

The determinants of Covid-19 mortality rates across Europe: Assessing the role of demographic and socio-economic factors during the first wave of the pandemic

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Abstract. The aim of this paper is to examine empirically the impact of the demographic structure and socio-economic environment on the Covid-19 mortality rate across 29 European countries. The analysis is based on empirical data recorded cumulatively from 15th February 2020 until 26th May 2020, thus covering ‘the first wave of the pandemic’. Results indicate that, although countries with a higher degree of population ageing are anticipated to be more vulnerable to Covid-19, this study provides evidence that population ageing contributes only marginally to Covid-19 death rates across Europe. The degree of urbanization, the level of economic development, and the state of health care systems, seem to better explain patterns of interstate mortality rates. The analysis provides important policy implications since it underlines the importance of urbanization and socio-economic conditions in the accelerating incidence of casualties, and it signifies the importance of health care systems for the protection of people and places from the pandemic.

Key words: Covid-19, mortality rates, Europe, population ageing, urbanization, ANOVA, Bayesian BYM spatial model

1 Introduction

Over the past few months, the scientific community’s interest has been focused largely on the Covid-19 pandemic, which is spreading rapidly in almost all parts of the world. Researchers from different scientific fields have approached the issue from various angles, but in all instances there is a common goal, to understand the behaviour of the virus, to formulate methods and policies to control its spread and to find the right treatment.

However, the pandemic of Covid-19 is a very recent phenomenon, which is still in progress. Thus, scientific knowledge about the disease is imperfect and the statistical documentation limited. The numbers of documented events (deaths, cases) vary widely across and within countries. So far, estimations of the eventual impact on the population and on the spread of the disease rely largely on mathematical and statistical models which are formulated on an assortment of assumptions (Fauci et al. 2020, Georgiou 2020). Empirical research has led to some sound findings, revealing that people suffering from certain underlying conditions such as cardiovascular and respiratory diseases, neoplasms and diabetes face an elevated risk of an adverse outcome (Chen et al. 2020, Guan et al.

2020, Halvatsiotis et al. 2020). It is also pointed out that the elderly comprise the most vulnerable group of the population as they often have a less favourable clinical picture than younger people, and once infected they usually have lower chances of survival (Ioannidis et al. 2020). Statistical observations deriving from a wide range of countries demonstrate that deaths from Covid-19 are concentrated mostly among older people (Dowd et al. 2020). The implication of this finding is that demographic ageing may result in structural changes in the demo-pathology of the population that should be taken into account by the health and socioeconomic policy makers. Most European populations already exhibit an age-structure with a large number of older people, while national population projections indicate that demographic ageing will continue; therefore, in the short and medium term, the demographic aspects of the pandemic must not be ignored.

The actual number of cases and deaths due to the virus is not known; however, it can be argued that Covid-19 mortality data may be a more reliable means of analyzing the impact of the disease than statistics on confirmed Covid-19 cases. Of course, mortality reflects the incidence of the disease, the adequacy of the health system as well as practices of reporting, but mortality data, although potentially undercounted, may serve as a more tangible approach for assessing the effects of the disease.

Given that older people are more vulnerable to Covid-19, the demographic structure and ageing of the population could be considered as significant determinants of the mortality rates from Covid-19. However, the fact that the Covid-19 mortality rate disproportionately affects older people does not necessarily imply that the higher the degree of population ageing the higher are the risks for the society as a whole. In order to capture the incidence of the disease and the outcomes on mortality rates, additional factors such as urbanization and the socio-economic environment should be taken into consideration.

Socio-economic determinants are important contributing factors to the incidence and fatalities from the pandemic. Poverty, deprivation and job insecurity are important issues in poorer countries and more deprived populations within countries, cities and regions. Environmental degradation and pollution, poor education, employment insecurity, conditions of built environment, and access to care are factors unequally distributed across regions, that influence the population health in Europe (Marmot et al. 2012, Santana et al. 2017, Mitsakou et al. 2019). The health consequences of the economic crisis induced by Covid-19 are likely to be similarly, unequally distributed, exacerbating health inequalities. Health inequalities will probably increase during the pandemic (Bambra et al. 2020).

In this context, the aim of this study is twofold; first, to explore the demographic dimension of the pandemic with respect to age structure effects; more specifically we aim to examine whether populations experiencing a high degree of ageing tend to exhibit higher mortality rates due to Covid-19 and vice versa. Second, we further explore the demographic structure along with socio-economic determinants in order to test how they affect the mortality rates of the disease. To address our research questions, we employ recent statistical information from 29 European countries and we apply well established demographic, econometric and statistical techniques.

The analysis refers to the first wave of the pandemic and has some important merits. First, it provides an initial accounting of the mortality rates and the determinants of the pandemic across Europe. Second, this provides the baseline data which allow us to follow the evolution of the disease and to provide comparisons with subsequent waves. Third it serves as a basis for policy measures for better responses and preventive policies in response to future pandemics. Fourth, this analysis provides useful insights concerning Covid-19 which could enrich interdisciplinary dialogue across fields such as demography, economics, epidemiological studies, and health policy. Finally, it could be utilized for scientific discussion regarding the spread of disease that goes beyond the Covid-19 pandemic.

The paper is structured as follows. Following the introduction, section 2 provides a concise literature review regarding the demographic and socio-economic determinants of the pandemic. Section 3 presents data sources and methods of analysis for the estimation of the significance of the age structure on Covid-19 mortality rates. Section 4 presents and discusses the empirical results. Section 5 provides a Bayesian model for analysing Covid-19 mortality rates. Section 6 summarizes the findings, codifies policy proposals and sketches the framework for the expansion/extension of this work.

2 Literature review

The issue of the spread of the pandemic has attracted the attention of scientists, international organizations, citizens and governments across the globe. Epidemiological episodes and the spread of epidemiological diseases is not at all a new issue. Historically, on numerous occasions, humankind has faced similar outbreaks of diseases and a fair number of analyses have been the subject of scientific investigation (Carillo, Jappelli 2020, Jordà et al. 2020, Percoco 2016). However, under the current circumstances of economic globalization, the high degree of concentration of people and economic activities in large cities and urban agglomerations, the soaring income inequalities as well as the highly developed means of transportation and communication have made this disease unique in world health history. This disease could undermine: fundamental aspects of the organization of economic activity; social interaction and participation in the social processes; social activities and possibly personal life, and psychological health. Today, a vaccine has been used for the protection against Covid-19. However, during the first wave of the pandemic the absence of a medication or a vaccine to limit the spread, to protect against and eventually to cure Covid-19 make this disease a distinct case in world history. The shock was exogenous and global (Faggian 2020). However, it had an asymmetrical impact across countries, social groups and individuals. Demography and spatial statistical analysis and spatial epidemiology constitute scientific disciplines that have explicitly contributed to the analysis of diseases. Demography has provided some important insights regarding the spread and the consequences of Covid-19. Demographic ageing has been quite an important issue for Europe in recent decades. The ageing of the population exerts pressures on the pension systems and on the health-care systems, and it requires actions to support the everyday life of elderly people. Covid-19 brings an additional risk to elderly people and to societies. The lives of elderly people are at high risk: the mortality rate is higher among this category and the incidence of Covid-19 peaks in areas where elderly people are concentrated such as old-age homes. The higher vulnerability of older people to Covid-19 is a well-documented statistical fact. As a result, the age structure of a society and the vulnerability of populations, along with other socio-economic conditions that prevail in a society, should be examined in scientific research (ECDC 2020).

The level of urbanization is also an important determinant for the incidence and spread of the pandemic. Empirical analyses have demonstrated that the impacts of the current Covid-19 crisis alone will be vast, as well as spatially uneven. Given the high concentration of both population and economic activities in cities, these are often hotspots of Covid-19 infections (Sharifi, Khavarian-Garmsir 2020). Other factors being equal, for the first wave of the pandemic the incidence of Covid-19 is higher in urban areas compared to the semi-urban and rural areas of countries. Indeed, there are some who advocate a rediscovery of rurality as a reaction to the pandemic (Cotella, Vitale Brovarone 2020).

The social mix of the population is another important factor. The most deprived parts of the population tend to be more vulnerable to the disease. The UK Office of National Statistics (ONS) released the March–April 2020 data for England and Wales which revealed that Covid-19-related death rates in the most deprived areas are more than double those in the less deprived (Dodds et al. 2020, p. 289). Income inequality reflects different mortality rates in the USA. Mortality rate of the less well-off Black and Latino people, is twice that of White people (Wade 2020).

The level of economic development of an area is also factor that serves as an important determinant for explaining the incidence and spread of the disease. Spatial analysis for Italy provides statistical evidence that the level of economic development of regions is positively correlated with the incidence of Covid-19 (Ghose, Cartone 2020). The highest positive spatial correlation in the Northern provinces stresses the link between economic development and Covid-19. LISA indicators confirm that the most economically developed areas in the country are more likely to be affected by Covid-19. Ascani et al. (2020) corroborate these findings providing further statistical evidence that the striking spatial unevenness of Covid-19 suggests that the infection hits core economic locations harder.

Furthermore, empirical analysis for Germany highlights spatial patterns of the disease.

First, there was a regional outbreak in Western Germany centred around the Heinsberg district. Second, tourists returned to their home regions carrying the infection. Third, the spread of the disease took place through specific events (Kuebart, Stabler 2020).

Burlina, Rodríguez-Pose (2020) have shown that highly connected regions, in colder and dryer climates, with high air pollution levels, and relatively poorly endowed health systems witnessed the highest incidence of excess mortality.

These unprecedented conditions have made state intervention even more urgent. The intensity of state intervention has become obvious across the globe. National health systems have played an important role in the health care policy. European countries and others, including the United States, are now choosing to inject large sums of money in order to kick-start economics, resume business, and maintain good polling for the ruling parties. The EU recovery plan constitutes an initiative in this line of action (European Council 2020). The OECD has so far produced comprehensive briefings on policy responses including the topics of cities (OECD 2020a), rural development (OECD 2020b), as well as the territorial and multilevel governance (OECD 2020c).

This paper focuses on European countries. This aggregate level of analysis provides an initial approach to the European space which is characterised by a high degree of integration and interaction, and where geography and the socioeconomic environment are significant diversification factors.

3 Examining demographic factors: Data sources and methods of analysis

3.1 Data and data sources

Data that have been utilised for this analysis can be grouped into two main categories. The first category focuses on the data of deaths from Covid-19, while the second includes demographic and socio-economic variables. The statistical data regarding deaths from Covid-19 have been collected from various official sources (see Table A.1 in the Appendix).

For the purposes of the study, we used numbers of deaths recorded cumulatively until May 26, 2020. The comprehensive databases we used include 32 European populations (EU members, EEA countries as well as Switzerland and UK). Three countries (Iceland, Liechtenstein, and Malta) exhibit very small numbers of deaths (<15) and high relative standard errors (>25%); thus, they are excluded from our study as in such instances the results derived are unreliable (NCHS 1999, Klein et al. 2002). Hence, the present analysis focuses on 29 national populations. For 18 of these countries, the available statistical material refers to the total number of deaths (all ages, both sexes combined). Classification of deaths by age is available only for eleven European countries: Austria; Denmark; France; Germany; Greece; Italy; Netherlands; Norway; Spain; Switzerland; and Portugal. This provides a valuable piece of information which allows application of demographic age-standardisation techniques (see below).

The first Covid-19 death in Europe was reported on February 15, 2020 in France. By February 21, nine countries had reported cases: Belgium (1); Finland (1); France (12); Germany (16); Italy (3); Russia (2); Spain (2); Sweden (1); and the UK (9) (Spiteri et al. 2020). In the EU/EEA and the UK, 121 cases and three deaths had been reported as of February 23. The rate of infection and deaths rapidly expanded across Europe. In Greece for example, the first case was diagnosed on February the 26 and only a month later, on March the 23 there were 695 confirmed cases and 17 deaths. Nation-wide restrictions on the freedom of movement were imposed at that time.

Furthermore, the dataset includes demographic and socio-economic data. Information on the population by age (January 1, 2020), as well as on selected socioeconomic indicators used in the analysis, was obtained from Eurostat official site (see Table A.1). These data include Population, Gross Domestic Product per capita (ppp-adjusted), Number of Hospital Beds per 100,000 population, Life Expectancy at Birth and percent of Urban Population. The variables used in this analysis are presented in the Appendix Table A.2.

3.2 Variables and methods of analysis

Combining the basic statistical information (total numbers of deaths and cases due to Covid-19) with the relevant population data, we calculated three broad (crude) measures:

Death Rate (DR) defined as number of deaths per 100,000 population;

Incidence Rate (IR) referring to number of cases per 100,000 population;

Fatality Rate (FR) expressing number of deaths per 1,000 cases.

It is well known, however, that crude demographic rates are affected by the age-structure of the study populations; hence, for comparative purposes we computed standardised indices to eliminate age effects (Siegel, Swanson 2004). Two types of standardisation procedures are employed:

First, for the eleven European countries for which statistics on deaths from Covid-19 by age are available, we computed standardised death rates (DSDR) directly, choosing the average age composition of the eleven populations under consideration as the more appropriate reference age structure rather than the average European standard age-distribution, which encompasses populations excluded from the present analysis.

Second, for the 29 populations under investigation we calculated Standardised Mortality Ratios (SMR) using the age-specific death rates (of Covid-19) of the Italian population as the reference mortality schedule. The SMRs are expressed per 100 and compare the national figures of the study populations to the mortality levels of Italy. Multiplying the SMRs (per unit) by the observed death rate of the standard population (Italy) we obtain the corresponding indirectly standardised death rates (ISDR).

To explore the potential association between death rates and demographic and socio-economic factors, we applied a linear correlation analysis as well as a one-way analysis of variance (ANOVA). The factors of interest considered include the proportions of the elderly population (ages 65+, 70+, 80+), the percentage of the urban population, the per capita Gross Domestic Product (ppp-adjusted) and the number of hospital beds per 100,000 population. The statistical analysis was performed using SPSS version 24.

4 Results: ageing and Covid-19 death incidence

Table 1 presents the data used in the analysis considering up-to-date outcomes due to Covid-19 reported cumulatively until May 26. Cases and, particularly, deaths show large variations across European countries. Numbers of deaths range from 17 (Cyprus) to 36914 (UK) exhibiting a relative dispersion of 193%. Numbers of cases range from 937 (Cyprus) to 261184 (UK); the relative dispersion is 164%. The average death rate (DR) is about 18 deaths per 100,000 people, the average incidence rate (IR) 210 cases per 100,000 population while the average fatality rate (FT) is 71 deaths per 1000 cases.

Empirical research indicates that mortality risk due to Covid-19 is greatly concentrated in the older age ranges, mainly at the ages of 70, 80 and older. This finding often leads to the assumption that countries exhibiting higher proportions of older persons in the population are expected to experience higher death rates from the disease. To test this hypothesis, we apply four different approaches.

First, we computed correlation coefficients between ageing indicators (the percentages of the population aged 65, 70 and 80 years or more) and the Covid-19 rates. We also calculated the correlation coefficients between these indicators and the general economic conditions of the countries, based on the per capita gross product, the availability of hospital infrastructure (hospital beds per 100,000 inhabitants) and the percentage of the urban population as it reflects, to some extent, the concentration and density of the population. The correlation matrix is presented in Table 2. The correlation coefficients between incident rates and the ageing measures are inconsistent; for death and fatality rates they are very low and trivial, though they point in the expected direction for persons aged 70+ and 80+. Nevertheless, there is a palpable and noteworthy association between death and incidence rates and the proportions of the urban population while it seems that good hospital infrastructure plays a favourable role. It may be interesting to note that the associations and the impact of the proportion of the urban population, GDP

Table 1: Data used in the analysis and basic descriptive statistics (26/5/2020) and indirectly standardised death rates

Country	cases	deaths	death rate	incidence rate	fatality rate	Pop 65+ (%)	Pop 70+ (%)	Pop 80+ (%)	e(o)	GDP	Urban (%)	Beds	ISDR
Austria	16459	641	7.20	185	39	19.0	13.9	5.3	81.8	128	57	737	9.1
Belgium	57342	9312	81.06	499	162	19.2	13.8	5.7	81.7	118	98	566	100.3
Bulgaria	2433	130	1.87	35	53	21.6	15.0	4.9	75.0	51	76	745	2.4
Croatia	2244	100	2.47	55	45	21.1	14.5	5.5	78.2	63	58	554	3.1
Cyprus	937	17	1.92	106	18	16.3	11.2	3.7	82.9	90	67	340	3.1
Czechia	9004	317	2.97	84	35	20.0	13.6	4.1	79.1	91	74	663	4.1
Denmark	11387	563	9.64	195	49	19.8	14.3	4.7	81.0	129	88	261	12.7
Estonia	1824	65	4.90	137	36	20.1	14.3	5.9	78.5	82	68	469	6
Finland	6599	308	5.57	119	47	22.3	15.8	5.7	81.8	112	86	328	6.4
France	145279	28432	42.31	216	196	20.4	14.6	6.1	82.9	104	82	598	49.1
Germany	179002	8302	9.98	215	46	21.8	15.9	6.8	81.0	123	76	800	10.8
Greece	2882	172	1.61	27	60	22.3	16.6	7.2	81.9	69	85	421	1.7
Hungary	3771	499	5.12	39	132	19.9	13.3	4.5	76.2	71	72	702	7
Ireland	24698	1606	32.49	500	65	14.4	9.9	3.4	82.3	191	63	296	57.8
Italy	230158	32877	54.58	382	143	23.2	17.4	7.4	83.4	97	69	318	54.6
Latvia	1049	22	1.15	55	21	20.6	14.8	5.8	75.1	69	69	557	1.4
Lithuania	1635	63	2.28	59	39	20.1	14.5	5.9	76.0	81	71	656	2.7
Luxembourg	3993	110	17.58	638	28	14.6	10.2	4.1	82.3	263	88	466	28.8
Netherlands	45445	5830	33.62	262	128	19.6	13.8	4.7	81.9	130	92	332	44.4
Norway	8352	235	4.38	156	28	17.5	12.4	4.3	82.8	153	70	360	6.3
Poland	21631	1007	2.65	57	47	18.2	11.8	4.4	77.7	71	60	662	3.8
Portugal	30788	1330	12.96	300	43	22.2	16.1	6.6	81.5	77	66	339	14.2
Romania	18283	1197	6.21	95	65	19.0	12.7	4.8	75.3	66	55	689	8.5

Continued on the next page ...

Table 1: Data used in the analysis and basic descriptive statistics (26/5/2020) and indirectly standardised death rates (*continued*)

Country	cases	deaths	death rate	incidence rate	fatality rate	Pop 65+ (%)	Pop 70+ (%)	Pop 80+ (%)	e(o)	GDP	Urban (%)	Beds	ISDR
Slovakia	1511	28	0.51	28	19	16.6	10.5	3.3	77.4	74	54	582	0.9
Slovenia	1469	106	5.09	71	72	20.4	13.9	5.5	81.5	88	55	450	6.3
Spain	235400	26834	57.03	500	114	19.7	14.5	6.1	83.5	91	80	297	66.8
Sweden	33843	4029	38.93	327	119	19.9	14.7	5.2	82.6	121	88	222	49.0
Switzerland	30601	1645	19.11	356	54	18.7	13.7	5.3	83.8	156	78	453	24.4
UK	261184	36914	55.02	389	141	18.5	13.5	5.0	81.3	106	88	254	72.8

Statistics	cases	deaths	death rate	incidence rate	fatality rate	Pop 65+ (%)	Pop 70+ (%)	Pop 80+ (%)	e(o)	GDP	Urban (%)	Beds	ISDR
min	937	17	0.5	27.0	18.1	14.4	9.9	3.3	75.0	51.0	54.0	222	0.9
max	261184	36914	81.1	638.2	195.7	23.2	17.4	7.4	83.8	263.0	98.0	800	100.3
range	260247	36897	80.6	611.2	177.6	8.7	7.4	4.0	8.8	212.0	44.0	578	99.4
mean	47904	5610	17.9	209.9	70.5	19.6	13.8	5.2	80.4	105.7	73.6	487	22.7
std. dev.	78753	10817	21.8	173.2	48.6	2.1	1.8	1.0	2.8	44.2	12.4	173	26.9
CV (%)	164	193	121	83	69	11	13	20	3	42	17	35	119

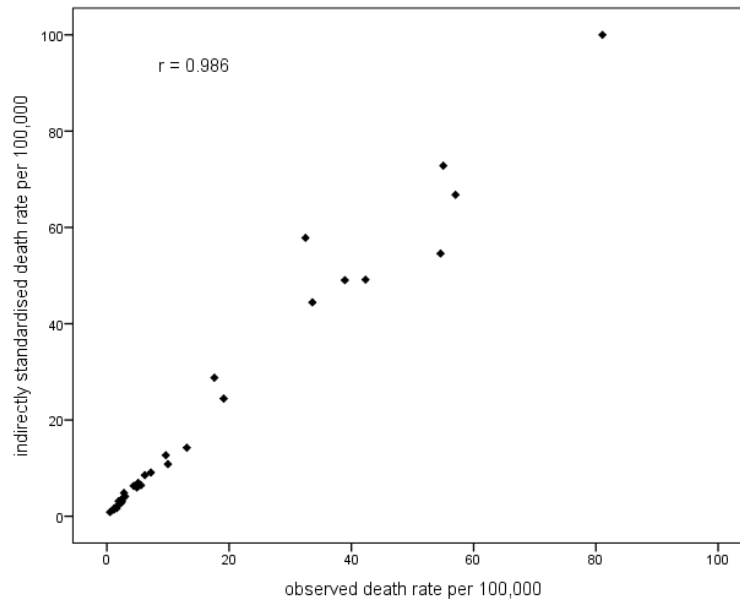


Figure 1: Association between observed death rate and standardised death rate using the indirect method of standardisation: data 26-5-2020

per capita and hospital infrastructure are clearer with respect to incidence rates. One explanation might be that countries with relatively higher levels of economic development are usually characterized by higher trade openness, interactions and connections with the international community. It seems that the spread of Covid-19 puts into question openness, internationalization and globalization. Covid-19 is following the paths of international connections and integration.

Second, in order to eliminate age structure effects and to increase the validity of our results, we calculated indirectly standardized death rates and we examined the association between observed and indirectly standardised death rates. Table 1 presents the computational results. Compared to Italy (standard population), Belgium, Spain and the UK exhibit higher mortality, however the overall association between observed and adjusted death rates is positive and very strong implying that ageing effects do not seem to be present (Figure 1).

Third, a direct comparison of the observed death rates with demographic ageing indicators across countries at different stages of the disease progression that have adopted different policies of social distancing and have different health systems and capabilities may be naive. To overcome to some extent these incompatibilities, it may be more appropriate to compare countries with roughly similar levels of mortality. Hence, we divided our sample into three sub-groups reflecting low, medium and high mortality rates (<5, 6-19 and 20+ deaths per 100000 population, respectively) and we applied one-way ANOVA to examine if the differences in mean population ageing indicators between the three groups differ considerably. The results of the statistical analysis are presented in Table 3 and confirm that the mean proportions of populations aged 65, 70 or 80 or more do not in fact differ across mortality levels (p-values 0.863, 0.936 and 0.661, respectively).

Fourth, we applied direct standardisation for countries where the relevant information was available, as this demographic technique perhaps more accurately clarifies the potential connection between observed death rates and population ageing. The results of our computations are presented in Figure 2. The pattern of the observed and standardised rates across countries is consistent; the association between observed and directly standardised death rates is very high ($r = 0.986$) implying that the age differentials do not seem to have an effect on the mortality rates.

Table 2: Correlation matrix of variables of interest (2-tailed p-values in parenthesis): data 26/5/2020

	Death rate	Incidence rate	Fatality rate	Pop 65+ (%)	Pop 70+ (%)	Pop 80+ (%)	e0	GDP	Urban % (%)	Beds
Death rate	1									
Incidence rate	0.762** (0.000)	1								
Fatality rate	0.807** (0.000)	0.387* (0.038)	1							
Pop 65+ (%)	-0.019 (0.923)	-0.349 (0.064)	0.216 (0.260)	1						
Pop 70+ (%)	0.118 (0.541)	-0.160 (0.407)	0.262 (0.169)	0.962** (0.000)	1					
Pop 80+ (%)	0.238 (0.214)	0.030 (0.877)	0.295 (0.120)	0.815** (0.000)	0.894** (0.000)	1				
e0	0.513** (0.004)	0.632** (0.000)	0.304 (0.109)	-0.117 (0.545)	0.069 (0.721)	0.170 (0.378)	1			
GDP	0.252 (0.187)	0.724** (0.000)	-0.025 (0.897)	-0.594** (0.001)	-0.436* (0.018)	-0.300 (0.114)	0.566** (0.001)	1		
Urban (%)	0.545** (0.002)	0.475** (0.009)	0.476** (0.009)	0.120 (0.536)	0.250 (0.190)	0.191 (0.321)	0.396* (0.034)	0.354 (0.060)	1	
Beds	-0.391* (0.036)	-0.464* (0.011)	-0.177 (0.357)	0.116 (0.549)	-0.025 (0.896)	0.004 (0.985)	-0.633** (0.000)	-0.310 (0.101)	-0.360 (0.055)	1

** Significant at the 0.01 level (2-tailed)

* Significant at the 0.05 level (2-tailed)

Table 3: One-Way Analysis of Variance examining differences in mean ageing indicators by low, medium and high levels of death rates due to Covid-19: 26-5-2020

		(A) Descriptive statistics			
		N	Mean	Std. Dev.	Std. Error
Pop 65+ (%)	death rate 0 - 5	14	19.8	1.9	0.5
	death rate 6 - 19	7	19.3	2.5	0.9
	death rate 20 +	8	19.4	2.4	0.9
	Total	29	19.6	2.1	0.4
Pop 70+ (%)	death rate 0 - 5	14	13.7	1.7	0.5
	death rate 6 - 19	7	13.9	2.0	0.8
	death rate 20 +	8	14.0	2.0	0.7
	Total	29	13.8	1.8	0.3
Pop 80+ (%)	death rate 0 - 5	14	5.0	1.0	0.3
	death rate 6 - 19	7	5.4	1.0	0.4
	death rate 20 +	8	5.5	1.2	0.4
	Total	29	5.2	1.0	0.2

		(B) ANOVA: F-test				
		Sum of Squares	df	Mean Square	F	Sig.
Pop 65+ (%)	Between Groups	1.447	2	0.723	0.148	0.863
	Within Groups	127.125	26	4.889		
	Total	128.572	28			
Pop 70+ (%)	Between Groups	0.470	2	0.235	0.066	0.936
	Within Groups	92.568	26	3.560		
	Total	93.039	28			
Pop 80+ (%)	Between Groups	0.964	2	0.482	0.421	0.661
	Within Groups	29.738	26	1.144		
	Total	30.702	28			

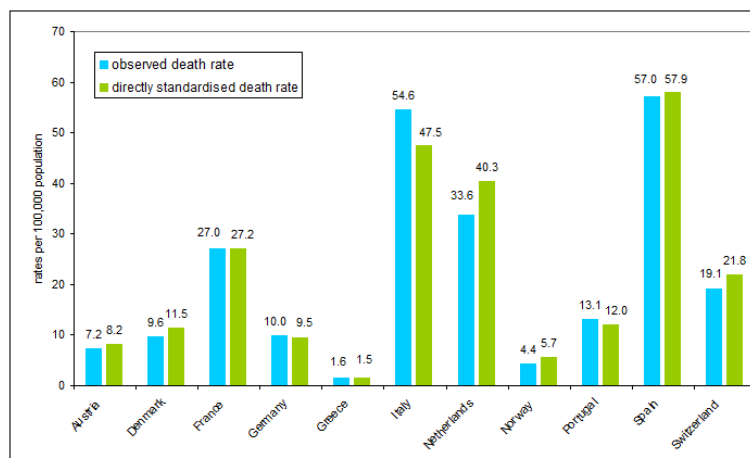


Figure 2: Observed and directly standardised death rates on the basis on the average population age-structure of the countries under investigation: data 26-5-2020

5 Modeling Covid-19 mortality rates: a Bayesian BYM spatial model

5.1 Presentation of the Model

In recent years, epidemiology has used Bayesian models widely (Greenland 2006). Quite frequently, the spatial and/or the temporal framework of the epidemiological data upgrades the Bayesian approach into a very efficient strategy for a plethora of epidemiological studies (Diggle, Ribeiro 2007, Jewell et al. 2009, Blangiardo et al. 2013).

In order to further analyse the risk of Covid-19 mortality rate, we employ a spatial econometric epidemiological model that explains the mortality rates integrating a number of covariates. Therefore, in the following section we have a dual goal: on the one hand to smooth the Standardized Mortality Ratios (SMRs) with the Hierarchical Bayesian method; and on the other hand to fit the Besag-York Mollie (BYM) spatial model with a view of estimating relative risk while quantifying the effect of a set of covariates (Mollié 1996, Morris et al. 2019).

The BYM model incorporates two types of effects: spatial and non-spatial: a spatially structured effect and an unstructured random effect. Rigorously, we assume that the observed counts, O_i , are conditionally independently Poisson distributed (Moraga 2019):

Model based approaches enable us to incorporate covariates and borrow information from neighbouring countries to improve local estimates, resulting in the smoothing of extreme values based on small sample size. We take the following equation:

$$O_i \sim \text{Poisson}(E_i\theta_i) \quad i = 1, \dots, n \quad (1)$$

where E_i is the expected count and θ_i is the relative risk in area i . The logarithm of θ_i is expressed as:

$$\log(\theta_i) = \mathbf{d}_i\boldsymbol{\beta} + u_i + v_i \quad (2)$$

$\mathbf{d}_i = (1, d_{i1}, \dots, d_{ip})$ is the vector of the intercept and p covariates corresponding to area i , and $\boldsymbol{\beta} = (\beta_0, \beta_1, \dots, \beta_p)$ denotes the coefficient vector.

The error term u_i is modeled with a CAR distribution $u_i|u_{-i} \sim N(\bar{u}_{\delta_i}, \frac{\sigma_u^2}{n_{\delta_i}})$ where $\bar{u}_{\delta_i} = \frac{\sum_{j \in \delta_i} u_j}{n_{\delta_i}}$, δ_i , and n_{δ_i} represent the set of neighbors and the number of neighbors of area i respectively. v_i is modeled as identically distributed normal variables with zero mean and variance σ_v^2 , namely, $v_i \sim N(0, \sigma_v^2)$.

For the analysis, R statistical software was used. Inferences for Bayesian Hierarchical models were approximated by Integrated Nested Laplace approximation (INLA) with R-INLA package (Rue et al. 2018).

5.2 Empirical application

We employ a spatial epidemiology model in order to estimate the disease risk due to Covid-19 in 29 European countries during the first wave of the pandemic. Following equation 1 as the dependent variable, we use observed deaths per country (O_i) which are conditionally independently Poisson distributed with expected deaths (E_i) and θ_i the relative risk for each country. Equation 2 allows us to include a set of covariates in our model in order to quantify the effect and incorporate this information into relative risk estimates. Five variables are examined as covariates in our spatial econometric model, Gross Domestic Product (GDP), ageing indicators (the percentages of the population aged 70 and 80 years or more), the availability of hospital infrastructure (hospital beds per 100,000 inhabitants) and the percentage of population living in an urban context. Our analysis comprises the mean posterior, the standard deviation and the 95% credible intervals of the relative risks which represent the 2.5 and 97.5 percentiles respectively. Additionally, with the purpose of interpreting the relative risk in our model, we construct an additional column where we calculate the factor increase, $\exp(\beta_j)$, keeping all other covariates constant. Finally, in order to compare the different Bayesian models we use the Watanabe Akaike information Criterion (WAIC) (Watanabe 2010).

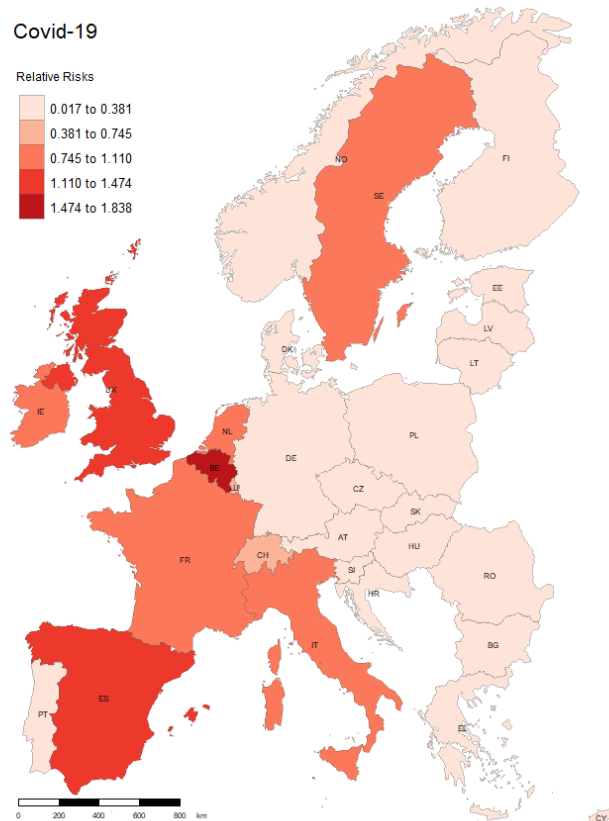


Figure 3: Mapping Covid-19 relative risk across European countries

5.3 Mapping the evidence

Figures 3 and 4 illustrate the output of the BYM model regarding the relative mortality risk, considering Italy as a baseline. As Italy exhibits the highest mortality rate, the probability of death is estimated based on $\text{Italy}=1$: higher values denote higher mortality rates and vice versa.

Figures 3 and 4 indicate that there is a geographical pattern in mortality rates. Countries on the left part of the map show higher probability rates than countries on the right. Belgium, Spain, UK and Ireland show the greatest values above the baseline. France, Slovenia and the Netherlands are a little below the baseline. Conversely, a large number of countries including Germany and Denmark from the North, Greece and Portugal from the South and a large number of former Eastern European countries exhibit rates below that of Italy and well below the baseline. This demonstrates the spatial heterogeneity of mortality rates across Europe.

5.4 The results

The application of the spatial epidemiology model provides some interesting results which are presented in Table 4. These could be summarized as follows:

First, in all models the coefficient of the variable URBAN is positive, indicating that urbanization is an important explanatory factor for the probability of the mortality rate and overall increases Covid-19 risk.

Second, in all models, the variable BEDS is negatively associated with the probability of mortality indicating an inverse relationship between hospital beds and Covid-19 risk. This is achieved taking into account the observed deaths from Covid-19, the expected number of deaths but also a set of covariates. The greater the bed availability per 100,000 population, the lower the Covid-19 mortality risk. This signifies the importance of sound health care systems to efficiently tackle the negative impacts of the pandemic.

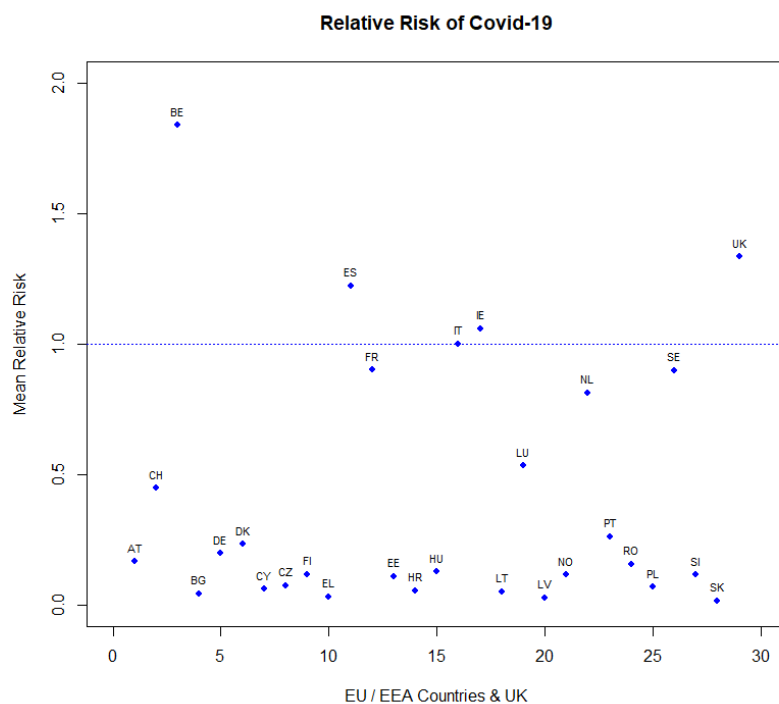


Figure 4: Covid-19 relative risk across European countries

Third, where the explanatory factor of GDP is taken into account, its coefficient was positive, suggesting that countries with greater GDP tend to have greater Covid-19 risk. The higher the market size and the level of development, the higher the risks. This finding corroborates the literature that the most advanced and open economies are more vulnerable to Covid-19 (Sorci et al. 2020). Developed economies are expected to be more affected in 2020 than developing economies, at -5.8 per cent and -2.1 per cent, respectively (United Nations 2020, p. 13). Since GDP and urbanization show a high level of correlation in the data, they are inserted separately in the analysis.

Fourth, the coefficient of variable P80 is positive, indicating that there is a higher risk of mortality for people above 80 years of age.

Finally, in line with WAIC criterion, the best model is model 3 which has the lowest value and therefore the highest explanatory power of those that are presented (Table 4).

Figure 4 presents all the posterior distributions of covariates P70, GDP, Urban and Beds. On the one hand, covariates GDP and Urban display positive distribution of values for the coefficients indicating an increase in Covid-19 risk. On the other hand, the posterior distribution of the coefficient of Beds is mainly negative, demonstrating this inverse relationship between Beds and Covid-19 risk.

6 Conclusions and discussion

The Covid-19 pandemic is a new phenomenon that has been ongoing for one year. Empirical studies from various countries reveal that older people are at a higher risk of developing the disease than younger people. Furthermore, not only are the majority of cases concentrated in older ages but elderly people have a much higher risk of a fatal outcome. These findings often lead to the assumption that countries with high proportions of aged population would tend to exhibit higher death rates from Covid-19.

However, our results based on recent cross-sectional data from 29 European countries, referring to what now is termed ‘the first wave of the pandemic’, do not agree with the standpoint expressed in the literature, that the population age structure may explain notable variations in fatality or death rates across countries (Dowd et al. 2020). Although a correlation is apparent between death rates and proportions of persons aged 70 or more,

Table 4: Besag-York-Mollié model using Bayesian Hierarchical smoothing on SMRs

Covariates	Mean	S.d.	2.5%	97.5%	Exp(Mean)
<i>Model 1:</i>					
P70+	-0.059	0.122	-0.301	0.183	0.943
Urban	0.047	0.019	0.009	0.085	1.048
Beds	-0.002	0.054	-0.005	0.000	0.998
Constant	-3.179	2.156	-7.450	1.076	
Marginal log-likelihood	-271.02				
WAIC	292.64				
<i>Model 2:</i>					
P80+	0.084	0.211	-0.332	0.500	1.088
Urban	0.043	0.019	0.005	0.081	1.044
Beds	-0.002	0.001	-0.005	0.000	0.998
Constant	-4.101	1.896	-7.854	-0.359	
Marginal log-likelihood	-270.52				
WAIC	292.58				
<i>Model 3:</i>					
P70+	0.111	0.141	-0.169	0.391	1.117
GDP	0.013	0.006	0.001	0.025	1.013
Urban	0.028	0.020	-0.013	0.068	1.028
Beds	-0.002	0.001	-0.004	0.001	0.998
Constant	-5.711	2.372	-10.411	-1.031	
Marginal log-likelihood	-277.38				
WAIC	292.47				
<i>Model 4:</i>					
P80+	0.282	0.210	-0.134	0.698	1.326
GDP	0.013	0.005	0.002	0.023	1.013
Urban	0.027	0.019	-0.010	0.064	1.027
Beds	-0.002	0.001	-0.004	0.001	0.998
Constant	-5.576	1.847	-9.235	-5.571	
Marginal log-likelihood	-276.34				
WAIC	292.48				

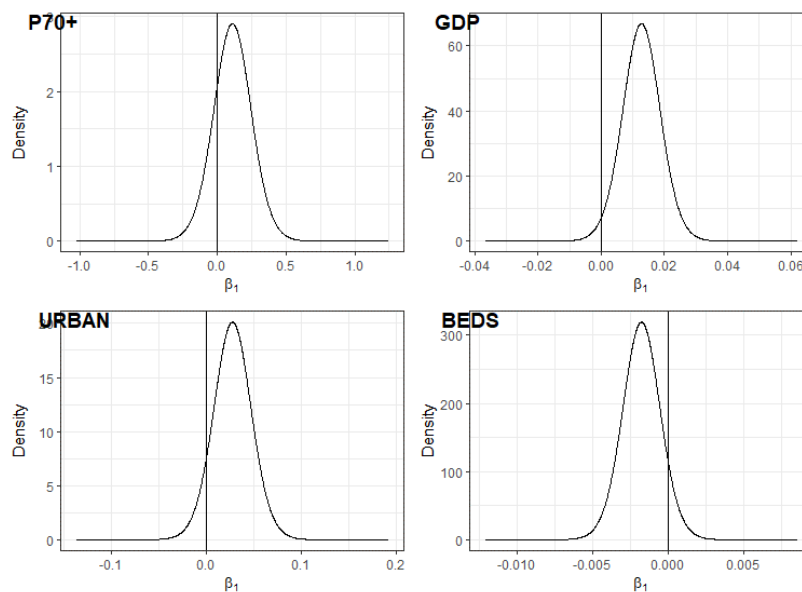


Figure 5: Posterior Distribution of the coefficient of covariate

and, especially, 80 or more, the associations are small in magnitude. Several factors contribute to this discrepancy. First, the degree of ageing does not differ substantially between European countries; hence, the standardization methodology used in this study did not result in sizeable differences. Second, it may be still too early to confirm the effects and the interrelationships of the disease with the structural characteristics of the population. As the Covid-19 pandemic is still under way additional deaths are recorded every day and more statistical material is collected globally. Comparisons may be inconsistent because different countries are at different stages of the epidemic while additionally, they employ different social and health policies to protect their citizens. Third, differential reporting of Covid-19 deaths (and of cases) adds to the confusion. There is evidence that, at present, there is a significant under-reporting of deaths from Covid-19, particularly in developing countries, while different definitions and practices are employed by different countries (for instance, in the UK, only deaths occurring in hospitals are registered; in Sweden deaths occurring in nursing homes are not recorded). Furthermore, even accurate identification of Covid-19 deaths is a difficult task. Additionally, in many instances, it is mainly some cities or regions that have been disproportionately affected by the virus compared with the rest of the country (e.g. in Sweden Stockholm, in Greece mostly Athens, etc.).

Analysis has shown that explanations on high fatality rates of Covid-19 for elderly people don't necessarily imply high fatality rates for aging societies. Moving from the individual determinants of fatality to societal fatality rates, the determinants are changing significantly. It is not only age that matters. It is the socio economic environment and the broader conditions that affect vulnerability to Covid-19.

Furthermore, our analysis has unveiled the issue that socio-economic variables exert a significant impact on the incidence of and fatalities from Covid-19. Testing for socio-economic and demographic factors, the Bayesian Besag-York Mollie (BYM) spatial model provides some interesting results which we present below.

First, the level of urbanization of a country is a significant determinant of death rates from Covid-19. The level of urbanization proxies the market size along with the level of interaction and interconnections. The higher the level of interactions, the higher the risk of the disease. This risk is caused by the large number of those affected vis-a-vis the limits of the health system. As a result this observation signifies the role of health systems and corroborates previous findings in the literature of epidemiological studies (Neiderud 2015). At the same time the more deprived populations within urban areas are more vulnerable to fatality rates (Wade 2020).

Second, the level of economic development emerges as a significant factor for the spread of the disease. The level of economic development proxies the openness and the international connectedness of the economy. The higher the connections through trade and transport, the higher the risks from the disease. According to Sorci et al. (2020), GDP per capita was positively associated with the levels of fatality rates in Europe. Similarly, Hamidi et al. (2020) identified connectivity as a risk factor for COVID-19 in the US, while Burlina, Rodríguez-Pose (2020) show that highly connected regions witnessed the highest incidence of excess mortality.

The 'first wave of the pandemic' made evident that Covid-19 challenges the two fundamental trends/issues of the contemporary global economic system: globalization and urbanization. This could mean that factors which were clear advantages for the economic development in the past (such as agglomeration and interactions) might operate differently in the context and aftermath of Covid-19 (Bailey et al. 2020).

Third, the number of beds, which proxies the quality of health system, plays a significant role in protection from the disease. The higher the standards of the health system, the greater the protection of people from the disease. This finding corroborates with the results of Sorci et al. (2020) who demonstrated that fatality rates in the EU countries were negatively associated with the number of hospital beds per 1000 inhabitants.

The present pandemic is raising fundamental questions about what makes a community, a population and a nation resilient and sustainable to external shocks (Psycharis et al. 2014). As a result, this analysis highlights some interesting challenges and policy implications for the future.

First, this disease questions the pace of urbanization and the functioning of urban systems. The international trend towards urbanization witnessed in recent years is anticipated to be affected or even halted by the recent spread of the pandemic. In addition, the organization of everyday life and the economic activities within cities has changed drastically. It is very early to predict the long term consequences. However, it is certain that these trends introduce another factor that should be taken into consideration in urban development and urban policy in the future.

Second, the Covid-9 pandemic questions the pace of globalisation. The world appears to be becoming less globalized as the pandemic persists ([United Nations 2020](#)).

Third, these trends place into question: the specialization of the economy; the organization of production; and location choices. More remote and rural areas may provide safer and healthier types of economic activity and choices for residence. Although it is still early, the location choices of people and enterprises may be affected by the spread of the disease. Will people move to peripheral areas? It is very early and would be premature to make such a prediction. However, the balance between centrifugal or centripetal forces that operate and determine the location choices of people and enterprises will probably change and the underlying forces will be reshuffled in the post-Covid-19 period.

Fourth, the pandemic threatens the inclusiveness of societies. Historically, pandemics have hit minorities and people at the bottom of the socioeconomic ladder disproportionately ([Wade 2020](#)). During the pandemic the most vulnerable populations have been hit the hardest ([United Nations 2020](#), p. 111). Inequality, one of the major issues in contemporary societies, will probably deteriorate further.

Fifth, the spread of the pandemic requires the improvement of public health care systems. An unequal distribution of resources or the uneven delivery of healthcare could incur harmful effects on people across and within regions. The structure of health systems is a vital condition for the wellbeing of people and the proper functioning of the economy. Thus, a more active role of states in upgrading the health systems is a fundamental factor in modern public policy.

Finally, the European Union has launched the Recovery Fund for the support of the economy and society. It seems that the disease is leading to a reconstruction of the priorities and the means of cohesion policy. This may transform the cohesion policy and the functioning of public policy as we knew it in the pre-Covid-19 era.

This study also opens some new directions for future work.

We believe that a robust age-specific analysis of the mortality from Covid-19 cannot be performed at this time. Such studies will be much more reliable and fruitful later on, when governments relax the restrictive measures already taken. There may also be more recurrent waves of the disease. No clear conclusions can be drawn yet with respect to the correlation between demographic dimensions and the levels of mortality due to the virus. It is however a fact that the Covid-19 pandemic has already led most countries into a major economic recession. The adverse effects of this crisis could impact public health care service capabilities and efficiency, adding a further future complication to the estimation of the association of demographic factors with Covid-19 mortality.

Nevertheless, one of the interesting outcomes of the present analysis is that higher rates of the disease are associated with higher levels of economic development and urbanization. These factors could offer a partial explanation of the patterns and the spread of disease. The most developed countries are usually those with greater trade openness and frequent interactions on a global scale. Furthermore, empirical studies have shown that in urban areas, certain population groups tend to advance the transmission of pathogens and provide suitable conditions for the manifestation of infectious disease ([Neiderud 2015](#)). At the same time Covid-19 places an unequal burden on more deprived populations ([Wade 2020](#)). Therefore, Covid-19 requires a place-specific and people-centered implementation of public policy ([Bag et al. 2020](#)). This constitutes an important challenge for public policy in the current circumstances. A closer analysis of the association of urbanization with the spread of and fatalities from the disease, the impact of income level and spatial segregation on the spread of the disease, as well as analyses on smaller geographical scales constitute fruitful avenues for future research.

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A Appendix:

Table A.1: Data sources

Country and material	Source of data
Deaths and cases of Covid-19	
<i>Deaths by age</i>	
Austria, Denmark, France, Germany, The Netherlands, Norway, Spain, Portugal	Institut National D' Etudes Démographiques (INED) https://dc-covid.site.ined.fr/en/
Greece	Greek National Public Health Organisation (EODY) https://eody.gov.gr/en/covid-19/
Italy	Instituto Superiori di Sanita (epicentre) https://www.epicentro.iss.it/coronavirus/sars-cov-2-sorveglianza-dati
Switzerland	Switzerland's Federal Office of Public Health https://www.bag.admin.ch/bag/en/home/krankheiten/ausbrueche-epidemien-pandemien/aktuelle-ausbrueche-epidemien/novel-cov/situation-schweiz-und-international.html#1867597016
<i>Total deaths and cases (all ages)</i>	
EU countries, EEA (European Economic Area) countries U.K.	European Center for Disease Prevention & Control (ECDC) for the EU / EEA https://www.ecdc.europa.eu/en/cases-2019-ncov-eueea
Socio-economic and demographic data and indices	
Population size and structure (1.1.2020); Life expectancy at birth (both sexes, last available year); Percent urban population (2017); Hospital beds per 100,000 population (2017); Gross Domestic Product per capita in 2018 (ppp-adjusted)	https://ec.europa.eu/eurostat/data/database

Table A.2: Variable definition and variable name

Variable	Definition
(death rate):	deaths of covid-19 per 100000 population
(incidence rate):	cases of covid-19 per 100000 population
(fatality rate):	deaths of covid-19 per 1000cases
Pop (65+) %:	percentage of population aged 65 or higher
Pop (70+) %:	percentage of population aged 70 or higher
Pop (80+) %:	percentage of population aged 80 or higher
e(o):	life expectancy at birth (latest data)
GDP:	Gross Domestic Product per capita ppp adjusted (2018)
Urban (%):	percentage of urban population (latest data)
Beds:	Hospital beds per 100,000 inhabitants
ISDR:	Indirectly Standardised Death Rates per 100000 population

