**Supplementary:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Category | Variable Label | Description | Time span | Data Source |
| SPATIAL | Country | Country | - | - |
| TEMPORAL | Year | Report year | - | - |
| TEMPORAL | Week | Report week | - | - |
| POPULATION | Population | Annual country population (July 1) | 2020-2021 | Department of Economic and Social Affairs, Population Division, United Nation |
| POPULATION | Population density | Annual country population density | 2020-2021 | Department of Economic and Social Affairs, Population Division, United Nation |
| POPULATION | Median age | Median age of population | 2020-2021 | Department of Economic and Social Affairs, Population Division, United Nation |
| POPULATION | Life expectancy | Life expectancy at birth, total (years) | 2020 | Demographic and Health Surveys, Multiple Indicator Cluster Surveys, Household surveys, UN Population Division |
| POPULATION | Hypertension | Prevalence of hypertension (% of adults ages 30-79) | 2019 | Health Nutrition and Population Statistics |
| POPULATION | Diabetes | Diabetes prevalence (% of population ages 20 to 79) | 2021 | Health Nutrition and Population Statistics |
| POPULATION | Obesity | Prevalence of overweight (% of adults) | 2016 | Health Nutrition and Population Statistics |
| POPULATION | Percent of population more than 65 years old | Percentage of total population by select age group, both sexes combined (per 100 total population) | 2020-2021 | Department of Economic and Social Affairs, Population Division, United Nation |
| SOCIOECONOMIC STATUS | Gross Domestic Products (GDP) | GDP per capita, PPP (constant 2017 international $) | 2020-2021 | World Bank |
| SES SOCIOECONOMIC STATUS | Human development index (HDI) | Human development index | 2021 | UNDP, Human Development Report |
| SES SOCIOECONOMIC STATUS | Inequality-adjusted Human Development Index (IHDI) | Inequality in Human development index | 2021 | UNDP, Human Development Report |
| SOCIOECONOMIC STATUS | Gini index | Income inequality | 2010-2020 | UNDP, Human Development Report |
| SOCIOECONOMIC STATUS | Control of corruption | Control of Corruption: Estimate | 2020-2021 | Worldwide Governance Indicators (WGI) |
| SES SOCIOECONOMIC STATUS | Government Effectiveness | Government Effectiveness: Estimate | 2020-2021 | Worldwide Governance Indicators (WGI) |
| SOCIOECONOMIC STATUS | Unemployment | Unemployment rate, total (% of total labor force) (modeled ILO estimate) | 2022 | World Bank |
| SOCIOECONOMIC STATUS | Government revenue | Government revenue (% of GDP) | 2020-2021 | The Organization for Economic Co-operation and Development (OECD) & International Monetary Fund (IMF) |
| SOCIOECONOMIC STATUS | Prosperity Index | Annual prosperity Index | 2023 | The Legatum Prosperity Index |
| SOCIOECONOMIC STATUS | GII | Gender Inequality Index | 2020-2021 | UNDP, Human Development Report |
| HEALTH RESOURCES | Universal Health Coverage | Universal Health Coverage effective coverage index | 2020 | The Institute for Health Metrics and Evaluation (IHME) |
| HEALTH CARE RESOURCES | Health expenditure | Current health expenditure (% of GDP) | 2019 | Health Nutrition and Population Statistics |
| HEALTH CARE RESOURCES | Hospital beds per thousand | Hospital bed density per 1,000 population | Last available year | The Organization for Economic Co-operation and Development (OECD) & World Bank |
| HEALTH CARE RESOURCES | Total number of nursing personnel  | National Health Workforce Accounts Data Portal (per 10,000 population) | Last available year | WHO NHWA Data Platform - December 2022 update. |
| HEALTH CARE RESOURCES | Total number of medical doctors | National Health Workforce Accounts Data Portal (per 10,000 population) | Last available year | WHO NHWA Data Platform - December 2022 update. |
| HEALTH CARE RESOURCES | Total vaccinations | Total vaccinations per hundred in that week | 2020-2021 | Our World in Data |
| HEALTH CARE RESOURCES | Fully vaccinated | People fully vaccinated per hundred in that week | 2020-2021 | Our World in Data |
| HEALTH CARE RESOURCES | Completeness of vital registration | Completeness of vital registration systems as assessed in 2019 | 2019 | GBD 2019 Diseases and Injuries Collaborators. Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. |
| HEALTH CARE RESOURCES |  Healthcare Access and Quality Index (HAQ) |  Healthcare Access and Quality Index | 2019 | Global Burden of Disease Study 2019 (GBD 2019)  |
| HEALTH CARE RESOURCES | COVID incidence | COVID incidence | 2020-2021 | Our World in Data |
| POLICY | Stringency index | Mean stringency index in that week | 2020-2021 | Blavatnik School of Government, University of Oxford |
| AIR POLLUTION | PM2.5 (air pollution) | PM2.5 air pollution, mean annual exposure (micrograms per cubic meter) | 2019 | World Development Indicators |

*\* For Northern Irland, Wales, and England, data is only available for "population" and "vaccination". Hence, for other variables, we used the U.K. data.*

*Table S 1 Input variables and their descriptions*

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  VariablesCountries | Stringency index | Fully vaccinated people with 3 weeks lag | COVID incidence per 1000 population with 3 weeks lag | population density | hospital beds per thousand | Gini index | Government Effectiveness | Unemployment | Prevalence of obesity among adults, BMI >= 30 (age-standardized estimate) (%) |
| Australia | 62.50 | 10.47 | 0.04 | 3.36 | 3.84 | 34.30 | 1.56 | 5.73 | 29 |
| Austria | 58.37 | 17.10 | 0.42 | 108.04 | 7.05 | 30.20 | 1.60 | 5.80 | 20.1 |
| Belgium | 54.34 | 19.16 | 0.59 | 382.75 | 5.52 | 27.20 | 1.12 | 5.94 | 22.1 |
| Brazil | 62.95 | 10.82 | 1.11 | 25.58 | 2.09 | 48.90 | -0.45 | 13.63 | 22.1 |
| Cyprus | 60.39 | 17.04 | 0.20 | 134.31 | 3.40 | 31.20 | 0.80 | 7.52 | 21.8 |
| Denmark | 49.83 | 18.93 | 0.25 | 137.79 | 2.55 | 27.70 | 1.95 | 5.33 | 19.7 |
| England & Wales | 60.89 | 19.78 | 0.50 | 276.76 | 2.38 | 35.10 | 1.32 | 4.67 | 27.8 |
| Estonia | 40.10 | 15.38 | 0.51 | 30.58 | 4.46 | 30.80 | 1.36 | 6.54 | 21.2 |
| France | 57.38 | 17.03 | 0.50 | 116.99 | 5.73 | 32.40 | 1.25 | 7.93 | 21.6 |
| Georgia | 61.47 | 3.98 | 1.80 | 54.13 | 2.89 | 34.50 | 0.14 | 11.98 | 21.7 |
| Greece | 68.29 | 16.48 | 0.33 | 80.08 | 4.18 | 33.10 | 0.44 | 15.44 | 24.9 |
| Israel | 58.37 | 25.50 | 0.44 | 408.20 | 2.91 | 38.60 | 1.20 | 4.33 | 26.1 |
| Italy | 69.00 | 17.72 | 0.37 | 200.56 | 3.19 | 35.20 | 0.38 | 9.34 | 19.9 |
| Northern Ireland | 61.24 | 18.61 | 0.21 | 276.76 | 2.38 | 35.10 | 1.32 | 4.66 | 27.8 |
| Norway | 49.24 | 16.42 | 0.14 | 17.72 | 3.40 | 27.70 | 1.88 | 4.39 | 23.1 |
| Poland | 54.18 | 13.99 | 1.03 | 125.28 | 6.19 | 30.20 | 0.32 | 3.27 | 23.1 |
| Slovenia | 55.96 | 13.85 | 0.42 | 105.20 | 4.28 | 24.40 | 1.17 | 4.85 | 20.2 |
| Spain | 59.66 | 19.92 | 0.45 | 94.42 | 2.95 | 34.30 | 0.92 | 15.11 | 23.8 |
| Sweden | 51.00 | 15.68 | 0.36 | 25.59 | 2.05 | 29.30 | 1.68 | 8.52 | 20.6 |
| Ukraine | 58.44 | 3.55 | 1.29 | 75.44 | 7.46 | 25.60 | -0.40 | 9.67 | 24.1 |
| United States | 60.88 | 20.12 | 0.65 | 36.79 | 2.80 | 41.50 | 1.32 | 6.5875   | 36.2 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  VariablesCountries | Government revenue | Universal Health Coverage | Health expenditure | Hypertension (% of adults ages 30-79) | Diabetes (% of adults ages 30-79) | Nursing Personnel Doctors per 10000 population | MedicalDoctors per 10000 population | Population over 65 years | PM2.5 | HAQ |
| Australia | 35.28 | 89.42 | 9.91 | 29.30 | 6.40 | 136.27 | 41.02 | 16.42 | 8.55 | 90.18 |
| Austria | 49.43 | 86.37 | 10.43 | 33.80 | 4.60 | 104.94 | 54.10 | 19.31 | 12.48 | 87.97 |
| Belgium | 49.93 | 87.30 | 10.66 | 30.00 | 3.60 | 191.03 | 48.77 | 19.32 | 12.89 | 86.60 |
| Brazil | 31.53 | 64.83 | 9.59 | 45.00 | 8.80 | 55.13 | 21.42 | 9.44 | 12.71 | 52.97 |
| Cyprus | 42.44 | 99.90 | 7.01 | 30.80 | 8.60 | 42.82 | 53.75 | 14.32 | 17.29 | 86.17 |
| Denmark | 54.12 | 84.14 | 9.96 | 35.90 | 5.30 | 101.64 | 42.64 | 20.17 | 10.03 | 85.54 |
| England & Wales | 39.88 | 67.16 | 10.15 | 26.40 | 6.30 | 85.90 | 31.12 | 18.83 | 10.47 | 83.34 |
| Estonia | 39.21 | 82.04 | 6.73 | 40.20 | 6.50 | 91.86 | 38.63 | 20.28 | 6.73 | 76.45 |
| France | 52.51 | 90.77 | 11.06 | 29.10 | 5.30 | 118.53 | 33.24 | 21.18 | 11.81 | 88.02 |
| Georgia | 25.42 | 55.95 | 6.66 | 44.50 | 5.70 | 58.17 | 51.32 | 14.53 | 22.20 | 57.71 |
| Greece | 49.89 | 80.14 | 7.84 | 31.30 | 6.40 | 34.28 | 63.06 | 22.36 | 16.22 | 83.88 |
| Israel | 41.58 | 81.38 | 7.46 | 29.10 | 8.50 | 53.84 | 36.22 | 11.87 | 21.38 | 83.08 |
| Italy | 47.74 | 88.90 | 8.67 | 33.80 | 6.40 | 62.65 | 40.66 | 23.54 | 16.75 | 89.60 |
| Northern Ireland | 39.87 | 67.16 | 10.15 | 26.40 | 6.30 | 85.88 | 31.12 | 18.83 | 10.47 | 83.34 |
| Norway | 57.71 | 94.24 | 10.52 | 30.50 | 3.60 | 181.87 | 51.30 | 17.93 | 6.96 | 90.40 |
| Poland | 41.92 | 72.66 | 6.45 | 49.20 | 6.80 | 60.27 | 37.14 | 18.64 | 20.88 | 73.20 |
| Slovenia | 44.08 | 89.83 | 8.52 | 45.30 | 5.80 | 103.90 | 32.79 | 20.32 | 16.02 | 87.80 |
| Spain | 42.90 | 90.01 | 9.13 | 27.20 | 10.30 | 61.04 | 45.77 | 19.80 | 9.70 | 89.67 |
| Sweden | 49.32 | 90.36 | 10.87 | 30.20 | 5.00 | 203.02 | 70.62 | 20.07 | 6.18 | 90.38 |
| Ukraine | 36.94 | 63.81 | 7.10 | 43.10 | 5.60 | 62.95 | 29.90 | 17.30 | 20.31 | 63.05 |
| United States | 32.68 | 82.14 | 16.77 | 31.60 | 10.70 | 124.68 | 35.55 | 16.47 | 7.41 | 80.58 |

*Table S 2 Descriptive analysis of retained predictor variables, after checking for collinearity*



*Fig. S 1 Trajectory of z-score for each country/region (each point represents the means of z-score in six months) based on their assigned cluster. Countries in red are assigned to the second cluster and countries in black are assigned to the first cluster. Additionally, the blue horizontal line shows the z-score exceeding +4 indicates substantial excess mortality.*

|  |  |  |
| --- | --- | --- |
| Number of Latent classes | AIC | BIC |
| 1 | 7182.451 | 7188.72  |
| 2 | 7172.854 | 7182.25  |
| 3 | 7175.242 | 7187.78  |
| 4 | 7176.735 | 7192.4 |

* *AIC:* *Akaike information criterion*
* *BIC: Bayesian information criterion*

*Table S 3 The performance of each LCMM model*

**Generalize linear Mixture Model GLMM:**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variable | Estimate | Std. Error | df | t value | Pr(>|t|) |
| (Intercept) | 2.54045 | 0.71289 | 5.36726 | 3.564 | 0.014331 \* |
| Population density | -0.32636 | 0.26306 | 5.68065 | -1.241 | 0.263517 |
| Hospital beds per thousand | 0.05973 | 0.28453 | 4.70644 | 0.210 | 0.842501 |
| Gini index | -0.38023 | 0.63667 | 4.45354 | -0.597 | 0.579419 |
| Government effectiveness | -0.36147 | 0.09938 | 568.23708 | -3.637 | 0.000301 \*\*\* |
| Unemployment | -0.15323 | 0.06894 | 390.71156 | -2.223 | 0.026809 \* |
| Government revenue | -0.70024 | 0.13073 | 178.92966 | -5.356 | 2.58e-07 \*\*\* |
| Universal Health Coverage | -0.90447 | 0.67463 | 5.93184 | -1.341 | 0.229081 |
| Health expenditure | -0.68795 | 1.13230 | 4.60674 | -0.608 | 0.572164 |
| Hypertension | -0.86618 | 0.61460 | 4.86707 | -1.409 | 0.219311 |
| Diabetes | -0.42135 | 0.33019 | 4.69931 | -1.276 | 0.261350 |
| Obesity | -1.19581 | 0.45274 | 6.01290 | -2.641 | 0.038398 \* |
| Total number of nursing personnel | -0.20212 | 0.05756 | 1407.67658 | -3.511 | 0.000460 \*\*\* |
| Total number of medical doctors | -0.11493 | 0.02506 | 1058.60407 | -4.586 | 5.06e-06 \*\*\* |
| Population age over 65 years | -0.70517 | 0.24636 | 34.64168 | -2.862 | 0.007087 \*\* |
| PM2.5 | -0.15794 | 0.54176 | 5.16552 | -0.292 | 0.781990 |
| Healthcare Access and Quality (HAQ) | 1.39054 | 1.02018 | 5.30552 | 1.363 | 0.227872 |
| Stringency index  | 0.12385 | 0.01224 | 1592.79457 | 10.122 | < 2e-16 \*\*\* |
| Fully vaccinated per 1000 with three weeks lag | 0.14291 | 0.01871 | 1594.98865 | 7.637 | 3.81e-14 \*\*\* |
| COVID incidence with three weeks lag | 0.8556 | 0.33159 | 1591.89046 | 2.580 | 0.009961 \*\* |
| Fully vaccinated per 1000 with three weeks lag: COVID incidence with three weeks lag | -0.53024 | 0.19591 | 1592.33660 | -2.707 | 0.006870 \*\* |
| Stringency index: Fully vaccinated lag3 | -0.11531 | 0.03866 | 1584.56922 | -2.983 | 0.002901 \*\* |
| Stringency index: COVID incidence lag3 | -0.7802 | 0.39877 | 1591.75937 | -1.957 | 0.050580 . |

Note: 0 \, '\*\*\*' \, 0.001: The variable is highly significant at the 0.001 level.

0.001 \, '\*\*' \, 0.01: The variable is very significant at the 0.01 level.

0.01 \, '\*' \, 0.05: The variable is significant at the 0.05 level.

0.05 \, '.' \, 0.1: The variable is marginally significant at the 0.1 level.

*Table S 4 Results of GLMM for Cluster I*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| variable |  Estimate  | Std. Error  | df  | t value | Pr(>|t|)  |
| (Intercept) | -1.2530 | 0.5875 | 0.0020 | -2.1330 | 0.9907 |
| Hospital beds per thousand | 1.8280 | 0.6049 | 0.0011 | 3.0230 | 0.9942 |
| Gini index  | 2.0370 | 0.6874 | 0.0025 | 2.9630 | 0.9882 |
| Government effectiveness  | -0.3424 | 0.1615 | 368.0000 | -2.1200 | 0.03470 \*  |
| Unemployment  | 0.1716 | 0.0738 | 367.9000 | 2.3260 | 0.02059 \*  |
| Government revenue | -2.2340 | 0.7923 | 367.8000 | -2.8200 | 0.00507 \*\*  |
| Health expenditure | -0.0113 | 0.1949 | 0.0002 | -0.0580 | 0.9996 |
| Population age over 65 years | 1.9330 | 0.6363 | 367.8000 | 3.0380 | 0.00255 \*\*  |
| Stringency index | 0.0430 | 0.0196 | 368.0000 | 2.1960 | 0.02874 \*  |
| Fully vaccinated per 1000 with three weeks lag | 0.0303 | 0.0637 | 368.0000 | 0.4760 | 0.6347 |
| COVID incidence with three weeks lag | 8.2250 | 0.8942 | 368.0000 | 9.1990 | < 2e-16 \*\*\* |
| Fully vaccinated per 1000 with three weeks lag: COVID incidence with three weeks lag | -2.4330 | 0.8960 | 368.0000 | -2.7150 | 0.00693 \*\*  |
| Stringency index: Fully vaccinated lag3 | -0.1129 | 0.1305 | 368.0000 | -0.8650 | 0.3876 |
| Stringency index: COVID incidence lag3 | -6.3790 | 1.1980 | 368.0000 | -5.3240 | 1.77e-07 \*\*\* |

Note: 0 \, '\*\*\*' \, 0.001: The variable is highly significant at the 0.001 level.

0.001 \, '\*\*' \, 0.01: The variable is very significant at the 0.01 level.

0.01 \, '\*' \, 0.05: The variable is significant at the 0.05 level.

0.05 \, '.' \, 0.1: The variable is marginally significant at the 0.1 level.

*Table S 5 Results of GLMM for Cluster II*

**Univariate Logistic Regression**

|  |  |  |  |
| --- | --- | --- | --- |
| input | r\_squared | beta | p\_value |
| Healthcare Access and Quality (HAQ) | 0.44 | -6.25 | 0.024 |
| Hypertension | 0.33 | 6.39 | 0.032 |
| Life expectancy | 0.36 | -6.08 | 0.033 |
| Universal Health Coverage (UHC) | 0.29 | -5.66 | 0.041 |
| Human Development Index (HDI) | 0.25 | -4.48 | 0.044 |
| Gender Inequality Index (GII) | 0.53 | 12.11 | 0.045 |
| Government revenue  | 0.52 | -15.19 | 0.050 |
| Government Effectiveness  | 0.24 | -4.67 | 0.053 |
| Prosperity Index | 0.23 | -4.38 | 0.053 |
| Population age over 65 years | 0.24 | -6.00 | 0.055 |
| Inequality-adjusted Human Development Index (IHDI) | 0.32 | -7.39 | 0.064 |
| Gini index | 0.29 | 6.87 | 0.069 |
| Diabetes | 0.15 | 3.67 | 0.102 |
| Population | 0.34 | 7.47 | 0.121 |
| Median age of population | 0.13 | -4.38 | 0.127 |
| PM2.5 | 0.12 | 4.99 | 0.146 |
| Gross Domestic Products (GDP) | 0.11 | -3.35 | 0.150 |
| Control of corruption | 0.10 | -3.13 | 0.181 |
| Population density | 0.13 | -5.18 | 0.227 |
| Obesity | 0.06 | 2.43 | 0.260 |
| Total number of medical doctors | 0.07 | -3.60 | 0.298 |
| Total number of nursing personnel | 0.05 | -2.62 | 0.369 |
| Unemployment  | 0.03 | 1.55 | 0.403 |
| Hospital beds per thousand | 0.02 | -1.32 | 0.575 |
| Completeness of vital registration | 0.01 | -3.86 | 0.584 |
| Health expenditure | 0.01 | 1.40 | 0.593 |

*Table S 6 Results of univariate analysis*