Factors influencing the COVID-19 daily deaths peak across European countries

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Abstract

OBJECTIVES: The purpose of this study was to determine predictors of the height of COVID-19 daily deaths peak and time to the peak, in order to explain their variability across European countries.

STUDY DESIGN: For 34 European countries, publicly available data were collected on daily numbers of COVID-19 deaths, population size, healthcare capacity, government restrictions and their timing, tourism and change in mobility during the pandemic.

METHODS: Univariate and multivariate generalised linear models using different selection algorithms (forward, backward, stepwise and genetic algorithm) were analysed with height of COVID-19 daily deaths peak and time to the peak as dependent variables.

RESULTS: The proportion of the population living in urban areas, mobility at the day of first reported death and number of infections when borders were closed were assessed as significant predictors of the height of COVID-19 daily deaths peak. Testing the model with variety of selection algorithms provided consistent results. Total hospital bed capacity, population size, number of foreign travellers and day of border closure, were found as significant predictors of time to COVID-19 daily deaths peak.

CONCLUSIONS: Our analysis demonstrated that countries with higher proportions of the population living in urban areas, with lower reduction in mobility at the beginning of the pandemic, and countries which closed borders having more infected people experienced higher peak of COVID-19 deaths. Greater bed capacity, bigger population size and later border closure could result in delaying time to reach the deaths peak, whereas a high number of foreign travellers could accelerate it.

Keywords: COVID-19, mortality, healthcare capacity, modelling.

NOTE: This preprint reports new research that has not been certified by peer review and should not be used to guide clinical practice.
Introduction

The coronavirus infectious disease 2019 (COVID-19) outbreak was announced as a pandemic by the World Health Organization (WHO) on 11 March 2020.\(^1\) By the end of March, Europe exceeded Asia and became the region experiencing the highest percentage mortality from the virus across the world,\(^2\) until 10 June 2020, when the rapidly growing COVID-19 mortality rate in the Americas exceeded all other continents.\(^3\) According to the WHO report from 5 July 2020, 38% of the global mortality due to COVID-19 was from Europe.\(^4\)

Since incidence and mortality rates varied between countries, numerous studies have recently been published investigating factors associated with COVID-19 infection and death rate across countries. A variety of potential predictors have been assessed in the literature, such as country-specific demographic and health characteristics, economic and social indicators,\(^5\)–\(^8\) mobility scores and social-distancing measures,\(^9, 10\) as well as ecological and environmental perspectives.\(^8, 11\) To assess the relationship between covariates and COVID-19 incidence or mortality, the most common approach used by authors was to analyse multivariate regression models of total number of infections or deaths up to a given time point, using log-transformed data or without any transformation, as well as daily data on infections or deaths as outcomes.

In this study, we used data on numbers of deaths, not infections, since the former has a much higher degree of reliability than the latter, being better monitored and less dependent on the number of tests done. Since all European countries seem to already reach the peak of deaths by 3 June 2020 from the first wave of COVID-19 disease, our idea was to use height of daily deaths peak as a primary outcome of interest, and time to the peak as a secondary outcome. To the best of our knowledge, this perspective has not been investigated so far. When raw and cumulative daily numbers of infections and deaths are subject to deviations from between-country differences in reporting and depend on the date up to which the analysis is performed, maximum number of daily deaths can be assessed as an interesting new indicator of disease mortality magnitude. In addition, analysis of the height of daily deaths peak enables us to assess the overall capacity of healthcare systems.

This study aims to detect significant drivers of COVID-19 mortality with the use of multivariate generalised linear models (GLM) and distinct selection algorithms, to explain the variability of height of and time to the deaths peak among European countries. This will enable us to draw conclusions about how governments and societies can improve the future response on similar pandemic or global life-threatening situations.

Methods

Data collection

A total of 34 European countries were included in the analysis. The height of COVID-19 daily deaths peak was the primary outcome of interest, defined as maximum daily reported number of people who died due to COVID-19 per country up to 3 June 2020. The value was then divided by the number of inhabitants of a given country reported in January 2020 and multiplied by 1 million to obtain the deaths peak height per 1 million inhabitants.
The secondary outcome of interest was time to COVID-19 daily deaths peak, defined as number of days from the day when the first death was reported in a given country, up to the day of reaching the COVID-19 daily deaths peak.

A set of explanatory variables used to predict outcomes consisted of the following:

- **Healthcare capacity:**
  - All beds capacity (number of hospital bed units)
  - Intensive care unit (ICU) beds capacity (number of ICU)
  - Number of tests conducted up to the time of the peak

- **Government restrictions and associated factors:**
  - ‘Stay at home’ order date
  - Educational facilities closure date
  - Gathering restriction date
  - Businesses closure date
  - Border closure date
  - Total number of COVID-19 infected people when borders were closed
  - Total number of COVID-19 deaths when borders were closed

- **Indicators of the population size:**
  - Country population size (in January 2020)
  - Percentage of population living in urban areas
  - Percentage of population living in metropolitan cities with more than 1 million inhabitants
  - Median age

- **Tourism:**
  - Number of travellers that arrived at airports in 2018
  - Number of foreign tourists in 2018 (arrivals at any touristic accommodation)

- **Mean mobility score at the day of first reported COVID-19 death (as a difference from the average mobility reported before the pandemic), calculated across mobility scores at:**
  - Retail and recreation places
  - Workplaces
  - Transit stations

All dates were considered as number of days after the day of first reported COVID-19 death in each country. Variables indicating healthcare capacity and tourism were considered in relation to the population size of a given country (per inhabitant or 1 million inhabitants).

**Data sources**

Data on COVID-19 deaths, infections, number of tests, all and ICU beds capacity, dates of government restrictions, population size and urban population size were taken from Worldometer.com. Missing dates of government restrictions, if officially issued, were found on Wikipedia.

Mobility scores were uploaded from Google COVID-19 Community Mobility Reports. Scores were reported as percentage changes from a usual mobility calculated before the pandemic in Europe, between 3 January and 6 February 2020. Mobility scores were subject to oscillations due to daily reporting and presence of weekends and holidays; therefore, we used smoothed mobility scores produced with a nonparametric technique that uses local weighted regression and fits a smooth curve through points in a scatter plot, called loess regression.
Data on number of passengers arrived at airports, tourism and population living in metropolitan areas were downloaded from Eurostat, except for Russia, Turkey and Ukraine, for which data were gathered from other sources.

**Missing data and imputation**

If government restrictions were not officially set, the date was imputed with date of the peak in each country. Missing data on mobility for Cyprus and Iceland were imputed with average scores of remaining countries.

**Statistical analysis**

Descriptive statistics on outcomes and explanatory variables were produced. Since the distribution of deaths peak height per population size is right-skewed, a logarithmic transformation was applied.

Factors influencing the height of deaths peak were analysed using univariate and multivariate GLM with a normal distribution function and logarithmic link function. The base case scenario analysis was performed using data available for 34 countries and explanatory variables with a p-value <0.1 in univariate GLM models. To avoid multicollinearity issues between independent variables, Pearson correlations were investigated to detect highly correlated pairs of variables. The correlation was assessed as high if the absolute value exceeded 0.7 and as moderate if the absolute value was contained in a range 0.5–0.7.

Due to relatively low sample size, a risk of bias could appear for models with too high number of variables included. To overcome the problem and limit the number of covariates, sensitivity analyses were performed using variety of selection algorithms: stepwise, backward, forward and the genetic algorithm. For the backward, forward and stepwise algorithms, a criterion of having p-value lower than 0.1 was applied for each variable to stay in a model (backward and stepwise) and to enter a model (forward and stepwise). For the genetic algorithm, the best model was fitted based on the value of Akaike’s Information Criterion (AIC) corrected for small sample sizes (AICC). Models with only main effects were considered. Additional sensitivity analysis was performed removing countries for which imputation of government restriction dates was needed.

Similar methods were used to analyse time to deaths peak but without any transformation since it seemed to follow a normal distribution. GLM models with a normal distribution function and identity link function were analysed.

For all analyses, a p-value lower than 0.05 was considered as statistically significant. For each GLM model, fit statistics such as AIC and its equivalent AICC were produced with lower values indicating better fit.

Analyses were performed using SAS 9.4 software. R 3.6.2 software was used to apply the genetic algorithm with the package glmulti.
Results

Descriptive analysis

Characteristics of the countries included in the study are presented in Table 1, and a histogram of the height of COVID-19 deaths peak is depicted in Figure 1. The graph presenting deaths peak height by country is provided in Figure 2.

Median height of the peak per 1 million inhabitants per day was equal to 3.48 deaths ([lower quartile; upper quartile] = [1.68; 12.78]), with Belgium reaching outstandingly higher peak than other countries. As can be seen from these statistics and the histogram, the height of the deaths peak does not follow a normal distribution, but it seems it can be well approximated using a log-normal distribution. Median time to the peak equalled 31 days from the first death reported in each country with a comparable mean (31.32, SD=13.94). Average numbers of days when closing schools/universities and when gatherings were banned were both negative (-0.26 and -1.76, respectively).

Height of the deaths peak

Univariate GLM models of height of the peak were analysed (Table 2). Eight factors turned out to be significant: educational facilities closure day, gathering restrictions day, businesses closure day, proportion living in urban areas, mobility score at the day of first reported death, border closure day, number of COVID-19 infections when borders were closed, and number of COVID-19 deaths when borders were closed. All of them have positive estimates. Stay-at-home order day, as well as the proportion living in metropolitan cities >1 million inhabitants were close to reaching the significance level (p<0.1). Pearson correlations between variables reaching or close to reaching significance in univariate models were verified. Results can be found in Supplementary Materials.

A base case multivariate GLM model included six covariates. The proportion living in urban areas was found significant (p<0.001) and the mobility score at the day of first reported death was very close to reaching significance (p=0.052). Results are presented in Table 2. Considering small sample size (N=34), selection algorithms were applied to the base case model to limit the number of covariates, increase model precision and improve the model fit. All selection algorithms were consistent and selected the model with three significant parameters (“final” model), indicating its best fit. The proportion of the population living in urban areas (6.848, p<0.001), mobility score at the day of first reported death (0.049 p<0.001) and number of infections when borders were closed per 1 million inhabitants (0.0002, p=0.016) were all significantly associated with the deaths peak height (Table 2).

Analysis of data removing countries with imputed dates of businesses or borders closure (N=29) provided consistent results regarding the significance of all three covariates from the final models in relation to the deaths peak height (details are provided in Supplementary Materials).

Time to the deaths peak

Univariate GLM models of time to the peak were analysed (Table 3). Nine factors turned out to be potentially significant (with p<0.1): all beds capacity, ICU beds capacity, educational facilities closure day, gathering restrictions day, population size, arrivals at airports per
inhabitant, number of foreign tourists per inhabitant, mobility score at the day of first reported death, as well as day of border closure. The majority of these factors have positive estimates, except the number of arrivals and tourists. As for the next step, linear correlations between them were verified. Results can be found in Supplementary Materials.

A base case multivariate GLM model was run using six explanatory variables. All beds capacity, population size in millions and the number of foreign tourists per inhabitant were found significantly related with time to COVID-19 deaths peak. Results are presented in Table 3. Considering the small sample size (N=34), selection algorithms were applied to the above multivariate model. The “final” model had four covariates and was selected by the backward and the genetic algorithm (details in Supplementary Materials). All beds capacity per 1 million inhabitants (0.003, p=0.004), population size in millions (0.142, p=0.008), the number of foreign tourists per inhabitant (-2.651, p=0.037) and border closure day (0.297, p=0.008) were all significantly associated with time to the deaths peak (Table 3).

Analysis of data removing countries with imputed dates of borders closure (N=31) provided consistent results regarding the significance of all beds capacity and population size in relation to time to deaths peak, whereas number of foreign tourists and borders closure day were close in reaching significance, both with p<0.1 (details provided in Supplementary Materials).

**Discussion**

This study provides some evidence about factors associated with COVID-19 mortality peak and time to the peak. One of the strongest predictors of the COVID-19 mortality peak identified in our analysis was the proportion of population living in urban areas. The relationship between urbanisation and COVID-19 infections ratio was earlier outlined by the United Nations Association, estimating that 90% of all reported COVID-19 cases (by July 2020) came from urban areas, becoming the epicentre of the pandemic. High population density increases the propensity of viruses spread by increasing the contact rates of individuals. However, some authors warn readers against putting too much weight on urban density, arguing that large cities just faced the coronavirus earlier (due to the higher number of incoming people) and that the timing of epidemic start was of bigger interest than population density itself. This observation seems to be on the contrary to our study, since neither proportion of population living in urban areas, nor proportion living in metropolitan cities were related with the time to deaths peak.

Number of infections when borders were closed was found to be another important factor associated with the COVID-19 deaths peak height, whereas a positive association between borders closure day and time to reach the peak was observed in this study. It shows that stopping arrivals to the country at the earlier stage of epidemic can be crucial in reducing the peak height, stopping the increase of daily number of deaths earlier and, consequently, to flatten the deaths curve. These findings are on the contrary to Chaudhry who showed no association between rapid border closures and COVID-19 mortality per million people, using cumulative data available as of 1 April 2020. However, the peak height and mortality may not be strongly correlated. For example some countries experience a point peak and dropping fast, (France, United Kingdom, Spain, Italy) while other countries may experience a flattened peak with a mortality staying high over a long period of time (US, Brazil, Mexico).
The difference in average mobility before the pandemic and at the day when first death was reported in a country was found to be associated with deaths peak height, which suggests that rapid reduction in mobility was important in terms of reducing overall mortality. These findings are consistent with other authors opinion that changes in social-distancing covariates can flatten the curve by changing the peak death rate.\(^9,10\)

Tourism indicators were found not to be associated with deaths peak height, but to be significant drivers of time to reach the peak. It suggests that the magnitude of inbound tourism can have an impact on accelerating the moment of reaching the peak. However, Aldibas\(^5\) and Garcia de Alcaniz\(^8\) found tourism to be a significant predictor of COVID-19 mortality and infection rates. Ostig and Askin\(^26\) also found a significant positive relationship between number of airline passengers and number of COVID-19 infections.

Another conclusion resulting from the study is that timing of government restrictions, especially border closure, can be found as an important factor in terms of COVID-19 mortality. What can be observed for many countries is that closing borders (and other government restrictions as well) took place several days before any death was reported in a country. Therefore, increase or decrease in mortality can be seen as a result of undertaking preventive action by the government.

There is no general conclusion on the association between COVID-19 fatality and hospital beds capacity in literature. Our study showed lack of association between beds capacity and deaths peak height, but higher beds capacity was related with longer time to peak. Garcia de Alcaniz showed no association between hospital beds density and both the number of infections and number of deaths at any moment of the pandemic.\(^8\) On the contrary, Sorci showed that case fatality rate was negatively associated with number of hospital beds per inhabitants.\(^7\) High bed capacity may be associated with more intensive treatment delaying time to death for a number of patients thus delaying time to peak but does not affect the peak height.

**Limitations**

Our study has several limitations. Data on a limited number of countries were used. We decided not to include countries for which reliable and comparative evidence could not be found, nor countries with very low mortality. Our idea was to focus only on Europe, not to merge it with countries from other continents and avoid data incomparability issues and eventual difference in strain as the virus mutate rapidly.

However, the number of observations can be assessed as high enough to draw conclusions based on multivariate GLM models by using selection algorithms. The stability of results was tested with models based on different variable selection algorithms, being consistent with base case findings.

The set of included explanatory variables can be viewed as non-exhaustive. We decided to focus on variables important from a social perspective, assuming that mobility factors, tourism, urbanisation, and government decisions are more of interest to inform upcoming decisions than other approaches observed in the literature; for example, ecological or environmental perspectives.\(^8,11\)
Conclusions

This study demonstrated the significant drivers of COVID-19 mortality magnitude in Europe and shed a light on reasons behind the variability between different countries. Countries with a higher proportion of population living in urban areas, without a rapid reduction in mobility and with delayed government restrictions, correlated with a higher COVID-19 deaths peak. These findings can help improve future response in similar situations or in case of a second wave.

Acknowledgements: The authors wish to thank Saima Khan (Apothecom) for proof reading and editing support.

Contributors: MT conceived the study, KJ collected and analysed the data, KJ, MT and SA interpreted the results, KJ wrote the first draft of the manuscript, KJ, MT and SA revised the manuscript and approved the final version.

Competing interests: The authors declare no competing interests.

References

1. World Health Organisation. Coronavirus disease 2019 (COVID-19) Situation Report – 51 (11 March 2020) 11 March 2020.
2. World Health Organisation. Coronavirus disease 2019 (COVID-19) Situation Report – 71 (31 March 2020).
3. World Health Organisation. Coronavirus disease (COVID-19) Situation Report – 142 (10 June 2020).
4. World Health Organisation. Coronavirus disease (COVID-19) Situation Report – 167 (5 July 2020).
5. Aldibasi OS, Alharbi NK, Alkelya M, Zowawi H, Alghnam S. The Association of Country-Level Factors with Outcomes of COVID-19: Analysis of the pandemic after one million cases. Research Square. 2020.
6. Burden SJ, Rademaker J, Weedon BD, Whaymand L, Dawes H, Jones A. Associations of Global Country Profiles and Modifiable Risk Factors with COVID-19 Cases and Deaths. medRxiv. 2020:2020.06.17.20133454.
7. Sorci G, Faivre B, Morand S. Why Does COVID-19 Case Fatality Rate Vary Among Countries? The Lancet. 2020.
8. Garcia de Alcaniz JG, Romero-Lopez J, Martinez RP, Lopez-Rodas V, Costas E. What variables can better predict the number of infections and deaths worldwide by SARS-CoV-2? Variation through time. medRxiv. 2020:2020.06.04.20122176.
9. Woody S, Garcia Tec M, Dahan M, Gaither K, Lachmann M, Fox S, et al. Projections for first-wave COVID-19 deaths across the US using social-distancing measures derived from mobile phones. medRxiv. 2020;2020.04.16.20068163.

10. Courtemanche C, Garuccio J, Le A, Pinkston J, Yelowitz A. Strong Social Distancing Measures In The United States Reduced The COVID-19 Growth Rate. Health Affairs. 2016;0:10.1377/hlthaff.2020.00608.

11. Bray I, Gibson A, White J. Coronavirus disease 2019 mortality: a multivariate ecological analysis in relation to ethnicity, population density, obesity, deprivation and pollution. Public Health. 2020;185:261-3.

12. Worldometer. Covid-19 coronavirus pandemic. [cited 2020, 25 June 2020]; Available from: https://www.worldometers.info/coronavirus/.

13. Wikipedia. National responses to the COVID-19 pandemic. [cited 2020, 25 June 2020]; Available from: https://en.wikipedia.org/wiki/National_responses_to_the_COVID-19_pandemic.

14. Google. COVID-19 Community Mobility Reports. [cited 2020, 25 June 2020]; Available from: https://www.google.com/covid19/mobility/.

15. Wicklin R. What is loess regression? SAS Blogs: SAS; 2016 [cited 2020 29 June 2020]; Available from: https://blogs.sas.com/content/iml/2016/10/17/what-is-loess-regression.html.

16. Eurostat. Eurostat Database. [cited 2020 25 June 2020]; Available from: https://ec.europa.eu/eurostat/data/database.

17. CEIC data. Visitor Arrivals. [cited 2020, 25 June 2020]; Available from: https://www.ceicdata.com/en/indicator/russia/visitor-arrivals, https://www.ceicdata.com/en/indicator/turkey/visitor-arrival, https://www.ceicdata.com/en/indicator/ukraine/visitor-arrivals.

18. Analytical Credit Rating Agency ACRA. Air traffic increases, finances in crisis [cited 2020, 25 June 2020]; Available from: https://www.acra-ratings.cn/research/1282.

19. Hurriyet Daily News. Air passenger traffic in Turkish airports rose 8.8 percent in 2018. [cited 2020, 25 June 2020]; Available from: https://www.hurriyetdailynews.com/air-passenger-traffic-in-turkish-airports-rose-8-8-percent-in-2018-140322.

20. Kyiv Post. Record-breaking 20.5 million passengers at Ukrainian airports in 2018. [cited 2020, 25 June 2020]; Available from: https://www.kyivpost.com/ukraine-politics/record-breaking-20-5-million-passengers-passed-through-ukrainian-airports-in-2018.html.

21. Mukaka MM. Statistics corner: A guide to appropriate use of correlation coefficient in medical research. Malawi Med J. 2012; 24:69-71.

22. Calcagno V, de Mazancourt C. glmulti: An R Package for Easy Automated Model Selection with ( Generalized ) Linear Models. Journal Of Statistical Software. 2010; 34.

23. Guterres A. COVID-19 in an Urban World. United Nations,; 2020 [cited 2020 13th August 2020]; Available from: https://www.un.org/en/coronavirus/covid-19-urban-world.

24. Barr J, Tassier T. Are Crowded Cities the Reason for the COVID-19 Pandemic? Placing too much blame on urban density is a mistake. Scientific American; 2020 [cited 2020 13th August 2020]; Available from: https://blogs.scientificamerican.com/observations/are-crowded-cities-the-reason-for-the-covid-19-pandemic/.
25. Chaudhry R, Dranitsaris G, Mubashir T, Bartoszko J, Riazi S. A country level analysis measuring the impact of government actions, country preparedness and socioeconomic factors on COVID-19 mortality and related health outcomes. EClinicalMedicine. 2020; 25.

26. Oztig LI, Askin OE. Human mobility and coronavirus disease 2019 (COVID-19): a negative binomial regression analysis. Public Health. 2020; 185:364-7.
Table 1. Characteristics of countries included in the analysis.

| Variable                                      | N  | Mean | SD  | Median | Lower quartile | Upper quartile | Min  | Max  |
|------------------------------------------------|----|------|-----|--------|----------------|----------------|------|------|
| Peak height [no. of deaths per 1 mln inhabitants] | 34 | 7.22 | 8.65| 3.48   | 1.68           | 12.78          | 0.48 | 42.80|
| Peak height [raw no. of deaths]                | 34 | 180.5| 322.67| 32.50 | 8.00           | 185.00         | 2.00 | 1172.0|
| Peak time [no. of days after first death reported] | 34 | 31.32| 13.94| 31.00  | 22.00          | 40.00          | 2.00 | 71.00|
| All beds capacity [per 1 mln inhabitants]     | 34 | 4940.25| 1744.89| 4634.17| 3427.67       | 6623.84        | 2512.45 | 8248.80|
| ICU beds capacity [per 1 mln inhabitants]     | 34 | 141.14| 82.61| 110.94 | 86.50         | 191.75         | 20.72 | 349.20|
| Total no. of tests up to time of the peak [per 1 mln inhabitants] | 34 | 763.09| 743.98| 526.54| 443.77        | 824.78        | 148.92 | 4166.11|
| Stay-at-home order day                         | 34 | 8.74 | 10.33| 8.00   | 1.00           | 14.00          | -6.00 | 41.00|
| Educational facilities closure day             | 34 | -0.26| 8.31 | 0.50   | -3.00          | 4.00           | -22.00 | 17.00|
| Gathering restrictions day                    | 34 | -1.76| 8.67 | -1.00  | -6.00          | 2.00           | -21.00 | 17.00|
| Businesses closure day                        | 34 | 3.32 | 10.14| 2.00   | -1.00          | 7.00           | -16.00 | 41.00|
| Population size [Jan 2020]                    | 34 | 23.82| 33.02| 9.33   | 4.94           | 37.85          | 0.34  | 145.93|
| Proportion living in urban areas              | 34 | 0.74 | 0.12 | 0.74   | 0.66           | 0.83           | 0.54  | 0.98 |
| Proportion living in metropolitan cities with more than 1 mln inhabitants | 34 | 0.28 | 0.19 | 0.31   | 0.12           | 0.44           | 0.00  | 0.56 |
| Median age                                    | 34 | 41.85| 2.96 | 42.50  | 40.50          | 44.00          | 32.00 | 46.70|
| Arrivals at airports in 2018 [per 1 inhabitant] | 34 | 2.27 | 2.63 | 1.52   | 0.84           | 2.79           | 0.24  | 14.86|
| No. of foreign tourists in 2018 [per 1 inhabitant] | 34 | 1.25 | 1.32 | 0.79   | 0.47           | 1.46           | 0.14  | 6.73 |
| Mobility score at the day of first reported death | 34 | -23.45| 18.93| -20.02 | -44.09       | -5.28          | -56.42 | 0.16 |
| Border closure day                            | 34 | 6.71 | 15.53| 2.50   | -1.00          | 11.00          | -19.00 | 46.00|
| No. of COVID-19 infections when borders were closed [per 1 mln inhabitants] | 34 | 490.54| 1116.56| 83.39 | 21.53         | 245.88        | 0.07  | 5223.83|
| No. of COVID-19 deaths when borders were closed [per 1 mln inhabitants] | 34 | 28.56| 71.73| 0.27   | 0.00           | 3.17           | 0.00  | 297.90|

Abbreviations: ICU, intensive care unit; SD, standard deviation; mln, million.
GLM univariate and multivariate models with normal distribution and logit link function were used to explore factors associated with COVID-19 deaths peak height as of 3rd June 2020. Each model was run using 34 observations. Variables significant in univariate models were included into the multivariate base case model, avoiding highly correlated pairs. The final multivariate model was selected based on the use of selection algorithms (backward, forward, stepwise and the genetic algorithm).

### Table 2. Results of univariate and multivariate GLM of COVID-19 deaths peak height, with normal distribution and logit link function

| Variable                                                                 | Estimate | Wald 95% confidence limit | p-value | Estimate | Wald 95% confidence limit | p-value | Estimate | Wald 95% confidence limit | p-value |
|--------------------------------------------------------------------------|----------|---------------------------|---------|----------|---------------------------|---------|----------|---------------------------|---------|
| All beds capacity [per 1 mln inhabitants]                               | -0.0002  | -0.001 - 0.0001           | 0.109   | -        | -                         | -       | -        | -                         | -       |
| ICU beds capacity [per 1 mln inhabitants]                               | -0.002   | -0.008 - 0.003            | 0.404   | -        | -                         | -       | -        | -                         | -       |
| Total no. of tests up to time of the peak [per 1 mln inhabitants]       | 0.000    | -0.001 - 0.001            | 0.961   | -        | -                         | -       | -        | -                         | -       |
| Stay-at-home order day                                                   | 0.027    | -0.001 - 0.053            | 0.057** | -        | -                         | -       | -        | -                         | -       |
| Educational facilities closure day                                       | 0.067    | 0.028 - 0.107             | 0.001   | -        | -                         | -       | -        | -                         | -       |
| Gathering restrictions day                                               | 0.045    | 0.006 - 0.084             | 0.023*  | -        | -                         | -       | -        | -                         | -       |
| Businesses closure day                                                   | 0.029    | 0.009 - 0.049             | 0.005*  | -0.001   | -0.022 - 0.020            | 0.944   | -        | -                         | -       |
| Population size [mnl]                                                    | 0.001    | -0.009 - 0.011            | 0.877   | -        | -                         | -       | -        | -                         | -       |
| Proportion living in urban areas                                         | 8.117    | 3.695 - 12.539            | <0.001* | 7.127    | 3.642 - 10.611            | <0.001* | 6.848    | 4.016 - 9.680             | <0.001* |
| Proportion living in metropolitan cities with more than 1 mln inhabitants| 2.428    | -0.464 - 5.319            | 0.099** | 1.063    | -1.331 - 3.457            | 0.384   | -        | -                         | -       |
| Median age                                                               | -0.0003  | -0.120 - 0.120            | 0.996   | -        | -                         | -       | -        | -                         | -       |
| Arrivals at airports in 2018 [per 1 inhabitant]                          | 0.016    | -0.097 - 0.129            | 0.784   | -        | -                         | -       | -        | -                         | -       |
| No. of foreign tourists in 2018 [per 1 inhabitant]                       | -0.076   | -0.421 - 0.270            | 0.668   | -        | -                         | -       | -        | -                         | -       |
| Mobility score at the day of first reported death                        | 0.048    | 0.001 - 0.096             | 0.046** | 0.041    | -0.0004 - 0.083           | 0.052*  | 0.049    | 0.022 - 0.077             | <0.001* |
| Borders closure day                                                      | 0.025    | 0.010 - 0.041             | 0.002*  | -0.005   | -0.030 - 0.021            | 0.729   | -        | -                         | -       |
| No. of COVID-19 infections when borders were closed [per 1 mln inhabitants] | 0.0002  | 0.0000 - 0.004            | 0.022*  | 0.0003   | -0.0001 - 0.001           | 0.113   | 0.0002   | 0.0001 - 0.0003           | 0.016*  |
| No. of COVID-19 deaths when borders were closed [per 1 mln inhabitants] | 0.004    | 0.001 - 0.007             | 0.002*  | -        | -                         | -       | -        | -                         | -       |

**Multivariate models statistics**

| Scale                                                                 | Estimate | Wald 95% confidence limit | p-value | Estimate | Wald 95% confidence limit | p-value | Estimate | Wald 95% confidence limit | p-value |
|-----------------------------------------------------------------------|----------|---------------------------|---------|----------|---------------------------|---------|----------|---------------------------|---------|
| GLM                                                                   | -        | -                         | -       | 5.020    | 3.958 - 6.367             | -       | 5.092    | 4.015 - 6.458             | -       |
| AIC                                                                    | -        | -                         | -       | 222.203  | -                         | -       | 217.169  | -                         | -       |
| AICC                                                                   | -        | -                         | -       | 227.963  | -                         | -       | 219.312  | -                         | -       |

*p-value <0.05; **p-value < 0.1.

Abbreviations: AIC, Akaike’s Information Criterion; AICC, AIC corrected for small sample sizes; GLM, generalised linear models; ICU, intensive care unit; mln, million.
**Table 3.** Results of univariate and multivariate GLM of time to COVID-19 deaths peak, with normal distribution and identity link function

| Variable                                                      | Univariate analysis | Multivariate analysis                                                                 |
|---------------------------------------------------------------|---------------------|---------------------------------------------------------------------------------------|
|                                                               | Estimate            | Wald 95% confidence limit | p-value | Base case GLM (Full model) | Base case GLM + selection algorithms (Final model) |                           |
|                                                               |                     | Lower | Upper                   |        | Estimate | Wald 95% confidence limit | p-value | Estimate | Wald 95% confidence limit | p-value |
| All beds capacity [per 1 mln inhabitants]                    | 0.003               | 0.001 | 0.006                   | 0.012* | 0.003    | 0.001 | 0.005                    | 0.006* | 0.003    | 0.001 | 0.005                    | 0.004* |
| ICU beds capacity [per 1 mln inhabitants]                    | 0.046               | -0.008 | 0.101                   | 0.095** | -0.007   | -0.049 | 0.034                    | 0.731 | -        | -        | -        | -        |
| Total no. of tests up to time of the peak [per 1 mln inhabitants] | -0.002              | -0.008 | 0.005                   | 0.598  | -        | -        | -                        | -        | -        | -        | -        | -        |
| Stay-at-home order day                                        | 0.201               | -0.248 | 0.649                   | 0.381  | -        | -        | -                        | -        | -        | -        | -        | -        |
| Educational facilities closure day                            | 0.680               | 0.164 | 1.195                   | 0.010* | -        | -        | -                        | -        | -        | -        | -        | -        |
| Gathering restrictions day                                    | 0.530               | 0.019 | 1.040                   | 0.042* | -        | -        | -                        | -        | -        | -        | -        | -        |
| Businesses closure day                                        | 0.365               | -0.081 | 0.810                   | 0.108  | -        | -        | -                        | -        | -        | -        | -        | -        |
| Population size [mln]                                        | 0.250               | 0.135 | 0.364                   | <0.001* | 0.117    | 0.002 | 0.231                    | 0.047* | 0.142    | 0.037 | 0.246                    | 0.008* |
| Proportion living in urban areas                              | 0.508               | -37.667 | 38.683                   | 0.979  | -        | -        | -                        | -        | -        | -        | -        | -        |
| Proportion living in metropolitan cities with more than 1 mln inhabitants | 13.812              | -10.931 | 38.554                   | 0.274  | -        | -        | -                        | -        | -        | -        | -        | -        |
| Median age                                                    | -0.278              | -1.860 | 1.304                   | 0.730  | -        | -        | -                        | -        | -        | -        | -        | -        |
| Arrivals at airports in 2018 [per 1 inhabitant]               | -1.908              | -3.573 | -0.243                   | 0.025* | -        | -        | -                        | -        | -        | -        | -        | -        |
| No. of foreign tourists in 2018 [per 1 inhabitant]            | -5.099              | -8.203 | -1.995                   | 0.001* | -2.872   | -5.341 | -0.403                    | 0.023* | -2.651   | -5.137 | -0.165                    | 0.037* |
| Mobility score at the day of first reported death             | 0.337               | 0.117 | 0.557                   | 0.003* | 0.132    | -0.092 | 0.356                    | 0.249  | -        | -        | -        | -        |
| Borders closure day                                           | 0.326               | 0.045 | 0.607                   | 0.023* | 0.215    | -0.047 | 0.477                    | 0.108  | 0.297    | 0.079 | 0.514                    | 0.008* |
| No. of COVID-19 infections when borders were closed [per 1 mln inhabitants] | 0.001              | -0.004 | 0.005                   | 0.739  | -        | -        | -                        | -        | -        | -        | -        | -        |
| No. of COVID-19 deaths when borders were closed [per 1 mln inhabitants] | 0.038              | -0.026 | 0.102                   | 0.244  | -        | -        | -                        | -        | -        | -        | -        | -        |
| **Multivariate models statistics**                            |                     |       |                         |        |          |          |                          |         |          |          |                          |
| Scale                                                         |                     |       |                         |        | 8.713    | 6.870 | 11.050                   | 8.901  | 7.018    | 11.289 |                |
| AIC                                                           |                     |       |                         |        | 259.693  | -        | -                        | 257.146 | -        | -        |                |
| AICC                                                          |                     |       |                         |        | 265.453  | -        | -                        | 260.257 | -        | -        |                |

*p-value < 0.05; **p-value < 0.1.

Abbreviations: AIC, Akaike’s Information Criterion; AICC, AIC corrected for small sample sizes; GLM, generalised linear models; ICU, intensive care unit; mln, million.

GLM univariate and multivariate models with normal distribution and identity link function were used to explore factors associated with time to COVID-19 deaths peak (starting from the day when the first death was reported in a given country), as of 3rd June 2020. Each model was run using 34 observations. Variables significant in univariate models were included into the multivariate base case model, avoiding highly correlated pairs. The final multivariate model was selected based on the use of selection algorithms (backward, forward, stepwise and the genetic algorithm).
Figure 1. Histogram of the height of COVID-19 daily deaths peak per 1 million inhabitants with a fitted log-normal curve

Histogram presents the distribution of height of COVID-19 deaths peak per 1 million inhabitants across 34 countries. A log-normal curve was fitted to the distribution with scale parameter $\text{sigma}=1.12$ and location parameter $\text{zeta}=1.38$, assuming logarithm of height of the deaths peak is normally distributed $\text{Normal}([\text{zeta}, \text{sigma}])$. 
Figure 2. Height of COVID-19 daily deaths peak per 1 million inhabitants across countries

The plot presents the height of COVID-19 deaths peak per 1 million inhabitants across 34 countries, with Belgium having outstandingly highest peak per population size (>40 deaths per 1 million inhabitants).