ones reported high case fatality.

3 CFR stands for Case Fatality Rate. CFR is calculated as a ratio of COVID-19 death to confirmed cases.
Presumably, demographic factors namely the age of the population have an important role in explaining the reasons of COVID-19 fatalities across nations. Although the outbreak of COVID-19 has been affecting every community irrespective of the age groups, the elderly cohort is observed to be more vulnerable to significant health concerns (Zhou et al. 2020a, b; Sohrabi et al. 2020). Zhou et al. (2020a, b) conducted a study on 191 Chinese patients and find old age to be a significant factor in explaining the number of COVID-19 deaths. Other researches also arrive at similar findings and concluded that people aged 65 or more are the most affected as compared to other age groups in terms of COVID-19 deaths (Guo et al. 2020; University of Oxford 2020). A report of WHO also confirmed that the highest number of deaths are happening among people of age 80 years and above. Another joint report of WHO-China shows that mortality related to COVID-19 increases with an increase in age, and approximately 22% of deaths have happened to age group 80 years and above. The Union Health Ministry of India also confirmed that the coronavirus deaths are more among the elderly cohorts with an age group of 60 and above which accounts for 60% of total COVID-19 deaths following the international trends in India. The COVID-19 elderly deaths are because of the inability of elderly populations in producing sufficient white blood cells (WBCs) (India Today 2020). Kluge (2020) opined that age-related physiological transformations, decrease immunity and multi-morbidity are the prime reasons of elderly COVID-19 deaths. However, age is not the sole reason for such deaths. There are many exceptions when individuals of over 100 years of age have been recovered from COVID-19 ailment (Indo-Asian News Service 2020). Therefore, to control COVID-related fatality, immunity development policies supporting healthy ageing must be the utmost priority of the society’s agenda (Banik et al. 2020).

Population and Population densities are other demographic factors that is positively associated with the number of COVID-19 deaths. This is because greater the population and population density higher is the rate of contact. Anderson et al. (2020) hold that in case of SARS-COV-2 the basic reproduction number ($R_0$) fluctuates between 2–4 times greater as compared to influenza A. Rocklöv and Sjödin (2020) opine that population density is an important factor which has substantial impacts on $R_0$ via contact rates. In another study of this kind, Rocklöv et al. (2020) purport to show that in the case of Diamond Princess cruise ship, $R_0$ and population density were both around four times greater as compared to Wuhan, China.

Smoking habits accelerate the severity of health issues among the COVID-19 positive cases patients. Smoking habit is connected with the prognosis of adverse diseases, as it negatively affects the lung health (Tonnesen et al. 2019), aggravates the immune system of the smokers and makes them vulnerable to infectious diseases (Zhou et al. 2016), and doubles the likelihood to contract influenza than the non-smokers. It was also observed that the mortality rates were higher amongst those who smokes during the outbreak of MERS-CoV (Park et al. 2018). Using a retrospective study design, Guan et al. (2020) investigated on the severity of COVID-19 patients accustomed to smoking by collecting the data from 552 hospitals of 30 Chinese provinces. Out of 1099 COVID-19 patients accustomed to smoking, 173 were found to be severe cases. From these 173 cases, 16.9% are current smokers, 5.2% were former smokers, and 77.9% were non-smokers. During severity, the patients...
were admitted to ICUs, or used the mechanical ventilation, while others died due to the ailment. In another study, Liu et al. (2019) conducted a retrospective multi-centre cohort study by collecting samples from three hospitals in Wuhan. Their study sample includes 78 positive cases for COVID-19 patients. History of smoking is one among the other factors affecting the progression of COVID-19 namely age, maximum temperature of the body during hospital admission, C-reactive protein, failure of the respiratory system, and albumin. Therefore, going by the previous literature we hypothesize that higher the smoking habit the greater is the susceptibility of the prognosis of the COVID-19 which might eventually cause death of the patient.

Extreme poverty is another important factor that may cause high incidence of COVID-19 deaths across countries. Poverty increases exposure to the disease and increases mortality rate for many reasons. First, poor countries have little access to quality health care. People living in poverty are extremely vulnerable and likelihood of death is high due to lack of access to immediate treatment facility (Banik et al. 2020). Second, extreme poverty may lead to lack of compliance with social distancing norms. Studies suggest that stricter social distancing norms can significantly reduce incidence of COVID-19 deaths (Anderson et al. 2020; Friedson et al. 2020; Dave et al. 2020; Wright et al. 2020; Conyon et al. 2020). Third, the unemployment and labour market impact of COVID-19 would be much higher for people who serve as front line workers and are economically vulnerable (Mongey et al. 2020). One reason would be that lower income countries face severe constraints in terms of labour mobility during the lockdown period and the people living on subsistence livelihood would find it difficult to afford healthcare for immediate cure of the disease. Further, studies highlight that the income levels of countries are highly correlated with the mobility of labour (Wright et al. 2020). Again, people in low-income countries work mostly in the unorganized informal sector where they rely on daily income. Stringent self-isolation and distancing norms will in fact lower their income and lower the resilience to COVID-19 causing death. There are also chances that testing is carried out in a limited way and hence the death and incidence of COVID-19 is highly under reported in many poverty-ridden countries (Manski and Molinari 2020; Stock 2020; Avery et al. 2020).

HDI represents human development index which is a composite indicator of educational awareness, life expectancy, and per capita income. HDI figures stimulates debate on government policies concerning education and health status of a country. Although the trend shows that countries with high HDI values were the first to suffer from the health shock, these countries have robust health care infrastructures, sufficient resources to tackle any crises, strong economic systems, and supportive fiscal and monetary policies (Human Development Perspectives 2020). Developing countries were heavily affected because of the pandemic during the year 2020 which led to economic downfall and increasing uncertainty in these economies. We expect that, timely and effective policies catalyzing a rise in HDI figures tend to decline the COVID-19 mortalities.

The overview of previous literature shows that studies pertaining to COVID-19 deaths only discussed about specific factors. Departing from the previous studies, we analyse a list of factors in a single study that caused a recent surge in human casualty across countries. Most of the research on determinants of COVID-19-related
deaths has only been confined to particular geographical regions such as China. To the best of our knowledge, there are no other study that explore the reasons of the pandemic deaths by using the information from such a comprehensive and rich dataset. To consider a broad and holistic approach in examining factors of COVID-19 deaths is a major gap in the literature which is filled by the present research.

3 Data and Methodology

In this section, we discuss the methodological approach and data used in the analysis. We are interested to probe on the determinants that caused coronavirus deaths throughout the world. We consider every country which are affected from coronavirus pandemic in our analysis. The data period commences from 31.12.2019 and updated till 06.02.2022. We use this criterion to filter those nations on which the explanatory variables are available. After filtering the data, our final sample comprises of 94 countries. The data is sourced from https://ourworldindata.org/mortality-risk-covid (Roser et al. 2020). This data is updated daily as per 11.00 London time.

We first employ the cross-sectional regression technique to identify the determinants. After considering the post-diagnostic statistics, we further conducted the 2SLS IV regression and the 2SLS IV regression with robust standard errors regression to overcome the possibility of endogeneity issues. Finally, for the robustness of our results we have also supplemented the results of the LASSO regression which takes into consideration the variable selection, and regularization of the parameters. LASSO regression is credited to Tibshirani (1996). This innovative model is preferred over other cross-sectional models because it regularizes the value of the parameters based on the sparse assumption. LASSO regression is popular predictive approach as it helps identifying pertinent variables and omit irrelevant predictors. Unlike standard regression methods which are affected by a set of predictors leading to overfitting, LASSO regression aims to reduce the prediction error through the imposition of a constraint on the model parameters. This procedure shrinks the regression parameters towards zero, causing the summations of the absolute value of the regression coefficients to be less than a constant value.

The regressors of our interest for the estimation are total cases, population size, population density, total smokers, population over 70 years of age, hospital beds per 100,000 populations, extreme poverty, and HDI. All variables are changed to its natural logarithmic form\(^4\) except hospital beds per 100,000 populations, extreme poverty, and HDI. Identification of these variables is dictated from the previous literature and theoretical framework.\(^5\) Based on the identified variables, our estimated model is represented as:

\(^4\) Natural logarithmic transformation of a variable helps transforming highly skewed values normally distributed because of the presence of outliers in the data (Pradhan and Hiremath 2020), addresses heteroscedasticity by compressing the scale of the variables (Gujarati 2011), and enhance interpretation of the parameters of the independent variables as elasticities (McFarlane et al. 2022).

\(^5\) After employing the regression, we estimate the Ramsey reset test for variable specification. The result of Ramsey reset test indicate that the model is well specified with no missing and ignored variables.
where TCD is the total number of coronavirus deaths; Z represents the vector of independent variables included in the model; $\alpha_1$ an overall constant term of the model; and $\mu$ implies the net effect of the ignored variables in the model which may affect the total number of coronavirus deaths among the countries considered for the analysis. As we have several explanatory variables in our model which are expected to cause mortality risks, we applied proper econometric tool for model specification and to reduce the omitted variable bias. Therefore, we employed the LASSO regression method to identify potential variables that can best represent the relationship with the dependent variable using the STATA 16.0 software.

4 Results

In this section, we report the findings from empirical analysis. The summary of the selected variables taken for empirical analysis in the specification shown in Eq. (1) is presented in the Table 1. We segregate the variables into Panel A and Panel B. Panel A includes the absolute figures of all variables, Panel B contains the natural logarithmic transformation of the all variables and HOSBED, EXTPOV, and HDI which are the part of our analysis. As on 06.02.2022, there were 319,004,825 cases and 4,992,713 deaths reported for the 94 countries for which the analysis is being conducted. The mean of all the variables is positive, and the standard deviation of the variables is low as evident in the Panel B. This shows that the observations of these variables are not much deviated from the respective mean values of these variables. The skewness value of most of the variables is negative except HOSBED and EXTPOV. The positive skewness value of the variables namely HOSBED, and EXTPOV shows a longer distribution towards the right than the normal distribution. The kurtosis values of all the variables are significant (except LNTCD, LNTCC, LNAGE70, and HDI) which indicates leptokurtic distribution. Variables that follow leptokurtic distribution are susceptible to extreme events/shocks.

In the Table 2, we present the correlation matrix. We find positive and high degree of association between the variables LNTCD and LNTCC. This implies that both total coronavirus deaths and cases are positively associated with each other. However, we find high and significant values of the correlations among few selected independent variables such as LNTCC, LNAGE70, LNTSMOK, LNPOP, HOSBED, EXTPOV, and HDI indicating the possibility of multicollinearity among the regressors. To overcome this problem, we check the variance inflation factor (VIF) which we found to be 3.75 indicating moderate multicollinearity problem$^6$ (see Table 3). Later, we employ the LASSO Regression method (see Table 5) which is

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$^6$ Individual values of the VIF for each variable is presented in the appendix section.
**Table 1** Descriptive statistics

| Variables          | Mean     | S.D      | Skewness | Kurtosis |
|--------------------|----------|----------|----------|----------|
| **Panel A**        |          |          |          |          |
| TCD                | 53,113.97| 132,286.7| 4.375    | 24.327***|
| TCC                | 3,393,668| 9,555,134| 5.768    | 40.672***|
| POP                | 67,200,000| 209,000,000| 5.889    | 38.215***|
| PDEN               | 146.118  | 218.622  | 3.989    | 21.908***|
| TSMOK              | 42.537   | 19.927   | 0.293    | 2.633    |
| AGE70              | 6.439    | 4.281    | 0.562    | 1.982    |
| **Panel B**        |          |          |          |          |
| LNTCD              | 9.033    | 2.135    | −0.157   | 2.613    |
| LNTCC              | 13.314   | 2.037    | −0.229   | 2.694    |
| LNPOP              | 16.487   | 1.761    | −0.055   | 3.207*** |
| LNPDEN             | 4.316    | 1.225    | −0.437   | 3.764*** |
| LNTSMOK            | 3.602    | 0.629    | −1.676   | 7.516*** |
| LNAGE70            | 1.611    | 0.746    | −0.164   | 1.764    |
| HOSBED             | 2.959    | 2.279    | 1.324    | 4.978*** |
| EXTPOV             | 9.847    | 16.513   | 1.946    | 5.919*** |
| HDI                | 0.743    | 0.147    | −0.506   | 2.205    |

*TCD* total coronavirus deaths, *TCC* total coronavirus cases, *POP* population, *PDEN* population density, *TSMOK* total smokers gender-wise, *AGE70* age 70 years older, *HOSBED* hospital beds per 1 lakh population, *EXTPOV* extreme poverty, *HDI* human development index

Variables with a prefix LN is the natural logarithmic transformation of the variables discussed. Values in the parenthesis are *p* values

Asterisk symbol marked in the table for variables represent leptokurtic distribution

*Source: Authors’ calculations*

**Table 2** Correlation matrix

| Variables          | LNTCD | LNTCC | LNPOP | LNPDEN | LNTSMOK | LNAGE70 | HOSBED | EXTPOV | HDI  |
|--------------------|-------|-------|-------|--------|---------|---------|--------|--------|------|
| LNTCD              | 1     |       |       |        |         |         |        |        |      |
| LNTCC              | 0.917 | 1     |       |        |         |         |        |        |      |
| LNPOP              | 0.658 | 0.531 | 1     |        |         |         |        |        |      |
| LNPDEN             | −0.024| −0.085| 0.051 | 1      |         |         |        |        |      |
| LNTSMOK            | 0.133 | 0.205 | −0.143| 0.021  | 1       |         |        |        |      |
| LNAGE70            | 0.389 | 0.549 | −0.183| −0.044 | 0.489   | 1       |        |        |      |
| HOSBED             | 0.147 | 0.237 | −0.213| −0.099 | 0.535   | 0.604   | 1      |        |      |
| EXTPOV             | −0.422| −0.503| 0.107 | 0.052  | −0.366  | −0.719  | −0.443 | 1      |      |
| HDI                | 0.399 | 0.611 | −0.162| −0.140 | 0.417   | 0.903   | 0.574  | −0.779 | 1    |

Variables as discussed in the Table 1

*Source: Authors’ calculations*
another alternative approach to deal with the multicollinearity issue (Herawati et al. 2018).

We explain the empirical findings derived from the Eq. (1) in the Table 3. We are interested to probe on the potential factors that caused mortality risks pertaining to COVID-19 infection. To do so, we consider LNTCD as the dependent variable. The list of explanatory variables is LNTCC, LNPOP, LNPDEN, LNTSMOK, LNAGE70, HOSBED, EXTPOV, and HDI. A rise in the rate of contact multiplies the number of total coronavirus cases which eventually causes more fatalities. A positive and significant coefficient of the variable LNTCC indicates that countries

### Table 3 Determinants of COVID-19 deaths

| Variables    | Coefficients | Standard error |
|--------------|--------------|----------------|
| C            | −2.189       | 1.215 (0.075)  |
| LNTCC        | 0.962***     | 0.073 (0.000)  |
| LNPOP        | 0.187***     | 0.067 (0.007)  |
| LNPDEN       | 0.005        | 0.058 (0.930)  |
| LNTSMOK      | −0.075       | 0.134 (0.576)  |
| LNAGE70      | 0.484**      | 0.230 (0.039)  |
| HOSBED       | 0.047        | 0.041 (0.258)  |
| EXTPOV       | −0.027***    | 0.007 (0.000)  |
| HDI          | −6.827***    | 1.369 (0.000)  |

#### Diagnostic statistics

|                |               |
|----------------|---------------|
| VIF            | 3.75          |
| Breusch–Pagan test | 0.01 (0.928) |
| Link test      | −0.013        |
| Hatsq value    | (0.302)       |
| F statistics   | 111.96***     |
| Adj. $R^2/R^2$ | 0.905         |
| Root MSE       | 0.657         |

Variables are same as defined in Table 1. Values in the parenthesis are $p$ values. *, ** and *** denote statistical significance at 1%, 5% and 10% level respectively.

Source: Authors’ calculations
with higher coronavirus positive cases would experience more mortalities as compared to countries with less coronavirus contagion.\(^7\) We find positive and significant coefficient value of the variable LNTCC in all our models, i.e. linear regression, 2SLS IV regression,\(^8\) 2SLS IV regression with robust standard errors (see Table 4). The result of this variable is also validated with the LASSO regression outcomes (see Table 5). However, the number of deaths also depends on the pace at which people started developing a better immune system\(^9\) (Hamblin 2020) and vaccinations provided to them. The relationship between the total cases and total deaths can be clearly explained in Fig. 1.

Figure 1 shows a graphical comparison between the total cases and number of deaths due to coronavirus for countries with more than 5000 reported deaths till 06.02.2022. Considering USA as a benchmark for the total number of deaths, it can be observed that Brazil, India, Russia, Mexico and Peru are among the countries with higher proportion of total death cases upon total cases reported. While United Kingdom, Spain and Turkey are among the countries with lower proportion of total death cases upon total cases reported.

LNPOP represents population size which defines the demographic structure of a country. Countries with high population were more affected due to the coronavirus outbreak. China and India are glaring example.

We find a statistically positive and significant value of the coefficient LNPOP on LNTCD (see Table 3). We also find that the results of the linear regression are validated with the 2SLS IV regression, 2SLS IV regression with robust standard errors, and the LASSO regression results. For a clear picture, we provide a country-wise trend analysis of total deaths based on population (see Fig. 2).

In Fig. 2, we provide a graphical comparison between the population and number of deaths due to coronavirus for countries with more than 5000 reported deaths till 06.02.2022. The countries with high number of deaths due to COVID-19 are USA, Brazil, India, Russia, Mexico, Peru, United Kingdom, etc.

We use LNPDEN as an alternative proxy to LNPOP. However, the rationale of keeping this variable in the regression models is basically due to the low degree of correlation coefficient of LNPDEN with LNPOP. Presumably there can be a connection between countries with high population density and its susceptibility to epidemics. The general argument in favour of such association is that countries with high population density are more vulnerable to epidemics because of high frequencies of

\(^7\) The total COVID-19 cases considered in the models can be interpreted with a caution because this variable can be a confounding factor in the models.

\(^8\) We use the variable LNPDEN as instrumented variable as we treat this variable as endogenous regressor while performing the 2SLS IV regression. We also include two other variables namely LNTSMOK and HOSBED as instruments since we believe that these variables are correlated with LNPDEN but uncorrelated with the error term. The reason of choosing these two variables is based on the linear regression results as reported in the Table 1, where we find that these two variables does not affect the LNTCD variable directly. Therefore, LNTSMOK and HOSBED are not the part of the 2SLS IV regression.

\(^9\) The release of cytokine molecule in the body can help contain a virus and develop fatal immune system.
Table 4: Determinants of COVID-19 deaths

| Variables | 2SLS IV regression | 2SLS IV regression with robust standard errors |
|-----------|--------------------|-----------------------------------------------|
|           | Coefficients | Standard error | Coefficients | Robust standard error |
| C         | 1.766 | 5.993             | 1.766 | 6.279             |
|           | (0.768) |                  | (0.779) |                  |
| LNTCC     | 0.898*** | 0.134             | 0.898*** | 0.114             |
|           | (0.000) |                  | (0.000) |                  |
| LNPOP     | 0.251*  | 0.133             | 0.251**  | 0.112             |
|           | (0.060) |                  | (0.025) |                  |
| LNPDEN    | −0.681  | 0.931             | −0.681  | 0.960             |
|           | (0.465) |                  | (0.478) |                  |
| LNAGE70   | 1.027   | 0.773             | 1.027   | 0.700             |
|           | (0.184) |                  | (0.143) |                  |
| EXTPOV    | −0.033**| 0.014             | −0.033**| 0.016             |
|           | (0.014) |                  | (0.033) |                  |
| HDI       | −9.705**| 4.737             | −9.705* | 5.108             |
|           | (0.040) |                  | (0.057) |                  |

Diagnostic statistics

Post-estimation endogeneity

- Durbin (score) $\chi^2$ 1.402 (0.236)
- Wu–Hausman $F$ test 1.302 (0.257)

Robust score $\chi^2$ 1.494 (0.222)

Robust regression $F$ 1.152 (0.286)

Post-estimation validity of instruments check

- Sargan (score) $\chi^2$ test 0.016 (0.899)
- Basmann $\chi^2$ 0.015 (0.904)

Score $\chi^2$ 1.569 (0.210)

Wald $\chi^2$ statistics 373.57*** (0.000)

$R^2$ 0.770

Root MSE 1.018

Variables are same as defined in Table 1. Values in the parenthesis are $p$ values. *, ** and *** denote statistical significance at 1%, 5% and 10% level respectively.

Source: Authors’ calculations
Table 5  Determinants of COVID-19 deaths

| Model                      | Double-selection linear LASSO regression |
|----------------------------|-----------------------------------------|
| Variables                  | Coefficients                             |
|                            | Robust standard error                    |
| LNTCC                      | 0.964***                                 |
|                            | 0.075                                    |
|                            | (0.000)                                  |
| LNPOP                      | 0.185***                                 |
|                            | 0.059                                    |
|                            | (0.002)                                  |
| LNPDEN                     | 0.004                                    |
|                            | 0.071                                    |
|                            | (0.957)                                  |
| LNTSMOK                    | −0.078                                   |
|                            | 0.178                                    |
|                            | (0.661)                                  |
| LNAGE70                    | 0.283                                    |
|                            | 0.838                                    |
|                            | (0.736)                                  |
| HOSBED                     | 0.047                                    |
|                            | 0.043                                    |
|                            | (0.279)                                  |
| EXTPOV                     | −0.027***                                |
|                            | 0.008                                    |
|                            | (0.001)                                  |
| HDI                        | −6.827***                                |
|                            | 1.924                                    |
|                            | (0.000)                                  |

Diagnostic statistics

Wald chi2 statistics 772.36*** (0.000)

Variables are same as defined in Table 1. Values in the parenthesis are \( p \) values. *, ** and *** denote statistical significance at 1%, 5% and 10% level, respectively.

Source: Authors’ calculations

Fig. 1 Comparison between country-wise total COVID-19 cases and total deaths
interpersonal contacts (Fang and Wahba 2020). However, other authors find a contrary result.

The authors also observed that cities with dense population were also wealthier ones, which make them mobilize sufficient resources in order to tackle the coronavirus pandemic. Our results are also in congruence with these findings. The variable LNPDEN is found to be statistically insignificant. In a nutshell, we did not find the variable LNPDEN as a significant factor affecting the mortalities happened due to COVID-19 as evidenced in any of the regression models.

The variable LNTSMOK represents the natural logarithmic transformation of the summation of both the male and female smokers in a country. This indicator explains the intensity of smoking habits among the population of a country. This variable turned out insignificant in our study across all specifications. Again, we find a positive and statistically significant coefficient of the variable LNAGE70 when the linear regression was performed. However, the variable is not significant when we used the 2SLS IV regression and the 2SLS IV regression with robust standard errors and LASSO regression approach. The findings of these results are also consistent with previous empirical studies (Upadhyaya et al. 2020; Goh et al. 2020). Further, in our empirical model we use hospital beds per 1 lakh population (HOSBED) as an indicator of healthcare service system of the countries. We did not find any significance of this variable in any regression model. Insignificant result of this variable is also consistent with previous empirical studies (Upadhyay and Shukla 2021). EXT-POV variable indicating extreme poverty is statistically significant with a negative sign. This indicate that countries with extreme poverty will experience less COVID-19 deaths than those countries with more population below the poverty line. We also include HDI which measures human capabilities and helps in guiding analysis and policy. Our results show that deaths due to COVID-19 contraction reduces with an increase in human capabilities, opportunities, better quality of life and enhancement in standard of living of the people. It is also important to note about the high magnitude of the coefficient value of the variable HDI. Therefore, it is clear from
the empirical results that the variable HDI has the dominant power in reducing the COVID-19 mortalities. This result is similar for all the models and also with prior empirical literature (Upadhyay and Shukla 2021).

We performed the diagnostic checks for each models. All our models pass through the post-estimation tests. In the linear regression model, we applied the Breusch–Pagan test of heteroscedasticity and Link test statistic to check the specification of the model. We find insignificant values of both the tests implying that our model is free from both heteroscedasticity and omitted variable bias problem. The $F$ statistics indicates that independent variables included in the models have better predictive power which explains the overall significance of the models. A high value of the Adjusted $R^2$ (model is a good fit to the data) represents that the variation in the dependent variable is being explained by the explanatory variables included in the models.

After employing the 2SLS IV regression and 2SLS IV regression with robust standard errors, we conduct the post-estimation for endogeneity. In case of 2SLS IV regression approach, we apply the Durbin (score) Chi-square and Wu–Hausman $F$ test to check for the persistence of endogenous regressors in the model. We find insignificant values of these statistics which shows that the explanatory variables are exogenous. Similarly, we conduct the robust score Chi-square test and robust regression $F$ test to check for endogeneity issues in the 2SLS IV regression with robust standard errors model. The insignificant values of these statistics imply that the independent variables are exogenous. Furthermore, we apply the Sargan (score) Chi-square test and Basmann Chi-square tests in the 2SLS IV regression method to see whether the overidentifying restrictions are valid or not. These statistics confirm that the instruments used in the model are well specified. In case of 2SLS IV regression with robust standard errors, we employ the Score Chi-square test and find that the over identifying restrictions are valid. The null hypothesis of the Wald Chi-square is that all the included coefficients are equal to zero. A significant result implies that not all the coefficients are simultaneously equal to zero. The significance of the Wald Chi-square test for both the models implies that the independent variables in the models are significant. The results of Wald Chi-square test explain that the set of variables results is a statistically significant improvement in the model fit than including nothing. Additionally, the higher value of the Adjusted $R^2$ (goodness of the fit of the model) in both the models indicates the variation in the dependent variable is being explained by the independent variables included in the models.

We also report the results of Wald Chi-square statistic after employing the Double-selection linear LASSO regression. The statistical significance of the Wald Chi-square statistic implies that the set of explanatory variables are statistically significant in enhancing the predictive power of the model in comparison of incorporating no variables. To foreshadow the key results, we find that the variables namely total cases, population size, population over 70 years of age, extreme poverty, and HDI are contributory factors determining the COVID-19 deaths across the sample of 94 nations. The consistency of the sign of these variables increases the robustness which further merits the demand of government policies related to containment, mitigation and preparatory plans for lockdowns to reduce the speed of contagion.
5 Discussion

The estimated results reported in the above section show that total COVID-19 mortality rates across countries are highly dependent on the confirmed reported cases. Number of COVID-19 cases is expected to be an important indicator which can cause mortalities because it is the origin of virus spread or infection. People who are infected can carry the infection and it is treated contagious which can multiply the risks if no proper or timely care is being provided to the patients affected from this ailment. Moreover, with the increase in the number of cases the availability of hospital bed occupancy, medical resources and services keeps on declining. Hence, decline in care provided to the critical patients can also led to an increase in the number of mortalities. A recent study by Elezkurtaj et al. (2021) using the full body autopsy of 26 patients found that comorbidities or any preexisting health issue is not an immediate cause of the death of these patients. The authors also concluded that multi organ failure, respiratory failure and septic shock are the prime reasons of these mortalities among the patients. Our results are also supported by trend analysis.

Our findings highlight that countries with high population reported more COVID-19 deaths. These findings are similar to (Leung et al. 2020) in the context of China. One argument in favour of this is that countries with high population have also reported more internal labour movements and migration. For example, (O’Brien and Eger 2020) reports that an unprecedented health shock like the COVID-19 propelled a wave of panic swept among the crowd which shoots up labour movements and population migration across the globe. Again in the case of China, Leung et al. (2020) find that large-scale migration across the countries and among the states increases the rate of transmission of the infection among the masses. A professor of public health at the University of New South Wales, Padmanesan Narashimhan opined that the probability of spreading this infection is high in India because of internal migration, population density and constraints in healthcare infrastructure (The Times of India 2020).

Further, our finding supports the view that countries with older population are most affected during any epidemic (LNPOP is positive and significant). COVID-19 event is no exception to this. Population with 70 years’ elderly cohorts are unable to sufficiently produce WBCs, face multi-morbidity issues, and are accustomed to physiological changes. The amount of cytokine molecule production in the bodies of the older people is also lower as compared to the younger generation. A decline in the cytokine molecule content reduces the ability of the body in containment of the virus which eventually develop weaker immune system (India Today 2020). Therefore, there is a high probability of mortalities among the elderly cohorts. Considering these arguments, we find that our results are in align with the previous studies (Zhou et al. 2020a, b; Guo et al. 2020; University of Oxford 2020).

Coronavirus pandemic has caused severe toll across the nations, causing crisis, ailments, economic despair and fatalities. During such a dramatic event, people lost their jobs, became homeless and had to migrate to distant places with their family members without sufficient food and other basic amenities. The
lower strata of the society are the hardest hit. According to a report, COVID-19 is expected to push 49 million of the global population impoverished by the year 2020 (Mahler et al. 2020). Furthermore, people already living below the poverty line had to migrate in masses. The number of people infected due to COVID-19 transmission has risen due to such internal migration. These impoverished people were unable to afford better medical facilities, and accessibility of healthcare to cope up from the COVID-19 infections. Additionally, the rescue operations by various nations and regions caused labour to migrate from COVID-19 affected areas to safer zones which again increases the rate of positive cases by infecting more people. This is obvious that a rise in the number of total COVID-19 positive cases would cause an increase in the rate of mortality. Nevertheless, our findings highlight that countries with extreme poverty reported less COVID-19 deaths. But the coefficient value of the variable EXTPOV was found to be very low. Therefore, a low value of the regression coefficient for this feature (indicating a lower effect in COVID-19 deaths) indicate that this result should be analysed with caution. We obtain a negative relation between COVID-19 deaths and EXTPOV because of three possible reasons. One, extreme poor countries have limited logistics and resources to control a virus spread such as adequate amount of testing kits to identify the infection carriers, PPE kits, etc. Therefore, these countries might not be having stringent testing of COVID-19 infected people. Second, there are less migration by the foreign travelers to these poor nations during COVID-19 times. Poor health and medical facilities existing in these countries can be another reason for lower foreign visits. Therefore, there are less chances of contraction of a new variant amongst the people in these countries causing lower probability of mortalities due to COVID-19. Third, countries with high incidence of poverty have also low life expectancy rates and therefore low proportion of old age population causing low mortality rates. Because of these reasons, the COVID-19 deaths tend to reduce with an increase in poverty. This result is consistent in all the models. Our results contradict previous findings (Banik et al. 2020) and, however, also support their results when the BCG and regional poverty interaction term was considered in their study.

A country with high HDI figure indicates development process, better quality of life, and higher standard of living of the citizen. These countries are also expected to have robust fiscal policies and socio-economic infrastructures. Therefore, such countries are also economically and financially sound. We find a negative and significant relationship between the variable HDI and total COVID-19 mortalities. In align with the previous estimates, our results also indicate that counties with high HDI figures will be able to impose serious restrictions to COVID-19 spread, and control the epidemic effectively (Marziali et al. 2021). Moreover, we found HDI as the most crucial and dominant factor in hindering the growth of COVID-19-related deaths. Therefore, countries with high HDI figures will be able to deal with this health shock by implementing robust and timely economic policies, financing health infrastructures, bringing awareness among its citizens, and providing relief packages.
and logistics to contain the virus spread. Therefore, this result supports the view that timely and effective policies inducing a rise in countries HDI figures tend to decline the COVID-19 deaths.

6 Conclusion

In this paper, we attempt to examine the factors that determine COVID-19 deaths by drawing a sample of 94 countries. The results from our analysis show that the factors such as total cases, population size, population over 70 years of age, extreme poverty, and HDI are significant in explaining and understanding the reasons of the COVID-19 deaths. Therefore, it is advisable that the government must take necessary actions and corrective policy prescripts to deal with the COVID-19 pandemic. While controlling population size and increasing the immunity of the old age people is not a short term option, it is advisable to control the total cases and improve the healthcare infrastructure by increasing hospital beds. We also find that those who are in their late 60s are more vulnerable to this disease hence policies should be made keeping them in mind.

The total number of COVID-19 cases can be controlled through active lockdown measures to limit the mobility of people and thus decreasing its amplitude. Further, proactive contact tracing of those who are affected and increase the number of testing will help keep in track of the virus from community spread. An early detection of the disease will keep in check the transmission of the infection. These collective efforts are vital in dealing with and containing the spread of COVID-19.

With more than 2 years have passed since the initial case was detected, many governments have worked proactively to fight against this virus. Many had imposed partial and full lockdown measures. In some countries, the number of active cases has declined, while in many others it is still continuing with the detection of another variant. The government must announce fiscal financing and provide healthcare subsidies to its citizens during such crisis. All countries must come together and invest its resources by increasing the healthcare provisions, developing temporary health centres with sufficient hospital bed facilities and ventilators, ramping up the production of PPE kits, testing kits, sanitizer and generate funding for the invention of medicine and vaccine to eradicate the coronavirus pandemic. It is also equally necessary to pump more fiscal funding and announce more relief packages for the citizens to cope up with the current situation of COVID-19 pandemic. In align with our findings, we suggest the supply of more testing kits to the health centres and large scale testing of the people who are expected to be carrying the symptoms connected to COVID-19. While the population size cannot be controlled but the stop in mobilization will help in making discreet clusters of population. So if the disease spread is occurring in one of these clusters, isolating the infected clusters won’t affect the other population and government can actively try to tackle the virus in those clusters during the upcoming waves of this pandemic. While taking all these measures there could be challenges of providing
essential commodities and services to the people, employability, starvation, decrease in attention to other major diseases and taking care of lower section of the society which needs to be handled carefully.

7 Future Directions for Research

Every research has some scope for its extension because of certain limitations. With the availability of rich datasets, we highlight scope for future researches. Hence, two directions can be considered for further exploration. The first one is from the grouping perspective. With data availability, countries can be categorized based on several aspects such as development level, governance, trade and commerce, economic growth, strategic geographical regions, or other categories as grouping factors, and the analysis may reveal differences among country groups. Alternatively, we propose the use of data-driven methods namely the latent profile analysis, which will be helpful in identifying unobserved subgroups within the cluster of countries based on the several factors in the model. The second direction is about the consideration of the timewise perspective. As COVID-19 enters its third year, several variants have been discovered. The factors examined in this study may contribute differently with the changes in death rates. Unlike the cross-section study, conducting a longitudinal analysis and exploring the longitudinal trend of inter-country differences and the intra-country change can provide a timely picture of the mortality-related factors and patterns. However, the study, especially the time variables, should be carefully designed as the periods for each county may not be simultaneous. Observing the death plot, and a roughly splitting based on some milestone stages can be a good starting point, for instance the time taken by COVID-19 variants such as Delta and Omicron variants surge.

Appendix

| Variables | VIF  | 1/VIF |
|-----------|------|-------|
| LNTCC     | 4.74 | 0.211 |
| LNPOP     | 3.03 | 0.330 |
| LNPDEN    | 1.08 | 0.924 |
| LNTSMOK   | 1.52 | 0.657 |
| LNAGE70   | 6.38 | 0.157 |
| HOSBED    | 1.88 | 0.532 |
| EXTPOV    | 2.59 | 0.386 |
| HDI       | 8.78 | 0.114 |
| Mean VIF  | 3.75 |       |

VIF refers to variance inflation factor and 1/VIF denotes the tolerance.
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Declarations

Conflict of interest  The authors warrant that the article is the authors’ original work. The authors of the current paper also declare no conflict of interest.

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**Ashis Kumar Pradhan** is working as an Assistant Professor at Maulana Azad National Institute of Technology, India. His area of research interest is Macroeconomics, Finance and Energy economics.

**Ronny Thomas** has a Ph.D. in economics and M.Phil. in Planning and development from IIT Bombay, Mumbai. Prior to joining Rajagiri Business School, he has one and half years of teaching experience at the School of Management Studies, NIT Calicut, Kozhikode. His research interests include international trade and FDI inter-linkage with econometric application and productivity analysis. His teaching interests are managerial economics, micro economics, applied industrial organisation and applied econometrics.

**SandhyaRani Rout** has completed her M.Phil. degree from the Department of Economics, Fakir Mohan University, Odisha, India. Her area of research interest is Macroeconomics, Finance, and Environmental Economics.

**Alok Kumar Pradhan** has completed MBA from Indian Institute of Management Nagpur. He has over five years of corporate experience. He is currently working as a Business Analytics Manager for Creditvidya and has a rich analytical experience.