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Magnitude and determinants of excess total, age-specific and sex-specific all-cause mortality in 24 countries worldwide during 2020 and 2021: results on the impact of the COVID-19 pandemic from the C-MOR project

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ABSTRACT

Introduction To examine the impact of the COVID-19 pandemic on mortality, we estimated excess all-cause mortality in 24 countries for 2020 and 2021, overall and stratified by sex and age.

Methods Total, age-specific and sex-specific weekly all-cause mortality was collected for 2015–2021 and excess mortality for 2020 and 2021 was calculated by comparing weekly 2020 and 2021 age-standardised mortality rates against expected mortality, estimated based on historical data (2015–2019), accounting for seasonality, and long-term and short-term trends. Age-specific weekly excess mortality was similarly calculated using crude mortality rates. The association of country and pandemic-related variables with excess mortality was investigated using simple and multilevel regression models.

Results Excess cumulative mortality for both 2020 and 2021 was found in Austria, Brazil, Belgium, Cyprus, England and Wales, Estonia, France, Georgia, Greece, Israel, Italy, Kazakhstan, Mauritius, Northern Ireland, Norway, Peru, Poland, Slovenia, Spain, Sweden, Ukraine, and the USA. Australia and Denmark experienced excess mortality only in 2021. Mauritius demonstrated a statistically significant decrease in all-cause mortality during both years. Weekly incidence of COVID-19 was significantly positively associated with excess mortality for both years, but the positive association was attenuated in 2021 as percentage of the population fully vaccinated increased. Stringency index of control measures was positively and negatively associated with excess mortality in 2020 and 2021, respectively.

Conclusion This study provides evidence of substantial excess mortality in most countries investigated during the first 2 years of the pandemic and suggests that COVID-19 incidence, stringency of control measures and vaccination rates interacted in determining the magnitude of excess mortality.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ A limited number of studies, focusing on more than one country, have investigated sex-specific and age-specific COVID-19 excess mortality for the whole of 2020 and 2021, and they evidenced substantial excess mortality in the majority of included countries. There is a paucity of studies investigating drivers of excess mortality across countries.

INTRODUCTION

In late 2019, the first cases of SARS-CoV-2 were reported in Wuhan, China. Since then, the causative agent of COVID-19 has

WHAT THIS STUDY ADDS

⇒ Most of the countries studied had excess all-cause mortality, which was particularly higher among men and among people in the older age groups (65+ or 70+). Further, this study indicates that reported COVID-19 incidence, stringency of control measures and vaccination rates interact in determining the magnitude of excess mortality.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The results can serve as evidence of the need to strengthen health resilience in the most affected countries, sex and age groups. They also provide quantification on the effectiveness of public health interventions and control measures used during the COVID-19 pandemic to lessen its impact on mortality.

rapidly spread worldwide, causing dreadful disruptions.[1] COVID-19 vaccines were developed with an incredible speed and the first vaccine was administered outside of a clinical trial setting in England on 8 December 2020.[2 3] However, up to May 2023, more than 3.5 million COVID-19-related deaths have been recorded since the delivery of the first vaccine.[4 5]

The impact of the pandemic on mortality is not fully captured in national published COVID-19 mortality estimates.[6–9] This might be due to a number of reasons including the limited testing capacity which led to undercounting,[10 11] the improper attribution of deaths as COVID-19 deaths instead of deaths from other causes, a delay in the processing of death certificates which created a lag in data,[7 12] and the disruption of the healthcare systems, including disruptions of pathology testing[13] and delays in health-seeking behaviour. The latter was provoked not only by the COVID-19-related anxiety but also by the lack of hospital resources for non-COVID-19 emergencies, since ambulances and intensive care beds had been mostly used for COVID-19 patients, at the expense of other patients, leading consequently to a large healthcare burden, with patients with life-threading diseases (eg, myocardial infarction patients) not being hospitalised.[14]

It is challenging to obtain accurate estimates of the death toll of the pandemic. The misclassification of unrelated deaths as COVID-19 deaths, as well as the undercounting of COVID-19-related mortality due to the limited availability of testing, can result in inaccurate estimation of the true COVID-19-related mortality.[15 16] These methodological challenges in reporting of COVID-19 deaths are also not comparable across countries as different countries use different definitions and processes to count COVID-19 deaths, and these often vary over time.

A reasonable way to overcome the above challenges is to estimate the excess all-cause mortality at country level, by comparing the observed to the expected number of deaths during a specified time period.[17–19] As discussed in Demetriou *et al*,[15] the expected number of deaths can be predicted using historical data and time series analyses accounting for seasonality and other secular trends.

Many studies have investigated COVID-19 excess mortality.[9 20–22] However, most focused on single countries or world regions during the first months of the pandemic. They also used publicly available data that were often provisional at the time of analysis. The frequency of updates also influenced the consistency of data.[7 15 20] The one study that estimated excess mortality due to the COVID-19 pandemic for both the whole years 2020 and 2021 in 191 countries and territories could not provide estimations by sex and age group.[22] However, several studies incorporating data from more than one country have investigated sex-specific and age-specific excess mortality for the whole of 2020 and 2021, and they evidenced substantial excess mortality in the majority of included countries.[15 23 24] Understanding the impact of stringency of control measures and of vaccination on the toll of the pandemic at a global level is imperative given the variability of governmental responses and differences in vaccination access and uptake across populations. One study quantified the global impact of the first COVID-19 vaccinations and determined that the death toll was underestimated or overestimated in many countries, compromising the estimates of vaccine effectiveness.[3]

An international consortium, the COVID-19 MORtality (C-MOR) Consortium, consisting of more than 50 countries across 6 continents was established to investigate the mortality impact of the COVID-19 pandemic.[15 16] The consortium encompasses countries worldwide without restriction and focuses all analyses on data from national primary sources. The current analysis estimates overall, sex-specific and age-specific excess all-cause mortality in the 24 countries where age–stratified and sex-stratified data were available, and investigates correlates of overall excess all-cause mortality during the whole of 2020 and 2021.

METHODS

Data acquisition

In this study, we examined the mortality data from 24 countries or regions participating in the international consortium that have collected and provided data.[25] The participating countries or regions include Australia, Austria, Brazil, Belgium, Cyprus, Denmark, England and Wales, Estonia, France, Georgia, Greece, Israel, Italy, Kazakhstan, Mauritius, Northern Ireland, Norway, Peru, Poland, Slovenia, Spain, Sweden, Ukraine, and the USA. Total, sex-specific and age-specific weekly all-cause mortality for 2015–2021 was collected from national vital statistics databases, made either publicly available or with restricted access (online supplemental table S1).[25] Depending on the country, all-cause mortality was reported by either ISO week, starting on Monday; Epi week, starting on Sunday or other national counting week system.

Data were assembled between June and September 2022, that is, several months after the end of the study period, to allow for reporting delays[7 14] and enough time for data consolidation by reporting authorities to improve data quality.[26]

Statistical analysis

Mortality rates

For the calculation of mortality rates, total, age-specific and sex-specific mid-year population estimates for the participating countries were obtained from the World Bank,[27] except for the UK nations for which population data from the Office for National Statistics[28] was extracted separately for England and Wales, Scotland and the Northern Ireland, and for Cyprus for which Eurostat data[29] was used to include only the population in the Republic of Cyprus government-controlled area.

Crude mortality rates (CMRs) were calculated for the total population and sex-specific groups using equation (1)

$$CMR_{y,w} = \frac{D_{y,w}}{P_y/N} \quad (1)$$

where $D_{y,w}$ denotes the number of deaths in all age groups in year y and week w, P_y denotes the mid-year population for year y and N denotes the number of weeks in the year.

Age-specific mortality rates (ASpMRs) were calculated using equation (2)

$$ASpMR_{y,w,i} = \frac{D_{y,w,i}}{P_{y,i}/N} \quad (2)$$

where $D_{y,w,i}$ denotes the number of deaths in the age group $\boldsymbol{i}$ in year $y$and week w, $P_{y,i}$ denotes the mid-year population of age group $\boldsymbol{i}$ in year y, and N denotes the number of weeks in the year.

Weekly (directly) age-standardised mortality rates (ASMRs) were calculated as a weighted average of the ASMRs using the equation 3 as previously described,[15] where, index $\boldsymbol{i}$ denotes the aggregate age groups (see online supplemental table S2) and the standard population weights p_i^s correspond to the proportion of population in the i^{th} age interval in the WHO World Standard Population 2000–2025.[30]

$$ASMR = \sum_{i=1}^{n} \left(p_i^s ASpMR_{y,w,i} \right) \quad (3)$$

The aggregate age groups created for each country, based on the provided age-specific all-cause mortality data, are presented in online supplemental table S2, followed by the equations used for the age standardisation.

Excess mortality

Total, and sex-specific, weekly excess mortality for 2020 and 2021 was calculated by comparing weekly 2020 and 2021 ASMR (per 100 000 population) against a baseline mortality (expected weekly ASMR in 2020 and 2021, respectively), estimated based on historical data (2015–2019) accounting for seasonality, and long-term and short-term trends, as previously described.[15 31–33] The regression model is specified in online supplemental material. Similarly, age-specific weekly excess mortality for 2020 and 2021 was calculated by comparing weekly 2020 and 2021 CMR (per 100 000 population) against a baseline mortality (expected weekly CMR in 2020 and 2021, respectively), estimated based on historical data (2015–2019).

The regression models were built on complete weeks and truncated weeks were excluded. Truncated weeks are usually a result of the different death counts observed around Christmas and New Year,[34] and these included week 53 (applicable for Australia, Austria, Brazil, Belgium, Cyprus, Denmark, Estonia, France, Georgia, Greece, Israel, Italy, Norway, Peru, Poland, Spain, Sweden, Ukraine and the USA), weeks 1 and 52 for England and Wales, weeks 1 and 53 for Kazakhstan and Mauritius, weeks 51 and 52 for Northern Ireland, and weeks 52 and 53 for Slovenia. For all countries, observed and expected weekly mortality rates for 2020 and 2021 were each summed up to week 52, except for England and Wales (weeks 2–51), Kazakhstan and Mauritius (weeks 2–52), Northern Ireland (up to week 50) and Slovenia (up to week 51). Sex-specific excess mortality for 2020 and 2021 could not be calculated for Northern Ireland due to the lack of sex-specific all-cause mortality data, and thus Northern Ireland was not included in this analysis. Also, sex-specific weekly all-cause mortality for Peru was collected from 2017 to 2021.

The weekly results of the observed versus expected mortality rates are presented graphically using z-scores [(number of observed deaths–expected mortality)/SD of the residuals]. Z-scores ranging from −2 and +2 are considered 'normal', while a z-score >4 is considered a substantial increase.[35 36]

Subsequently, the cumulative expected 2020 and 2021 mortality rates were subtracted from the respective cumulative observed 2020 and 2021 mortality rates to obtain estimates of excess mortality separately for the years 2020 and 2021. The statistical significance of the excess mortality rate was determined using the 95% confidence intervals (CIs) estimated by the model.

P-score, defined as the ratio of the cumulative excess to the cumulative expected mortality, expressed as a percentage, was calculated for both years 2020 and 2021, for the total, male and female population, as well as for the age groups <65, 65+, <70 and 70+.

Ecological analysis of correlates of excess mortality

In an attempt to identify correlates of excess mortality in the participating countries (ecological analysis), a database of twenty country-level sociodemographic variables (reported yearly) and three pandemic-related variables (reported weekly), was built using publicly available sources as outlined in online supplemental table S3. The variables collected were variables previously investigated in association with excess mortality during the COVID-19 pandemic in published research[37] and included: (1) population-related variables (population density, population median age, percentage of population aged 65+ years, life expectancy, hypertension, diabetes and obesity prevalence, and air pollution (PM2.5 concentration)); (2) government and economy-related variables (gross domestic products (GDP), Human development index (HDI), Inequality-adjusted HDI (IHDI), Gini index, Government Effectiveness index and government revenue); (3) health resource variables (hospital beds per thousand population, total medical doctors and total nursing personnel (per 10 000 population), universal health coverage (UHC), completeness of vital registration system and Healthcare Access and Quality Index (HAQ)) and (4) pandemic-related variables (weekly incidence of COVID-19 per 1000 population, stringency index of government control measures (with a 3-week lag) and percentage of people fully vaccinated (with a 3-week lag)). Mauritius was excluded from this analysis due to the lack of recent data from reliable sources.

Initially, the association between each of these variables and excess mortality z-score was examined across countries, for 2020 and 2021 combined, using a linear regression model. A strong association was observed between completeness of vital registration systems and excess mortality ($\beta=-0.42$, $p<0.001$) suggesting that level of completeness may be biasing the excess mortality results. Therefore, countries with a completeness of <90%, namely Kazakhstan and Peru, were excluded from this and subsequent analyses. Then, three multivariable models were built using (1) population variables, (2) economic and government-related variables and (3) healthcare resource variables, as indicated in online supplemental table S3. Multicollinearity was examined within each class of variables, and among the collinear variables the ones that returned the best model fit were retained. The retained variables for each model, all with a variance inflation factor of less than 10, were rescaled to a mean of 0 and an SD of 1.

Following, the pandemic-related variables were examined using multilevel models, with country as a random effect, the pandemic-related variables as fixed effects, and with the method of restricted (residual) maximum likelihood. Two separate multilevel models were run, one for 2020 (excluding vaccination) and one for 2021. Interactions between the pandemic-related variables were also examined for each year. In all models above, weeks with z-scores larger than 15 were excluded as outliers, based on bag plots, and the normality of the z-scores outcome variable was examined (online supplemental figures S1–S3).

Lastly, the associations between stringency of control measures (3-week lag) during 2020–2021 and percentage of population fully vaccinated (3-week lag) during 2021 with excess mortality z-scores were investigated in regression models with time-varying exposure against excess mortality, adjusting for weekly COVID-19 incidence. A separate model was run for each country and the time-varying coefficients were illustratively compared with the static regression model coefficients. All analyses were performed using R Statistical Software, V.4.2.2 (The R Foundation for Statistical Computing, Vienna, Austria).

Patient and public involvement

Patients or the public were not involved in the design, or conduct, or reporting, or dissemination plans of our research.

RESULTS

Weekly comparisons-total population and by sex in 2020 and 2021

In 2020, 18 countries showed a substantial increase in the ASMR ranging from 1 to 29 weeks, while in 2021, 17 countries showed a substantial increase in the ASMR ranging from 1 to 37 weeks. Figure 1 shows the weekly ASMR z-score over time from week 1 2020 to week 52 2021. The countries that showed a substantial increase (>4 z-scores) in the ASMR over time from week 1 2020 to week 52 2020 for the total population include Peru (29 weeks), the USA (26 weeks), Brazil (25 weeks), Belgium and Italy (14 weeks), Sweden (13 weeks), Poland (12 weeks), France and Spain (11 weeks), Slovenia (9 weeks), Georgia, England and Wales and Kazakhstan (8 weeks), Austria (7 weeks), Israel (6 weeks), Greece (4 weeks), Northern Ireland (2 weeks) and Cyprus (1 week). In 2021, the countries that showed a substantial increase in the ASMR over time from week 1 2021 to week 52 2021 for the total population include Kazakhstan (37 weeks), Brazil (32 weeks), Peru and the USA (28 weeks), Poland and Georgia (23 weeks), Greece (14 weeks), Israel (10 weeks), Slovenia (7 weeks), Estonia (6 weeks), England and Wales (5 weeks), Austria (4 weeks), Norway and Sweden (3 weeks), Cyprus and Spain (2 weeks) and Belgium and Northern Ireland (1 week). In contrast, Australia, Denmark, Mauritius and Ukraine did not display substantial excess mortality for any week during either year. Norway and Estonia did not show substantial excess mortality for any week during 2020, and we did not find any substantial excess mortality for any week during 2021 for France and Italy.

Sex-specific weekly ASMR z-scores over 2020 and 2021 are shown for each country in figure 2 for males and females, respectively. The countries that showed a substantial increase (>4 z-scores) in the ASMR over 2020 for the male population include Austria, Belgium, Brazil, Cyprus, England and Wales, France, Georgia, Greece, Israel, Italy, Kazakhstan, Peru, Poland, Slovenia, Spain, Sweden, and the USA. The excess mortality duration between countries in 2020 varied between 1 and 33 weeks for 2020. The same countries, besides Cyprus, showed a substantial increase in the ASMR over 2021 for the male population, with the addition of Norway and Estonia. The excess mortality duration between countries varied between 1 and 39 weeks in 2021 for 2021. Australia, Denmark, Mauritius and Ukraine did not display substantial excess mortality in males for any week during the years 2020 and 2021. Norway and Estonia did not display substantial excess mortality in males for any week during 2020, while Cyprus did not display substantial excess mortality for any week during 2021.

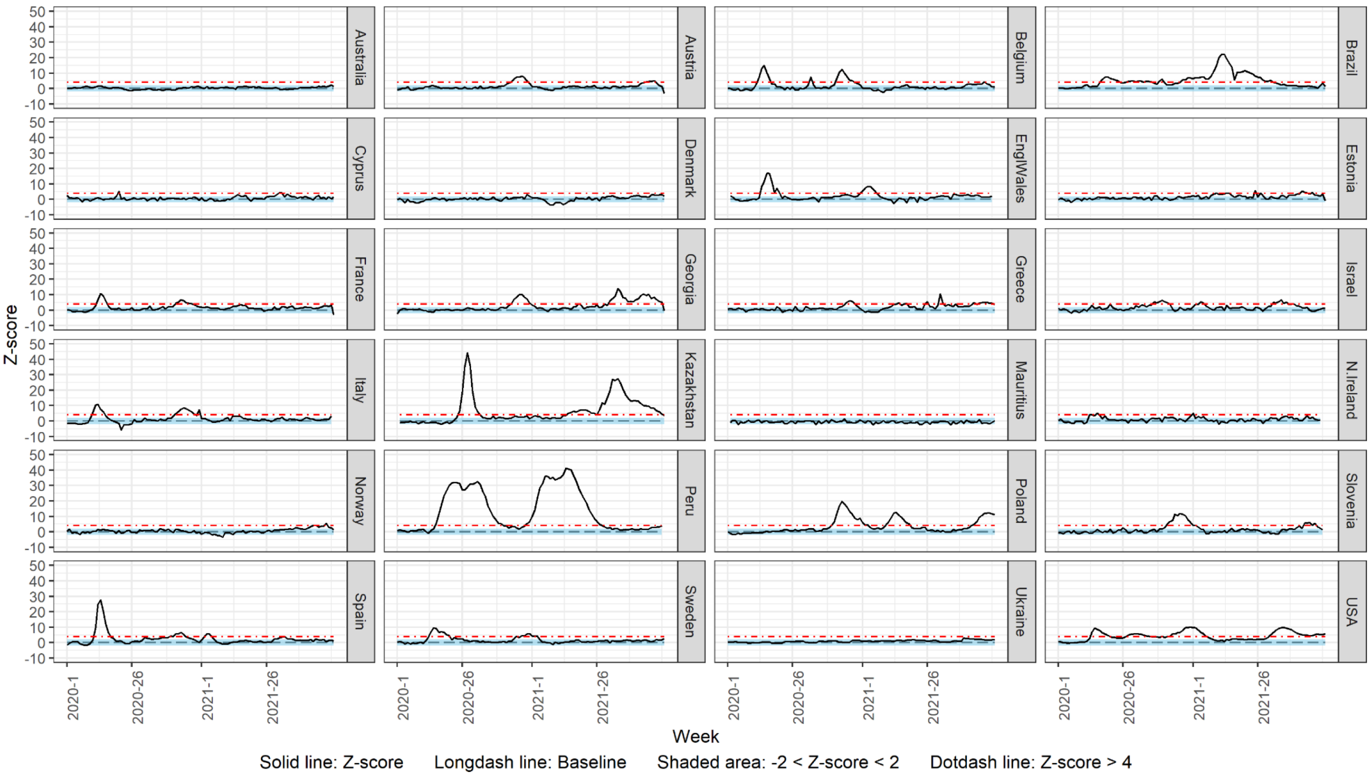

Figure 1 Weekly z-score of age-standardised all-cause mortality rate for total population for 2020 and 2021.

In 2020, the countries that showed a substantial increase in the ASMR over time for the female population included Austria, Belgium, Brazil, England and Wales, France, Georgia, Greece, Israel, Italy, Kazakhstan, Peru, Poland, Slovenia, Spain, Sweden, and the USA. The excess mortality duration between countries varied between 2 and 24 weeks for 2020. The same countries, besides Belgium, France, Italy and Sweden, showed a substantial increase in the ASMR over time during 2021 for the female population as well, with the addition of

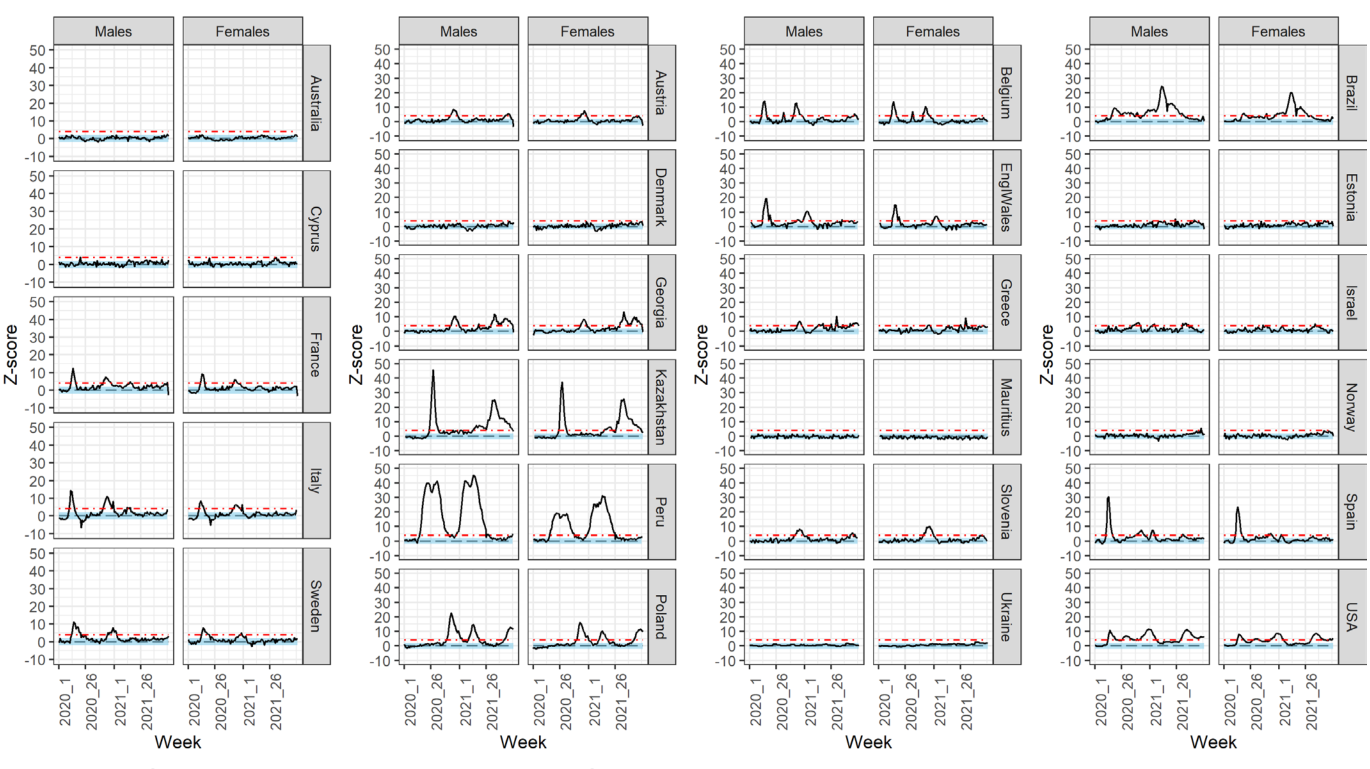

Figure 2 Weekly z-score of age-standardised all-cause mortality rate by sex for 2020 and 2021.

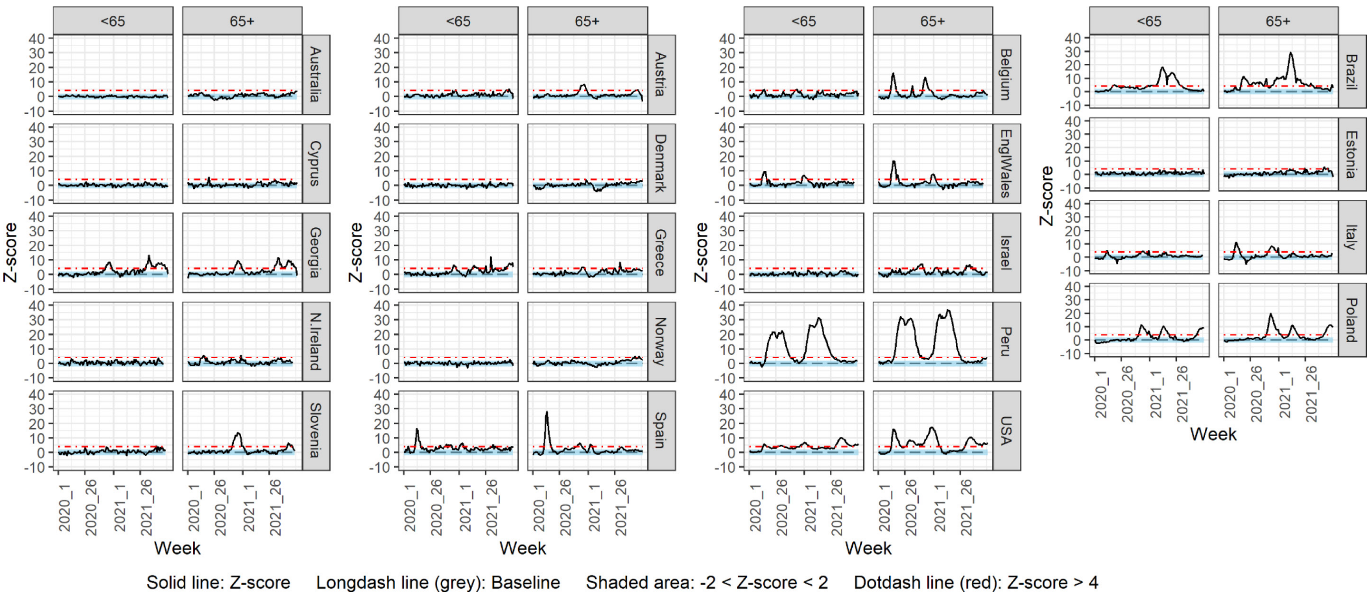

Figure 3 Weekly z-score of all-cause mortality rate for age groups <65 and 65+ for 2020 and 2021.

Estonia. The excess mortality duration between countries varied between 1 and 32 weeks for 2021. Australia, Cyprus, Denmark, Mauritius, Norway and Ukraine did not display substantial excess mortality in females for any week during both years 2020 and 2021. Estonia did not display substantial excess mortality in females for any week during 2020, while Belgium, France, Italy and Sweden did not display substantial excess mortality for any week during 2021.

Weekly comparisons by age group for total population in 2020 and 2021

Figures 3 and 4 show the weekly mortality rate z-score over time in 2020 and 2021 for ages <65, 65+, <70 and 70+ years for the total population. The countries that showed a substantial increase in the weekly mortality rate over 2020 for the younger age group investigated include Austria, Belgium, Brazil, England and Wales, Georgia, Greece, Italy, Peru, Poland, Spain, and the USA (age group <65), and France, Georgia, Italy, Kazakhstan, Peru, Poland, and Sweden (age group <70). In 2021, apart from France and Sweden, these countries also showed a substantial increase in the weekly mortality rate for the younger age groups, with the addition of Slovenia.

Cumulative excess mortality in 2020 and 2021

Figure 5 shows the comparison of the cumulative excess all-cause mortality for 2020 and 2021. Online supplemental tables S4 and S5 show the cumulative observed and expected all-cause ASMRs for each year, 2020 and 2021, respectively. Online supplemental table S6 shows

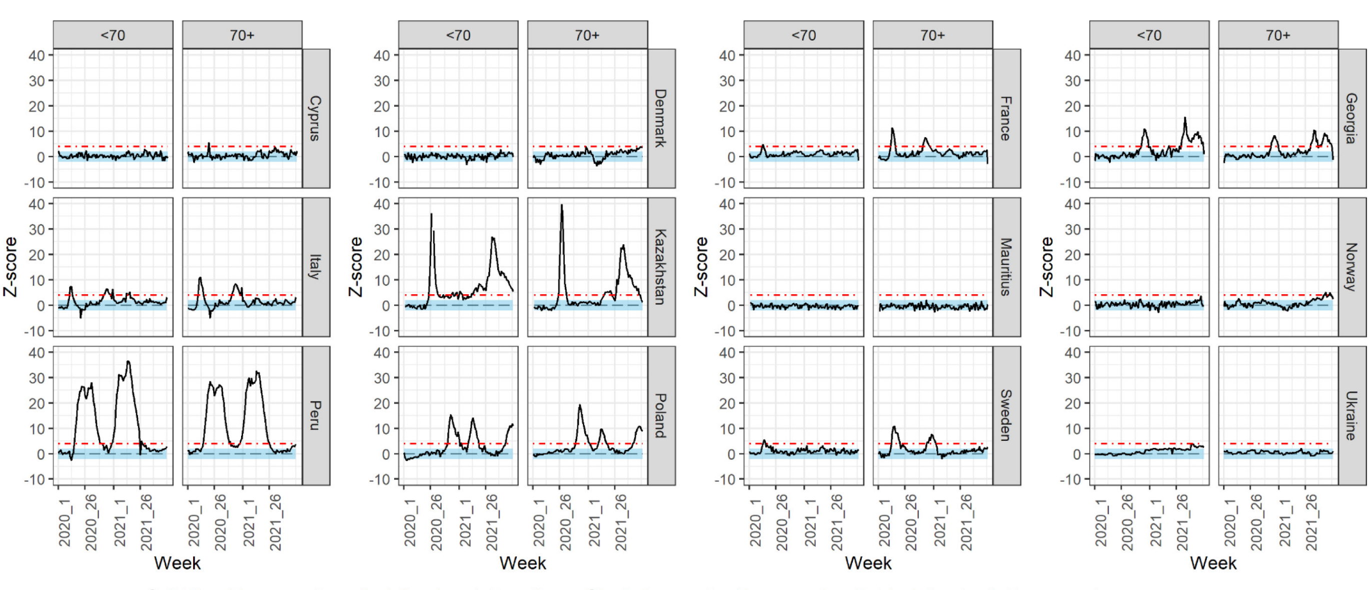

Figure 4 Weekly z-score of all-cause mortality rate for age groups <70 and 70+ for 2020 and 2021.

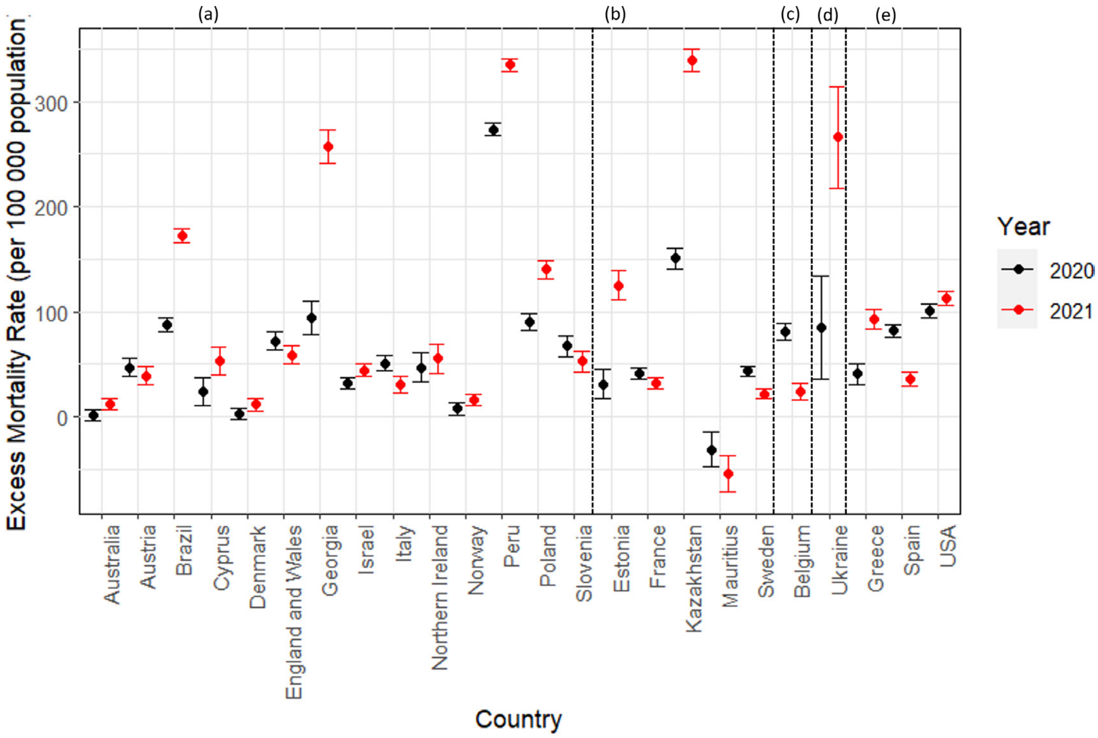

Figure 5 Cumulative excess age-standardised mortality rate for total population for 2020 and 2021. Plot letters correspond to the age groups in which countries have provided data, and therefore, the age groups used for age standardisation: (A) age groups <15, 15–44, 45–64, 65+; (B) age groups <20, 20–49, 50–69, 70+; (C) age groups <45, 45–64, 65+; (D) age groups <20, 20–69, 70+; (E) age groups <15, 15–64, 65+.

the cumulative observed and expected all-cause ASMRs for both 2020 and 2021 together.

All participating countries, with the exception of Australia, Denmark and Mauritius, presented statistically significant excess cumulative mortality rates during 2020. On the other hand, Mauritius revealed a statistically significant decrease in yearly all-cause mortality rate, while Australia and Denmark showed no statistically significant differences in all-cause mortality rate in 2020. During 2021, all countries included in this analysis, except for Mauritius, reported statistically significant excess cumulative mortality rates. Mauritius demonstrated a statistically significant decrease in yearly all-cause mortality rate during both years 2020 and 2021.

Online supplemental tables S7 and S8 report the yearly cumulative mortality rate differences (observed - expected) by sex for 2020 and 2021, respectively. For the male population, all countries demonstrated statistically significant excess cumulative mortality rates during 2020 and 2021, except for Australia in 2020, Denmark in 2020, and Mauritius in both years. For the female population, with the exception of Australia, Denmark, Norway and Ukraine, all countries demonstrated statistically significant excess cumulative mortality rates during 2020. In 2021, excess all-cause mortality was observed in all countries except Belgium and Mauritius.

Figure 6 and online supplemental table S9 show the male to female cumulative excess ASMR ratios for 2020 and 2021. Females were more affected than males in Mauritius only in 2020, and in Australia, Denmark, Mauritius and Ukraine in 2021. Cumulative excess all-cause mortality for males and females during 2020 and 2021 are shown in online supplemental figures S4 and S5.

Online supplemental tables S10 and S11 demonstrate the cumulative CMR differences (observed - expected) by age group for the years 2020 and 2021, respectively. Age-specific differences in all-cause mortality for the whole years 2020 and 2021 were observed in the majority of the countries included in the present study. However, the differences were higher in the older age groups; 65+ and 70+ than those in the younger age groups for both years. During 2020, only Australia observed no statistically significant differences in all-cause mortality for any of the age groups, and Denmark demonstrated statistically significant cumulative CMR difference only in the 70+ age group. Norway and Israel demonstrated statistically significant increase in the cumulative CMR difference in the older groups only. Mauritius demonstrated statistically significant decrease in the cumulative CMR difference in the <70 age group, and significant increase in the 70+ age group.

During 2021, all the countries observed statistically significant increases in cumulative CMR difference in the 65+ age group. In the <65 age group, all countries showed statistically significant increase in cumulative CMR difference, except for Australia, Denmark and Norway. Also, in the 70+age group, all countries observed statistically significant increases in cumulative CMR difference, except for Mauritius that showed a statistically significant

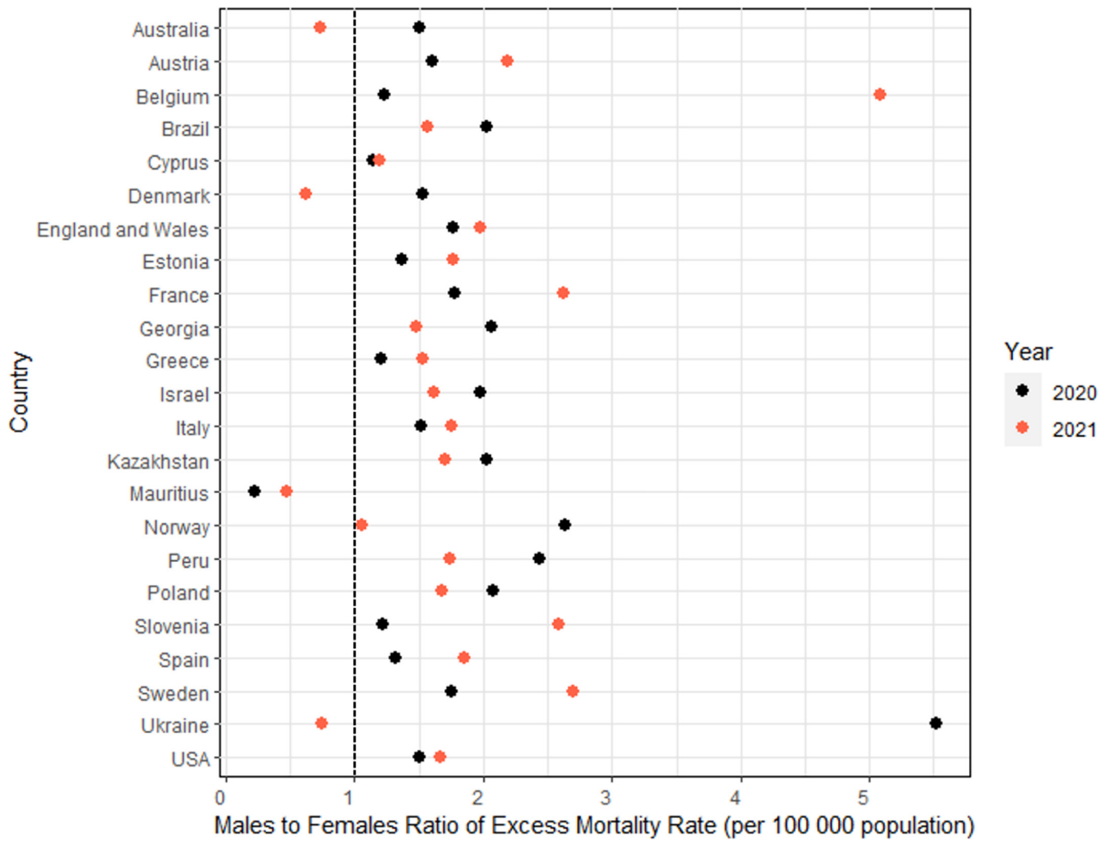

Figure 6 Males to females cumulative excess age-standardised mortality rate ratio for 2020 and 2021.

decrease. In the <70 age group, the following countries observed statistically significant increases in cumulative CMR difference: Cyprus, France, Georgia, Italy, Kazakhstan, Norway, Peru, Sweden and Ukraine. Mauritius and Poland demonstrated statistically significant decrease in the cumulative CMR difference in the <70 age group.

Ecological analysis of correlates of excess mortality

The univariable regression results for each of the 20 investigated variables are included in table 1 and the distribution of these variables across countries is shown in online supplemental table S12. In the multivariable model of population-related variables, median population age and life expectancy were removed due to collinearity. Of the remaining variables, hypertension prevalence (β=0.54, p<0.001), diabetes prevalence (β=0.43, p<0.001) and obesity prevalence (β=0.35, p<0.001) were positively associated with excess mortality (table 1). In the multivariable model of government and economy-related variable, GDP, IHDI and government effectiveness were removed due to collinearity between them and the retained HDI. Of the retained variables, HDI (β=−0.28, p<0.001) was negatively associated with excess mortality, whereas, GINI index (β=0.66, p<0.001) was positively associated. Lastly, of the healthcare resource-related variables, UHC was removed due to collinearity with HAQ. Of the included variables hospital beds per 1000 population (β=−0.26, p<0.001) and HAQ (β=−0.67, p<0.001) were both negatively associated with excess mortality, whereas completeness of vital registration systems (β=0.13, p=0.023) was significantly positively associated with excess mortality. Total medical and nursing personnel were not significantly associated with excess mortality (table 1).

Across all models, 1 SD increase in Gini, diabetes and hypertension prevalence produced the strongest positive effect estimates, whereas HAQ and HDI had the strongest negative effect estimates. Nevertheless, the R^2 values of the predictive models were low (0.101, 0.106 and 0.089, respectively) suggesting the influence of additional predictors.

In the year-specific models built for examining the influence of pandemic-related variables, the random effect of country introduced variation in the model, with an intraclass correlation coefficients of 0.24 for 2020 and 0.38 for 2021 (table 2). In the mixed model including 2020 weeks only, weekly incidence of reported COVID-19 cases (β=0.75, p<0.001) and stringency of control measures (β=0.312, p<0.001) were positively associated with excess mortality z-scores, given a zero (average) value for the other variable. For higher values of stringency of control measures, the influence of the weekly incidence of reported COVID-19 cases on excess mortality was decreased, but this was of borderline significance ($\beta_{interaction}$=-0.18, p=0.050).

In the model including 2021 weeks only, weekly incidence of reported COVID-19 cases (β=0.59, p<0.001) was again positively associated with excess mortality, whereas

Table 1 Country-level sociodemographic determinants of excess mortality*

		Unadjusted model on scaled data		Adjusted model on scaled data—population-related variables†		Adjusted model on scaled data—government and economy-related variables‡		Adjusted model on scaled data—health resources-related variables§	
				R^2=0.101		R^2=0.106		R^2=0.089	
		Regression coefficient	P value	Regression coefficient	P value	Regression coefficient	P value	Regression coefficient	P value
Population variables	Population density	−0.11	0.0565	0.07	0.414				
	Median age	−0.34	<0.001						
	Percentage of population more than 65 years old	−0.46	<0.001	−0.07	0.280				
	Life expectancy	−0.52	<0.001						
	Hypertension	0.42	<0.001	0.54	**<0.001**				
	Diabetes	0.62	<0.001	0.43	**<0.001**				
	Obesity	0.38	<0.001	0.35	**<0.001**				
	PM2.5 (air pollution)	0.32	<0.001	0.07	0.433				
Government and economy	Gross domestic products (GDP)	−0.33	<0.001						
	Human Development Index (HDI)	−0.53	<0.001			−0.28	**<0.001**		
	Inequality-adjusted Human Development Index (IHDI)	−0.71	<0.001						
	Gini index	0.79	<0.001			0.66	**<0.001**		
	Government Effectiveness	−0.55	<0.001						
	Government revenue	−0.58	<0.001			−0.06	0.439		
Health resources	Hospital beds per thousand population	−0.20	0.008					−0.26	**<0.001**
	Total medical doctors (per 10 000 population)	−0.04	0.511					−0.03	0.606
	Total nursing personnel (per 10 000 population)	−0.37	<0.001					0.04	0.541
	Universal health coverage	−0.48	<0.001						
	Completeness of vital registration	0.02	0.75					0.13	**0.023**
	Healthcare Access and Quality Index (HAQ)	−0.62	<0.001					−0.67	**<0.001**

Bold fonts indicate statistically significant p-values, at an alpha level of 0.05.
*Kazakhstan and Peru were excluded from this analysis due to a completeness of vital registration systems of <90% which affects excess mortality estimates.
†Life expectancy removed from model due to collinearity (r≥0.60) with hypertension and median age due to collinearity (r≥0.94) with proportion of population 65+.
‡GDP, IHDI and government effectiveness were removed from model due to collinearity (r≥0.90) between them and with HDI.
§Universal health coverage removed from model due to collinearity (r≥0.80) with HAQ.

Table 2 Multilevel model results on the ability of pandemic-related variables to predict excess mortality (z-scores) during 2020 and 2021

	2020*			2021*		
Predictors	**Estimates**	**95% CI**	**P value**	**Estimates**	**95% CI**	**P value**
(Intercept)	1.90	1.32 to 2.49	<0.001	1.94	1.26 to 2.62	<0.001
Weekly incidence of COVID-19 (3-week lag)	0.75	0.54 to 0.96	<0.001	0.59	0.40 to 0.78	<0.001
Stringency of control measures (3-week lag)	0.31	0.15 to 0.47	<0.001	−0.39	−0.61 to −0.17	<0.001
Weekly incidence of COVID-19×stringency of control measures (interaction)	−0.18	−0.35 to 0.00	0.050			
No of fully vaccinated per 100 population (3-week lag)				0.08	−0.13 to 0.29	0.449
Weekly incidence of COVID-19×No of fully vaccinated per 100 population (interaction)				−0.21	−0.32 to −0.10	<0.001
Random effects	**2020**			**2021**		
σ^2	5.41			3.90		
ICC	0.24			0.38		
$N_{\text{data\$location}}$	21			21		
Observations	910			1074		
Marginal R^2/conditional R^2	0.083 / 0.305			0.070 / 0.428		

*For each year, the model included all listed but not shaded variables. Kazakhstan and Peru were excluded from this analysis due to a completeness of vital registration systems of <90% which affects excess mortality estimates.
ICC, intraclass correlation coefficient.

stringency of control measures (β=−0.39, p<0.001) was inversely associated, given zero (average) values for all other variables in the model (table 2). The number of people fully vaccinated per 100 population was not independently associated with excess mortality (β=0.08, p=0.449), however, it interacted significantly with weekly incidence of reported COVID-19 cases so that a 1 SD increase in vaccination rates attenuated the positive relationship between weekly incidence of reported COVID-19 cases and excess mortality from 0.59 to 0.38 ($\beta_{interaction}$=-0.210, p<0.001).

Lastly, the results of the time-varying models for stringency of control measures and the effect of vaccination on the excess mortality in each country are presented and described in online supplemental figures S6–S26. Overall, the results indicate that in each country a different pattern of associations was observed with substantial fluctuations in the coefficients across the time period of investigation for both variables.

DISCUSSION

Summary of findings

The present study estimated total, sex-specific and age-specific excess all-cause mortality in 24 countries during the years 2020 and 2021. The majority of investigated countries showed significant excess mortality during at least 1 week of 2020 and 1 week of 2021, with varying duration. Australia, Denmark, Mauritius and Ukraine did not display excess mortality for any week during both years 2020 and 2021, while Norway did not display excess mortality during 2020, and France and Italy during 2021. Moreover, excess mortality was higher for people aged 65+ years and 70+ years than in younger age groups (<65 and <70) in most countries.

Excess of cumulative ASMRs was reported in all countries analysed in 2020 and/or 2021, except for Australia and Mauritius. Denmark showed no statistically significant differences in all-cause mortality rate in 2020 and Mauritius demonstrated a statistically significant decrease in yearly all-cause mortality rate during both years. The highest estimated excess mortality rate for 2020 was 273 deaths per 100 000 population in Peru, while the highest estimated excess mortality rate for 2021 was 338.7 deaths per 100 000 population in Kazakhstan. These findings are in accordance with those reported elsewhere, regardless of the use of different methodologies and data sources.[22 24 38 39] More specifically, Nepomuceno *et al*, using a combination of different methodologies, demonstrated that Italy, the USA, Slovenia and countries of the UK were the most heavily affected in terms of ASMRs.[40] Additionally, Karlinsky and Kobak estimated excess deaths by using data from the World Mortality Dataset until the end of 2020 or the first half of 2021, and showed that Peru, Brazil, the USA, Italy and countries of the UK were the most affected.[41] COVID-19 Excess Mortality Collaborators (2022) have also identified Italy, Greece, Norway, Spain, Sweden and the USA as having a high excess of all-cause deaths.[22]

The cumulative excess for all-cause mortality for the total population in 2020 was higher than in 2021 in

Austria, Belgium, England and Wales, France, Italy, Mauritius, Slovenia, and Spain. This may be due to the COVID-19 vaccination programmes that have been shown to reduce at least COVID-19-related mortality,[3 42] or due to the time of different waves as in the case of Belgium where a second wave arrived in late 2020 rather than early 2021.[43] The same scenario applies to both female and male populations, with the exception of Slovenia where for females the cumulative excess for all-cause mortality was higher in 2021 than in 2020. These results align with other published results. The Our World in Data also shows that in France, Belgium, Italy and Spain, excess mortality in 2020 was higher than in 2021.[44]

In the yearly cumulative comparison, increases or decreases in all-cause mortality were similar between sexes in both years except for Mauritius (statistically significant decrease only in females in 2020), Norway (statistically significant increase only in males in 2020), Ukraine (statistically significant increase only in males in 2020) and Belgium (statistically significant increase only in males in 2021). Moreover, males were more affected than females in terms of cumulative excess ASMR, with the exception of Australia and Mauritius in 2020, and Australia, Denmark, Mauritius and Ukraine in 2021. Many studies have previously reported the male predominance in excess mortality in most countries.[15 24 45–47] This may be due to a number of factors, such as occupation and lifestyle factors, or differences in comorbidities between males and females that may rise the possibility of SARS-CoV-2 exposure among males than females.[24]

The observed pattern of weekly excess mortality in the countries included in the current study demonstrates that some countries experienced substantial excess mortality during the first half of the year but not later, for both 2020 and 2021 (Kazakhstan, Peru, Spain in 2020, Brazil in 2021), while other countries did so during the second half of the year but not earlier (Austria, Georgia, Greece, Israel in 2020 and 2021). Similar peaks in excess mortality for the participating countries were reported elsewhere.[22 24 41 44]

Of the country-level sociodemographic variables investigated, hypertension, diabetes and obesity prevalence, as well as Gini index were positively associated with increased excess mortality, whereas HDI, hospital beds per 1000 population and HAQ were inversely associated with excess mortality as also shown elsewhere.[22 48–54] Interestingly, completeness of vital registration and excess mortality were significantly positively associated when the multivariable model was restricted to countries with higher than 90% of completeness. Below that completeness level, multiple factors unique to under resourced health system settings are likely to influence the death rate, and deaths recording, and as a result the observed relationship with excess deaths is likely underestimated and biased. Therefore, interpretation of results from countries with less than 90% of completeness in their vital registrations should be treated with caution, as the observed mortality rates may underestimate the true excess mortality.

In the multilevel models investigating pandemic-related variables, the random effect of country explains a substantial proportion of the variability in the outcome, highlighting that different countries had a different experience with respect to the determinants of excess mortality. It is also important to highlight that in these models, the coefficients returned are an average of the experience of the included countries. Weekly reported incidence of COVID-19 significantly increased excess mortality during both years. Seroprevalence was also shown to be associated with excess mortality elsewhere.[22] During 2020, contrary to expectations,[16] the stringency of control measures was positively associated with excess mortality, whereas, during 2021, those countries that retained strict control measures experienced less excess mortality. In the time-varying models that investigated the effects of stringency on excess mortality, across 2020–2021, in each country independently, substantial fluctuations are evident in the observed coefficients suggesting that it might not be the overall stringency of measures, but specific policies that had a greater benefit in mitigating excess mortality in each country. Nevertheless, for most countries, despite the fluctuations, the coefficients were in the negative range for most of the duration of the 2 years indicating an overall protective effect of the stringency of control measures.

In the multilevel model for 2021, no significant association was observed between vaccination rates and excess mortality, despite a clear and significant trend between maximum achieved vaccination coverage and cumulative excess mortality, across countries, in 2021 (online supplemental figure S27). This non-significant association is likely attributed to the different experience of each country in terms of the prioritising older and vulnerable populations in vaccine distribution and to the variability of the development level of participating countries since high-income countries tended to have greater vaccine access, and managed to cover larger proportions of their older and at-risk populations. Conversely, lower-income and middle-income countries, such as Georgia and Ukraine, experienced delays in achieving sufficient vaccination coverage compared with high-income countries. Consequently, substantial benefits may not have been reflected during 2021. Similarly, as seen in online supplemental figures S6–S27, for many countries, sharp increases in vaccine coverage coincided with the increasing prevalence of the more virulent Delta variant (between July and November 2021), something that could be masking beneficial effects of vaccination. Vaccinations did benefit excess mortality through interaction with weekly incidence of reported COVID-19 cases; in countries and weeks with higher than average vaccination rates, increases in incidence of COVID-19 did not lead to as high excess mortality as compared with countries and weeks with average vaccination rates.

Despite the variable experience of countries, the time-varying models for vaccination display some common features between countries. Several countries (Austria, Belgium, Denmark, England and Wales, France, Israel, Northern Ireland, Norway, and Sweden) had negative coefficients for the association between vaccination coverage and excess mortality, during the first weeks of vaccine introduction, suggesting that the first wave of vaccinations that, in most countries prioritised older and vulnerable portions of the population, managed to mitigate excess mortality. For most of these countries, the coefficients of the association then increased to zero or even positive numbers. In fact, Australia, Austria, Belgium, Denmark, England and Wales, Norway, Poland, Slovenia, and Northern Ireland experienced positive coefficients during the second half of 2021, which could be explained by waning effectiveness of the first vaccinations, as well as by the rise in prevalence of the Delta variant. On the other hand, Brazil, Cyprus, Georgia, Greece and Italy all started with positive coefficients that declined as vaccination coverage increased. The reasons for the different experiences in these latter countries remain to be investigated.

Strengths and limitations

To the best of our knowledge, the present study belongs to a small group of studies that attempted to investigate total, sex-specific and age-specific excess mortality for multiple countries for the whole years 2020 and 2021, using national data sources for mortality estimates. This is also one of the few studies presenting mortality estimates for Kazakhstan and Mauritius.[15 22] The model used for the estimation of excess mortality, also used in our previous work,[15] was shown to produce estimates with the least bias compared with an array of methodologies.[39 40] In addition, investigating excess mortality by age group and applying age standardisation in the calculation of total and sex-specific excess mortality is a critical advantage as it was previously shown that the age stratification has an impact on excess death calculations.[55 56] Lastly, this is one of few existing studies that investigated several correlates of excess mortality in the participating countries.[37 57] One of the limitations of our study is that participating countries did not use consistent age groupings to calculate age-specific all-cause mortality. Therefore, age-standardised results are not entirely comparable between countries and direct comparisons between countries cannot be applied. Thus, the magnitude of excess mortality for 2020 and 2021 should not be used as a measure of comparison of impact between countries; rather as an indicator of the COVID-19 impact on all-cause mortality in each country, as previously discussed.[15] Another limitation is the ecological nature of the investigation of determinants of excess mortality since correlations at population level may be proxies for other factors that directly relate to excess deaths or the reporting of deaths. With numerous and strong correlations between the investigated variables, any findings should only be taken to indicate association rather than causation. Lastly, even though the reference period and the data collection for Ukraine predate the start of the war, we cannot preclude that updates to the data may have been adversely impacted by the disastrous war.

CONCLUSION

Our study estimating overall, sex-specific and age-specific excess all-cause mortality in 24 countries, demonstrated that during 2020 and 2021, most of the investigated countries presented excess all-cause mortality compared with what was expected based on the years 2015–2019. Furthermore, looking at the male to female ratio of excess mortality, females were more affected than males only in Australia, Denmark, Mauritius and Ukraine. Also, our findings showed that excess mortality was higher for people aged 65+ years and 70+ years than in younger age groups (<65 and <70) in most countries, but younger age groups were also affected in several countries. These findings can serve as evidence that health resilience needs to be strengthened in those countries and the sex and age groups that were most affected. Lastly, our results support that public health interventions, such as stringency of control measures and vaccinations, directly or indirectly influenced the impact of the pandemic in terms of mortality. Therefore, it is evident that continued tracking of excess all-cause mortality is crucial to accurately estimate the true toll of COVID-19.

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Supplementary Material

Methods:

Regression equation used to estimate expected deaths (SEq1)

$$Log[E(Yt_i)] = intercept + \beta_1 * t_i + \beta_2 * \sin(2\pi * t_i/(365.25/7)) + \beta_3 * \cos(2\pi * t_i/(365.25/7)) + \beta_4 * \sin(2\pi * t_i/((365.25/2)/7)) + \beta_5 * \cos(2\pi * t_i/((365.25/2)/7))$$

Where, $E(Yt_i)$ is the expected age standardized death rate at week i. Time trends were accounted for with a time variable "t_i" that took values from 1 (1/2015) to n (52/2019), and seasonality was addressed using sine and cosine terms of 1 year $(2\pi * t_i /(365.25/7))$ and half year $(2\pi * t_i/((365.25/2)/7))$ periods.

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Table S1. Summary of national data sources, period of available mortality data, time unit, availability of sex and age-specific data, and data quality of civil registration and vital statistics systems per country.

Country	Partners	Access Date	Source	Public data (Y/N)	Link (if available)	Notes	Time Unit	Weekly sex specific data available	Weekly age specific data available	% Completeness of vital registration systems*
Australia	Deakin University	May 9th, 2022	Australian Bureau of Statistics	YES			ISO	YES	YES	100
Austria	Department for Epidemiology, Center for Public Health, Medical University of Vienna	August 22nd, 2022	Cause of death statistics, Statistics Austria	NO			ISO	YES	YES	100
Belgium	Statistics Belgium	NA	National register	YES	Belgium		ISO	YES	YES	99.8
Brazil	Federal University of Rio de Janeiro and Fluminense Federal University	July 13th, 2022	The Mortality Information System	YES	Brazil		Epi	YES	YES	99.3
Cyprus	University of Nicosia & Health Monitoring Unit, Cyprus Ministry of Health	June 2022	Eurostat	YES	Cyprus		ISO	YES	YES	90.7
Denmark	Statistics Denmark	August 2022	Central Persons Register	YES	Denmark		Epi	YES	YES	100
England and Wales	St George's, University of London	June 25th, 2022	Office for National Statistics	YES	England and Wales		National	YES	YES	100
Estonia	National Institute for Health Development	June 14th, 2022	Estonian Causes of Death Register	YES	Estonia		ISO	YES	YES	100
France	EHESP	June 3rd, 2022	Institut National de la Statistique et des Etudes Economiques (INSEE)	YES	France		ISO	YES	YES	100
Georgia	National Center for Disease control and Public	June 2021, June 2022	Vital Registration System	NO			ISO	YES	YES	94.3

	Health (Primary organization), National Statistics Office of Georgia (partner organization)									
Greece	Laboratory for Health Technology Assessment, University of West Attica	October 3rd, 2022	Hellenic Statistical Authority	YES	Greece		ISO	YES	YES	100
Israel	Central Bureau of Statistics	2021-2022	Code list from death certificates	NO			Epi	YES	YES	100
Italy	Department of Medicine, University of Perugia	2019-2021	National Health System	NO			Epi	YES	YES	100
Kazakhstan	Asfendiyarov Kazakh National Medical University	2021-2022	Ministry of health reports and the Republican Center of e-health records	NO			ISO	YES	YES	88.3
Mauritius	Statistics Mauritius	2022	Statistics Mauritius - Government agency	NO			National	YES	YES	99.8
Northern Ireland	St George's, University of London	June 25th, 2022	Northern Ireland Statistics and Research Agency	NO			National	NO[a]	YES	100
Norway	University of Oslo	Regularly	Statistics Norway, The Cause of Death Registry	YES	Norway		ISO	YES	YES	100
Peru	Universidad del Pacífico	2021-2022	Ministerio de Salud	YES			ISO	NO[b]	YES	64.4
Poland	Nicolaus Copernicus University in Toruń	October 10th-11th, 2022	Statistics Poland	YES	Poland		ISO	YES	YES	100
Slovenia	National Institute of Public Health	2022	Human Mortality Database	YES			ISO	YES	YES	94.8
Spain	University of Oviedo	July 31st, 2022	Spanish Institute of Statistics	YES	Spain		ISO	YES	YES	100
Sweden	Karolinska Institutet	2022	National Board of Health and Welfare	YES	Sweden		ISO	YES	YES	100
Ukraine	Bogomolets National medical University	April 2020, 2021	Bogomolets National medical University, http://database.ukrcensus.gov.ua/MULT/Dialog/statfile_c_fil	YES	Ukraine Ukraine		ISO	YES	YES	100

			es/az.html							
USA	Our World in Data	July 2022	Human Mortality Database (HMD) and the World Mortality Dataset (WMD)	YES	USA		Epi	YES	YES	99.9

Abbreviations: ISO: International Organization for Standardization; Epi: epidemiological

* Source: Supplementary Appendix 1 from Abbafati C, Abbas KM, Abbasi-Kangevari M, et al. 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. *Lancet*. 2020;396(10258):1204-1222. doi:10.1016/S0140-6736(20)30925-9

Table S2. Description of aggregate age groups created for the age-standardization according to age-specific all-cause mortality data availability.

Country	Age groups_Category 1	Age groups_Category 2	Age groups_Category 3	Age groups_Category 4	Age groups_Category 5
	<15, 15-44, 45-65, 65+	<20, 20-49, 50-69, 70+	<45, 45-64, 65+	<20, 20-69, 70+	<15, 15-64, 65+
Australia	x				
Austria	x				
Belgium			x		
Brazil	x				
Cyprus	x				
Denmark	x				
England and Wales	x				
Estonia		x			
France		x			
Georgia	x				
Greece					x
Israel	x				
Italy	x				
Kazakhstan		x			
Mauritius		x			
N. Ireland	x				
Norway	x				
Peru	x				
Poland	x				
Slovenia	x				
Spain					x
Sweden		x			
Ukraine				x	
USA					x

Equation used for age-standardization for the aggregate age groups category 1 (<15, 15-44, 45-65, 65+); CDR = age specific crude death rate

asdr1_totalpop=((CDR0-14*0.2615)+(CDR15-44*0.4597)+(CDR45-64*0.1968)+(CDR65+*0.08235))

(same equation applies for male and female population)

Equation used for age-standardization for the aggregate age groups category 2 (<20, 20-49, 50-69, 70+); CDR = age specific crude death rate

asdr2_totalpop=((CDR0-19*0.3462)+(CDR20-49*0.4354)+(CDR50-69*0.166)+(CDR70+*0.5275))

(same equation applies for male and female population)

Equation used for age-standardization for the aggregate age groups category 3 (<45, 45-64, 65+); CDR = age specific crude death rate

asdr3_totalpop=((CDR0-44*0.7212)+(CDR45-64*0.1968)+(CDR65+*0.08235))

(same equation applies for male and female population)

Equation used for age-standardization for the aggregate age groups category 4 (<20, 20-69, 70+); CDR = age specific crude death rate

asdr4_totalpop=((CDR0-19*0.3462)+(CDR20-69*0.6014)+(CDR70+*0.05275))

(same equation applies for male and female population)

Equation used for age-standardization for the aggregate age groups category 5 (<15, 15-64, 65+); CDR = age specific crude death rate

asdr5_totalpop=((CDR0-14*0.2615)+(CDR15-64*0.6565)+(CDR65+*0.08235))

(same equation applies for male and female population)

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Table S3. Publicly available sources for the database of country-level sociodemographic variables (reported yearly) and pandemic related variables (reported weekly).

For Northern Ireland, England and Wales, data is only available for "population" and "vaccination". Hence, for other variables, the UK data were used.

Category	Variable Label	Description	Time span	Range of Values	Data Source	Weblink
			Sociodemographic Variables			
POPULATION	Population density	Annual country population density per square kilometer	2020-2021	3.34 – 411.22	Department of Economic and Social Affairs, Population Division, United Nation	population_density
POPULATION	Median age	Median age of population (years)	2020-2021	27.96 – 46.83	Department of Economic and Social Affairs, Population Division, United Nation	median_age
POPULATION	Percent of population more than 65 years old	Percentage of total population in the select age group, both sexes combined	2020-2021	7.84 – 23.68	Department of Economic and Social Affairs, Population Division, United Nation	aged_65_older
POPULATION	Life expectancy	Life expectancy at birth, total (years)	2020	71.19 – 83.21	Demographic and Health Surveys, Multiple Indicator Cluster Surveys, Household surveys, UN Population Division	life_expectancy
POPULATION	Hypertension	Prevalence of hypertension (% of adults ages 30-79)	2019	20.70 – 49.20	Health Nutrition and Population Statistics	hypertension
POPULATION	Diabetes	Prevalence of Diabetes (% of population ages 20 to 79)	2019	3.60 – 10.70	Health Nutrition and Population Statistics	diabetes
POPULATION	Obesity	Prevalence of obesity among adults, BMI ≥ 30	2016	19.70 – 36.20	The Global Health Observatory, WHO	obesity
POPULATION	PM2.5 (air pollution)	PM2.5 air pollution, mean annual exposure (micrograms per cubic meter)	2019	6.18 – 24.79	World Development Indicators	PM2.5

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GOVERNMENT & ECONOMY	Gross Domestic Products (GDP)	GDP per capita, PPP (constant 2017 international $)	2020-2021	11176.9 – 65662.17	World Bank	gdp_per_capita
GOVERNMENT & ECONOMY	Human development index (HDI)	Summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and having a decent standard of living	2021	0.75 – 0.96 (full range 1-100, with higher values indicating a higher level of development)	UNDP, Human Development Report	human_development_index
GOVERNMENT & ECONOMY	Inequality-adjusted Human Development Index (IHDI)	IHDI adjusts the Human Development Index (HDI) for inequality in the distribution of each dimension across the population	2021	0.58 – 0.91 (full range 1-100, with higher values indicating a higher level of development adjusted for inequality)	UNDP, Human Development Report	IHDI
GOVERNMENT & ECONOMY	Gini index	Income inequality between individuals or households within an economy	2010-2020	24.40 – 48.90 (full range 1-100, with higher values indicating higher within population inequality)	UNDP, Human Development Report	Gini
GOVERNMENT & ECONOMY	Government Effectiveness	A measure of the quality of public services, civil service, policy formulation and implementation; including government investment in	2020-2021	-0.46 – 2.00 (full range -2.5 (less effective) to 2.5 (more effective))	Worldwide Governance Indicators (WGI)	Government_Effectiveness

		improvement and maintenance of these services				
GOVERNMENT & ECONOMY	Government revenue	Money received by a government from taxes and non-tax sources to enable it to undertake public expenditure (% of GDP)	2020-2021	14.94 – 59.25 (full range: 0-100)	The Organization for Economic Co-operation and Development (OECD) & International Monetary Fund (IMF)	Gov_rev1 , Gov_rev2, Gov_rev3
HEALTH CARE RESOURCES	Hospital beds per thousand population	Hospital bed density per 1,000 population	2019 or last available year	1.59 – 7.46	The Organization for Economic Co-operation and Development (OECD) & World Bank	hospital_beds_per_thousand1 , hospital_beds_per_thousand2
HEALTH CARE RESOURCES	Total nursing personnel	Total number of nurses (per 10,000 population)	2019 or last available year	16.46 – 75.03 19.89 – 186.22	WHO NHWA Data Platform - December 2022 update.	Nursing.Personnel.Total
HEALTH CARE RESOURCES	Total medical doctors	Total number of medical doctors (per 10,000 population)	2019 or last available year	19.89 – 186.22	WHO NHWA Data Platform - December 2022 update.	Medical.Doctors.Total
HEALTH CARE RESOURCES	Universal Health Coverage	% population coverage of essential health services (defined as the average coverage of essential services based on tracer interventions that include reproductive, maternal, newborn and child health, infectious diseases, non-communicable diseases and service	2020	55.95 – 99.90 (full range: 0 – 100, with 100 being full population coverage)	The Institute for Health Metrics and Evaluation (IHME)	uhc

		capacity and access, among the general and the most disadvantaged population)				
HEALTH CARE RESOURCES	Completeness of vital registration	Completeness of vital registration systems as assessed in 2019	2019	64.40 – 100.00	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.	Completeness
HEALTH CARE RESOURCES	Healthcare Access and Quality Index (HAQ)	Index based on death rates from 32 causes of death that could be avoided by timely and effective medical care (also known as 'amenable mortality')	2019	52.97 – 90.40 (full range: 0-100, with higher values indicating better healthcare access and quality)	Global Burden of Disease Study 2019 (GBD 2019)	HAQ
	Pandemic Related Variables					
POPULATION	Weekly incidence of COVID-19	Number of COVID-19 new cases per week per 1,000 population	2020-2021	0.002 – 230.6	Our World in Data	COVID19 new cases
POLICY	Stringency index	Mean stringency index per week	2020-2021	0 – 100 (full range: 0 – 100, with higher values indicating more stringent control measures)	Blavatnik School of Government, University of Oxford	stringency_index
HEALTH RESOURCES	Fully vaccinated	People fully vaccinated per hundred each	2020-2021	0.00 – 79.94	Our World in Data	fully_vaccinated_%

		week				

Table S4. Cumulative observed and expected ASMRs per 100,000 population for 2020; total population.

Country	Observed mortality rate / 100,000 population*	Expected mortality rate / 100,000 population*	Lower limit of 95% CI of Expected mortality rate	Upper limit of 95% CI of Expected mortality rate	Difference (Observed-Expected mortality rate)	Difference using the Lower limit of 95% CI of Expected mortality rate	Difference using the Upper limit of 95% CI of Expected mortality rate	P-score (the ratio of the excess to the expected, expressed as a percentage)
Australia	371.7	369.5	364.2	374.9	2.2	7.5	-3.2	0.6
Austria	499.5	452.5	443.9	461.2	47.0 ↑	55.6	38.3	10.4
Belgium	538.4	457.3	449.4	465.2	81.1 ↑	89.0	73.2	17.7
Brazil	666.2	578.2	571.5	584.8	88.0 ↑	94.7	81.4	15.2
Cyprus	410.8	386.8	373.7	400.0	24.0 ↑	37.1	10.7	6.2
Denmark	447.3	444.4	438.6	450.2	3.0	8.8	-2.9	0.7
England and Wales	521.4	449.3	440.8	457.9	72.1 ↑	80.6	63.5	16.0
Estonia	639.0	607.6	594.1	621.2	31.3↑	44.9	17.7	5.2
France	457.6	416.2	410.6	421.9	41.3 ↑	46.9	35.7	9.9
Georgia	864.7	770.6	754.4	786.8	94.2 ↑	110.3	77.9	12.2
Greece	577.5	536.6	527.1	546.2	40.8 ↑	50.3	31.3	7.6
Israel	432.2	399.9	394.3	405.6	32.3 ↑	37.9	26.5	8.1
Italy	479.8	428.9	421.5	436.4	50.9 ↑	58.4	43.4	11.9
Kazakhstan	770.8	620.2	610.0	630.4	150.6 ↑	160.8	140.3	24.3
Mauritius	663.9	694.7	678.1	711.4	-30.8 ↓	-14.2	-47.6	-4.4
Northern Ireland	512.3	465.2	451.6	478.9	47.1 ↑	60.7	33.4	10.1
Norway	395.4	387.6	382.1	393.1	7.8 ↑	13.3	2.3	2.0
Peru	651.9	378.9	373.0	384.7	273.0 ↑	278.8	267.1	72.1
Poland	666.5	576.6	568.5	584.7	89.9 ↑	97.9	81.8	15.6
Slovenia	523.3	456.0	446.5	465.7	67.2 ↑	76.8	57.6	14.7

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Spain	521.7	439.9	433.7	446.3	81.7 ↑	88.0	75.4	18.6
Sweden	395.6	352.3	347.1	357.5	43.4 ↑	48.5	38.2	12.3
Ukraine	699.5	614.1	565.6	664.0	85.4 ↑	133.9	35.5	13.9
USA	651.5	551.0	544.5	557.5	100.5 ↑	107.0	94.0	18.2

*For all countries, the sum of observed and expected deaths is up to week 52, with the exception of England & Wales (starting from week 2 up to week 51), Kazakhstan and Mauritius (starting from week 2 up to week 52), Northern Ireland (up to week 50), and Slovenia (up to 51).
↑ Indicates statistically significant excess all-cause mortality using the sum of deaths for 2020.
↓ Indicates a statistically significant reduction all-cause mortality using the sum of deaths for 2020.
Due to the variability in the provided age groupings by countries, age-standardised mortality values are not entirely comparable between countries and direct comparisons between countries should be avoided.

Table S5. Cumulative observed and expected ASMRs per 100,000 population for 2021; total population.

Country	Observed mortality rate / 100,000 population*	Expected mortality rate / 100,000 population*	Lower limit of 95% CI of Expected mortality rate	Upper limit of 95% CI of Expected mortality rate	Difference (Observed-Expected mortality rate)	Difference using the Lower limit of 95% CI of Expected mortality rate	Difference using the Upper limit of 95% CI of Expected mortality rate	P-score (the ratio of the excess to the expected, expressed as a percentage)
Australia	373.5	361.7	356.4	367.0	11.8 ↑	17.1	6.5	3.3
Austria	486.8	447.7	439.1	456.4	39.1 ↑	47.7	30.4	8.7
Belgium	471.3	447.7	439.9	455.5	23.7 ↑	31.5	15.8	5.3
Brazil	742.3	569.8	563.2	576.4	172.6 ↑	179.2	165.9	30.3
Cyprus	434.5	381.2	368.2	394.5	53.2 ↑	66.3	40.0	14.0
Denmark	452.5	440.5	434.7	446.4	12.0 ↑	17.8	6.1	2.7
England and Wales	500.9	441.8	433.3	450.4	59.0 ↑	67.5	50.5	13.4
Estonia	721.4	596.2	582.7	609.8	125.2↑	138.7	111.6	21.0
France	439.0	406.9	401.3	412.5	32.2 ↑	37.8	26.5	7.9
Georgia	1006.5	749.8	733.8	765.9	256.8 ↑	272.7	240.6	34.2
Greece	628.3	535.1	525.6	544.7	93.2 ↑	102.7	83.5	17.4
Israel	434.1	389.5	383.9	395.2	44.5 ↑	50.2	38.9	11.4
Italy	444.9	414.1	406.7	421.5	30.8 ↑	38.2	23.4	7.4
Kazakhstan	961.5	622.8	612.6	633.2	338.7 ↑	349.0	328.3	54.4
Mauritius	646.6	700.5	683.7	717.4	-53.9 ↓	-37.1	-70.8	-7.7
Northern Ireland	512.8	457.5	443.9	471.2	55.3 ↑	68.9	41.6	12.1
Norway	393.3	377.3	371.9	382.8	16.0 ↑	21.4	10.5	4.2
Peru	725.3	390.4	384.3	396.5	334.9 ↑	341.0	328.8	85.8
Poland	708.5	568.5	560.4	576.6	140.0 ↑	148.1	131.9	24.6
Slovenia	500.8	448.0	438.5	457.6	52.8 ↑	62.3	43.2	11.8

Spain	468.9	433.1	426.9	439.5	35.8 ↑	42.0	29.4	8.3
Sweden	360.7	338.7	333.7	343.9	22.0 ↑	27.1	16.8	6.5
Ukraine	853.2	587.2	539.5	636.2	266.0 ↑	313.7	216.9	45.3
USA	658.6	546.2	539.7	552.7	112.4 ↑	118.9	105.9	20.6

*For all countries, the sum of observed and expected deaths is up to week 52, with the exception of England & Wales (starting from week 2 up to week 51), Kazakhstan and Mauritius (starting from week 2 up to week 52), Northern Ireland (up to week 50), and Slovenia (up to 51).
↑ Indicates statistically significant excess all-cause mortality using the sum of deaths for 2021.
↓ Indicates a statistically significant reduction all-cause mortality using the sum of deaths for 2021.
Due to the variability in the provided age groupings by countries, age-standardised mortality values are not entirely comparable between countries and direct comparisons between countries should be avoided.

Table S6. Cumulative observed and expected ASMRs per 100,000 population for the years 2020 and 2021 together; total population.

Country	Observed mortality rate / 100,000 population*	Expected mortality rate / 100,000 population*	Lower limit of 95% CI of Expected mortality rate	Upper limit of 95% CI of Expected mortality rate	Difference (Observed-Expected mortality rate)	Difference using the Lower limit of 95% CI of Expected mortality rate	Difference using the Upper limit of 95% CI of Expected mortality rate	P-score (the ratio of the excess to the expected, expressed as a percentage)
Australia	372.6	365.6	361.9	369.4	7.0↑	10.7	3.2	1.9
Austria	493.1	450.1	444.0	456.3	43.0↑	49.1	36.9	9.6
Belgium	504.9	452.5	446.9	458.0	52.4↑	57.9	46.8	11.6
Brazil	704.3	574.0	569.3	578.7	130.3↑	135.0	125.6	22.7
Cyprus	422.6	384.0	374.7	393.4	38.6↑	47.9	29.3	10.1
Denmark	449.9	442.5	409.1	417.1	7.5↑	40.8	32.9	1.7
England and Wales	511.1	445.6	439.5	451.6	65.6↑	71.6	59.5	14.7
Estonia	680.2	601.9	592.4	611.5	78.3↑	87.8	68.7	13.0
France	448.3	411.6	407.6	415.5	36.7↑	40.7	32.8	8.9
Georgia	935.6	760.2	748.8	771.6	175.5↑	186.8	164.0	23.1
Greece	602.9	535.9	529.1	542.7	67.0↑	73.7	60.2	12.5
Israel	433.1	394.7	390.7	398.7	38.4↑	42.4	34.4	9.7
Italy	462.3	421.5	416.3	426.8	40.8↑	46.1	35.6	9.7
Kazakhstan	866.2	621.5	614.3	628.8	244.6↑	251.9	237.4	39.4
Mauritius	655.2	697.6	685.7	709.5	-42.3↓	-30.5	-54.2	-6.1
Northern Ireland	512.5	461.3	451.7	471.0	51.2↑	60.9	41.5	11.1
Norway	374.5	359.5	355.8	363.3	14.9↑	18.6	11.2	4.1
Peru	685.1	383.6	379.4	387.8	301.5↑	305.7	297.3	78.6
Poland	696.3	582.0	576.3	587.8	114.3↑	120.1	108.6	19.6

Slovenia	512.0	452.0	445.3	458.8	60.0↑	66.8	53.2	13.3
Spain	495.3	436.5	432.1	441.0	58.7↑	63.2	54.3	13.5
Sweden	378.2	345.5	341.9	349.2	32.7↑	36.3	29.0	9.5
Ukraine	776.3	600.7	566.5	635.5	175.7↑	209.8	140.9	29.2
USA	655.0	548.6	544.0	553.2	106.5↑	111.1	101.9	19.4

*For all countries, the sum of observed and expected deaths is up to week 52, with the exception of England & Wales (starting from week 2 up to week 51), Kazakhstan and Mauritius (starting from week 2 up to week 52), Northern Ireland (up to week 50), and Slovenia (up to 51).

↑ Indicates statistically significant excess all-cause mortality using the sum of deaths for 2020 and 2021.

↓ Indicates a statistically significant reduction all-cause mortality using the sum of deaths for 2020 and 2021.

Due to the variability in the provided age groupings by countries, age-standardised mortality values are not entirely comparable between countries and direct comparisons between countries should be avoided.

Table S7. Cumulative observed and expected mortality rate for 2020 by sex.

	Males								Females							
Country	Observed mortality rate / 100,000 population*	Expected mortality rate / 100,000 population*	Lower limit of 95% CI of Expected mortality rate	Upper limit of 95% CI of Expected mortality rate	Difference (Observed-Expected mortality rate)	Difference using the Lower limit of 95% CI of Expected mortality rate	Difference using the Upper limit of 95% CI of Expected mortality rate	P-score (the ratio of the excess to the expected, expressed as a percentage)	Observed mortality rate / 100,000 population*	Expected mortality rate / 100,000 population*	Lower limit of 95% CI of Expected mortality rate	Upper limit of 95% CI of Expected mortality rate	Difference (Observed-Expected mortality rate)	Difference using the Lower limit of 95% CI of Expected mortality rate	Difference using the Upper limit of 95% CI of Expected mortality rate	P-score (the ratio of the excess to the expected, expressed as a percentage)
Australia	418.5	415.7	410.1	421.3	2.8	8.4	-2.8	0.7	327.8	326.0	321.0	331.0	1.9	6.8	-3.1	0.6
Austria	564.4	505.4	495.5	515.3	59.0 ↑	68.8	49.0	11.7	441.5	404.7	396.1	413.5	36.7 ↑	45.4	28.0	9.1
Belgium	594.6	504.5	496.0	513.1	90.1 ↑	98.6	81.5	17.9	486.8	413.7	405.4	422.0	73.1 ↑	81.4	64.7	17.7
Brazil	824.7	702.7	695.4	710.1	122.0 ↑	129.3	114.7	17.4	528.8	468.7	462.7	474.7	60.1 ↑	66.1	54.1	12.8
Cyprus	471.4	446.0	427.8	464.4	25.4 ↑	43.6	7.0	5.7	354.9	332.6	316.9	348.7	22.3 ↑	38.0	6.3	6.7
Denmark	498.2	494.4	486.9	502.0	3.7	11.3	-3.8	0.8	399.8	397.3	391.0	403.7	2.4	8.8	-3.9	0.6
England and Wales	604.7	495.1	486.3	504.0	109.6 ↑	118.4	100.7	22.1	468.8	406.8	398.4	415.4	62.0 ↑	70.4	53.4	15.2
Estonia	812.5	776.6	755.3	798.1	35.9↑	57.2	14.5	4.6	497.7	471.3	458.4	484.3	26.4↑	39.3	13.4	5.6
France	546.0	491.3	485.2	497.5	54.7 ↑	60.8	48.5	11.1	380.6	350.0	344.8	355.1	30.7 ↑	35.8	25.5	8.8
Georgia	1180.4	1041.5	1019.3	1063.9	138.9 ↑	161.1	116.6	13.3	642.1	574.6	559.5	589.9	67.4 ↑	82.6	52.2	11.7
Greece	654.9	610.0	599.7	620.4	44.8 ↑	55.2	34.4	7.3	503.9	466.9	457.1	476.8	37.0 ↑	46.8	27.1	7.9
Israel	492.2	447.8	440.1	455.6	44.3 ↑	52.1	36.6	9.9	378.7	356.3	349.7	363.0	22.4 ↑	29.0	15.7	6.3
Italy	535.7	472.9	465.5	480.4	62.8 ↑	70.3	55.3	13.3	431.1	389.8	382.3	397.5	41.3 ↑	48.9	33.7	10.6
Kazakhstan	1009.9	791.4	777.8	805.1	218.5 ↑	232.1	204.8	27.6	606.6	498.5	489.1	507.9	108.1 ↑	117.5	98.7	21.7
Mauritius	816.3	826.9	801.8	852.3	-10.6	14.5	-35.9	-1.3	522.6	571.3	553.1	589.6	-48.7 ↓	-30.5	-67.0	-8.5
Norway	420.3	408.5	401.3	415.7	11.8 ↑	19.0	4.5	2.9	370.3	365.8	359.0	372.7	4.5	11.3	-2.4	1.2
Peru	820.0	425.2	418.4	431.9	394.8 ↑	401.6	388.1	92.9	497.9	335.5	329.7	341.4	162.3 ↑	168.2	156.5	48.4
Poland	847.1	718.9	709.4	728.5	128.1 ↑	137.6	118.6	17.8	515.5	453.9	446.6	461.2	61.6 ↑	68.9	54.2	13.6
Slovenia	594.4	516.8	501.7	532.0	77.6 ↑	92.7	62.4	15.0	461.7	398.3	387.6	409.0	63.4 ↑	74.1	52.7	15.9

Spain	607.0	513.2	506.6	519.8	93.8 ↑	100.4	87.2	18.3	445.8	374.5	368.1	380.9	71.3 ↑	77.7	64.8	19.0
Sweden	433.1	377.1	371.6	382.6	56.0 ↑	61.4	50.5	14.8	359.9	328.0	322.8	333.2	31.9 ↑	37.1	26.7	9.7
Ukraine	1278.4	1113.8	1007.0	1224.3	164.6 ↑	271.5	54.2	14.8	595.4	565.5	503.2	630.2	29.8	92.2	-34.9	5.3
USA	748.7	627.3	620.4	634.3	121.4 ↑	128.3	114.4	19.3	558.4	478.0	472.0	484.1	80.4 ↑	86.4	74.3	16.8

*For all countries, the sum of observed and expected deaths is up to week 52, with the exception of England & Wales (starting from week 2 up to week 51), Kazakhstan and Mauritius (starting from week 2 up to week 52), and Slovenia (up to 51).
↑ Indicates statistically significant excess all-cause mortality using the sum of deaths for 2020.
↓ Indicates a statistically significant reduction all-cause mortality using the sum of deaths for 2020.
Due to the variability in the provided age groupings by countries, age-standardised mortality values are not entirely comparable between countries and direct comparisons between countries should be avoided.

Table S8. Cumulative observed and expected mortality rate for 2021 by sex.

	Males								Females							
Country	Observed mortality rate / 100,000 population*	Expected mortality rate / 100,000 population*	Lower limit of 95% CI of Expected mortality rate	Upper limit of 95% CI of Expected mortality rate	Difference (Observed-Expected mortality rate)	Difference using the Lower limit of 95% CI of Expected mortality rate	Difference using the Upper limit of 95% CI of Expected mortality rate	P-score (the ratio of the excess to the expected, expressed as a percentage)	Observed mortality rate / 100,000 population*	Expected mortality rate / 100,000 population*	Lower limit of 95% CI of Expected mortality rate	Upper limit of 95% CI of Expected mortality rate	Difference (Observed-Expected mortality rate)	Difference using the Lower limit of 95% CI of Expected mortality rate	Difference using the Upper limit of 95% CI of Expected mortality rate	P-score (the ratio of the excess to the expected, expressed as a percentage)
Australia	418.5	408.5	402.9	414.1	10.0 ↑	15.6	4.4	2.5	331.2	317.6	312.7	322.6	13.6 ↑	18.6	8.7	4.3
Austria	555.7	500.7	490.8	510.6	55.0 ↑	64.9	45.0	11.0	425.0	399.9	391.3	408.7	25.1 ↑	33.7	16.3	6.3
Belgium	534.5	492.9	484.4	501.4	41.6 ↑	50.1	33.1	8.4	414.0	405.8	397.6	414.1	8.2	16.4	-0.1	2.0
Brazil	906.3	691.8	684.5	699.1	214.5 ↑	221.8	207.2	31.0	599.5	462.7	456.7	468.7	136.8 ↑	142.8	130.8	29.6
Cyprus	498.8	440.3	422.1	458.7	58.6 ↑	76.8	40.1	13.3	376.1	327.1	311.4	343.1	49.0 ↑	64.8	33.1	15.0
Denmark	501.2	491.9	484.4	499.5	9.2 ↑	16.8	1.6	1.9	407.2	392.3	386.0	398.7	14.9 ↑	21.2	8.5	3.8
England and Wales	587.4	489.4	480.5	498.3	98.0 ↑	106.8	89.1	20.0	447.5	398.0	389.6	406.5	49.5 ↑	57.9	41.0	12.4
Estonia	925.0	760.1	739.0	781.5	164.9↑	186.1	143.5	21.7	557.2	463.5	450.6	476.4	93.7↑	106.5	80.7	20.2
France	526.6	477.9	471.9	484.0	48.7 ↑	54.8	42.6	10.2	362.3	343.8	338.6	349.0	18.5 ↑	23.7	13.4	5.4
Georgia	1341.8	1020.5	998.4	1042.7	321.4 ↑	343.5	299.2	31.5	773.3	555.5	540.5	570.6	217.7 ↑	232.7	202.6	39.2
Greece	720.1	606.9	596.5	617.3	113.2 ↑	123.6	102.8	18.7	541.2	467.0	457.1	476.9	74.2 ↑	84.1	64.3	15.9
Israel	491.8	435.7	428.1	443.4	56.0 ↑	63.7	48.3	12.9	381.9	347.2	340.7	353.8	34.7 ↑	41.2	28.1	10.0
Italy	496.2	455.9	448.6	463.3	40.3 ↑	47.7	32.9	8.8	399.7	376.8	369.3	384.3	22.9 ↑	30.4	15.4	6.1
Kazakhstan	1244.5	793.4	779.7	807.2	451.0 ↑	464.8	437.2	56.8	765.4	501.2	491.8	510.8	264.2 ↑	273.6	254.6	52.7
Mauritius	795.7	829.1	803.8	854.7	-33.4 ↓	-8.1	-58.9	-4.0	507.9	578.6	560.2	597.2	-70.7 ↓	-52.3	-89.3	-12.2
Norway	414.2	397.6	390.5	404.8	16.6 ↑	23.7	9.4	4.2	371.9	356.2	349.4	362.9	15.8 ↑	22.5	9.0	4.4
Peru	869.5	439.0	431.9	446.0	430.5 ↑	437.5	423.4	98.1	592.9	345.1	339.0	351.2	247.9 ↑	254.0	241.7	71.8
Poland	888.8	707.3	697.8	716.9	181.4 ↑	190.9	171.9	25.7	556.0	447.8	440.5	455.2	108.2 ↑	115.5	100.8	24.2
Slovenia	588.6	504.2	489.2	519.3	84.4 ↑	99.4	69.3	16.7	425.4	392.7	382.0	403.4	32.7 ↑	43.3	21.9	8.3

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Spain	552.5	505.1	498.5	511.7	47.4 ↑	53.9	40.8	9.4	394.5	368.8	362.5	375.3	25.7 ↑	32.0	19.2	7.0
Sweden	394.5	361.7	356.3	367.1	32.8 ↑	38.1	27.4	9.1	328.3	316.2	311.1	321.4	12.1 ↑	17.3	7.0	3.8
Ukraine	1363.1	1106.5	999.3	1217.3	256.7 ↑	363.9	145.9	23.2	874.3	527.9	467.5	590.8	346.4 ↑	406.8	283.6	65.6
USA	765.7	624.3	617.3	631.2	141.4 ↑	148.3	134.4	22.6	556.4	471.7	465.7	477.8	84.7 ↑	90.7	78.6	17.9

*For all countries, the sum of observed and expected deaths is up to week 52, with the exception of England & Wales (starting from week 2 up to week 51), Kazakhstan and Mauritius (starting from week 2 up to week 52), and Slovenia (up to 51).
↑ Indicates statistically significant excess all-cause mortality using the sum of deaths for 2021.
↓ Indicates a statistically significant reduction all-cause mortality using the sum of deaths for 2021.
Due to the variability in the provided age groupings by countries, age-standardised mortality values are not entirely comparable between countries and direct comparisons between countries should be avoided.

Table S9. Male to female cumulative excess ratio for 2020 and 2021 respectively.

	2020			2021		
Country	**Male Excess**	**Female Excess**	**Ratio Males:Females**	**Male Excess**	**Female Excess**	**Ratio Males:Females**
Australia	2.8	1.9	1.5	10.0	13.6	0.7*
Austria	59.0	36.7	1.6	55.0	25.1	2.2
Belgium	90.1	73.1	1.2	41.6	8.2	5.1
Brazil	122.0	60.1	2.0	214.5	136.8	1.6
Cyprus	25.4	22.3	1.1	58.6	49.0	1.2
Denmark	3.7	2.4	1.5	9.2	14.9	0.6*
England and Wales	109.6	62.0	1.8	98.0	49.5	2.0
Estonia	35.9	26.4	1.4	164.9	93.7	1.8
France	54.7	30.7	1.8	48.7	18.5	2.6
Georgia	138.9	67.4	2.1	321.4	217.7	1.5
Greece	44.8	37.0	1.2	113.2	74.2	1.5
Israel	44.3	22.4	2.0	56.0	34.7	1.6
Italy	62.8	41.3	1.5	40.3	22.9	1.8
Kazakhstan	218.5	108.1	2.0	451.0	264.2	1.7
Mauritius	-10.6	-48.7	0.2*	-33.4	-70.7	0.5*
Norway	11.8	4.5	2.6	16.6	15.8	1.1
Peru	394.8	162.3	2.4	430.5	247.9	1.7
Poland	128.1	61.6	2.1	181.4	108.2	1.7
Slovenia	77.6	63.4	1.2	84.4	32.7	2.6
Spain	93.8	71.3	1.3	47.4	25.7	1.8
Sweden	56.0	31.9	1.8	32.8	12.1	2.7
Ukraine	164.6	29.8	5.5	256.7	346.4	0.7*
USA	121.4	80.4	1.5	141.4	84.7	1.7

For all countries, the sum of observed and expected deaths is up to week 52, with the exception of England & Wales (starting from week 2 up to week 51), Kazakhstan and Mauritius (starting from week 2 up to week 52), and Slovenia (up to 51).
*Indicates females are more affected than males.

Due to the variability in the provided age groupings by countries, age-standardised mortality values are not entirely comparable between countries and direct comparisons between countries should be avoided.

Table S10. Cumulative observed and expected mortality rate for 2020 by age group.

Country	Observed mortality rate / 100,000 population*	Expected mortality rate / 100,000 population*	Lower limit of 95% CI of Expected mortality rate	Upper limit of 95% CI of Expected mortality rate	Difference (Observed -Expected mortality rate)	Difference using the Lower limit of 95% CI of Expected mortality rate	Difference using the Upper limit of 95% CI of Expected mortality rate	P-score (the ratio of the excess to the expected, expressed as a percentage)	Observed mortality rate / 100,000 population*	Expected mortality rate / 100,000 population*	Lower limit of 95% CI of Expected mortality rate	Upper limit of 95% CI of Expected mortality rate	Difference (Observed -Expected mortality rate)	Difference using the Lower limit of 95% CI of Expected mortality rate	Difference using the Upper limit of 95% CI of Expected mortality rate	P-score (the ratio of the excess to the expected, expressed as a percentage)
	<65								65+							
Australia	136.2	135.0	131.8	138.2	1.2	4.4	-2.0	0.9	3252.3	3237.0	3204.2	3270.0	15.2	48.1	-17.7	0.5
Austria	179.8	168.5	164.9	172.1	11.4↑	14.9	7.8	6.7	4670.1	4185.9	4097.1	4275.3	484.2↑	573.0	394.7	11.6
Belgium	458.0	408.2	399.7	416.9	49.7↑	58.3	41.1	12.2	5010.0	4152.8	4072.3	4233.9	857.2↑	937.7	776.1	20.6
Brazil	315.5	272.3	267.7	276.8	43.2↑	47.8	38.7	15.9	4857.2	4206.7	4172.1	4241.4	650.5↑	685.1	615.8	15.5
Cyprus	136.7	126.0	117.4	134.8	10.7↑	19.3	1.9	8.5	3751.6	3551.4	3426.0	3678.4	200.1↑	325.5	73.2	5.6
Denmark	167.2	166.1	162.0	170.3	1.1	5.3	-3.0	0.7	4064.7	4047.7	3993.5	4102.2	17.0	71.2	-37.5	0.4
England and Wales	190.9	169.2	165.6	172.9	21.7↑	25.3	18.0	12.8	4691.9	3992.3	3906.3	4078.8	699.6↑	785.6	613.1	17.5
Estonia	292.4	261.8	250.4	273.3	30.6↑	42.0	19.1	11.7	4804.8	4717.7	4608.9	4827.2	87.2	195.9	-22.4	1.8
Georgia	393.3	355.1	347.0	363.3	38.2↑	46.4	30.0	10.8	6994.2	6170.9	6017.2	6325.9	823.3↑	977.0	668.3	13.3
Greece	1125.3	1055.5	1036.4	1074.7	69.8↑	88.9	50.6	6.6	4975.7	4596.8	4499.5	4694.8	378.9↑	476.2	280.9	8.2
Israel	109.5	107.4	104.6	110.3	2.1	5.0	-0.8	2.0	4013.3	3642.3	3584.8	3700.1	371.0↑	428.5	313.2	10.2
Italy	159.1	149.6	146.3	153.0	9.5↑	12.8	6.1	6.3	4696.0	4122.1	4043.3	4201.3	573.9↑	652.7	494.7	13.9

Northern Ireland	196.6	182.4	174.2	190.7	14.2↑	22.3	5.8	7.8	4486.4	4028.4	3902.5	4155.6	458.0↑	583.9	330.7	11.4
Norway	124.3	121.8	118.3	125.4	2.4	6.0	-1.1	2.0	3727.5	3652.4	3597.8	3707.3	75.1↑	129.7	20.2	2.1
Peru	255.9	151.3	147.9	154.8	104.6↑	108.0	101.1	69.1	4970.3	2877.3	2832.4	2922.4	2093.1↑	2138.0	2047.9	72.7
Poland	324.8	300.9	296.1	305.7	23.9↑	28.7	19.1	8.0	5396.9	4481.0	4404.9	4557.5	915.9↑	991.9	839.3	20.4
Slovenia	195.2	187.9	180.9	194.9	7.3↑	14.3	0.3	3.9	4853.7	4089.4	3996.1	4183.4	764.3↑	857.5	670.3	18.7
Spain	944.7	833.5	824.3	842.8	111.1↑	120.3	101.9	13.3	4661.5	3837.6	3771.7	3903.8	823.9↑	889.7	757.7	21.5
USA	314.9	263.4	258.9	267.9	51.5↑	56.0	47.0	19.5	4644.9	3950.1	3920.5	3979.8	694.8↑	724.4	665.1	17.6
				<70								**70+**				
Cyprus	180.8	171.3	161.4	181.4	9.5	19.4	-0.6	5.6	5028.0	4816.0	4639.6	4994.6	211.9↑	388.4	33.3	4.4
Denmark	242.6	240.5	235.8	245.3	2.1	6.9	-2.7	0.9	5090.7	5004.5	4931.8	5077.6	86.1↑	158.9	13.1	1.7
Estonia	399.5	361.9	350.0	373.9	37.6↑	49.5	25.5	10.4	5957.7	5875.4	5734.9	6017.0	82.3	222.8	-59.2	1.4
France	258.8	242.6	238.3	247.0	16.1↑	20.4	11.8	6.6	5429.7	4835.1	4755.2	4915.4	594.7↑	674.5	514.4	12.3
Georgia	522.3	466.1	456.3	475.9	56.2↑	65.9	46.4	12.1	9247.0	8306.7	8093.7	8521.5	940.3↑	1153.2	725.5	11.3
Italy	223.1	204.8	200.9	208.8	18.3↑	22.2	14.3	8.9	5907.8	5164.9	5063.2	5267.2	743.0↑	844.6	640.6	14.4
Kazakhstan	403.6	316.5	311.2	321.9	87.1↑	92.4	81.7	27.5	5292.3	4656.5	6286.9	6532.2	635.8↓	-994.6	-1239.9	13.7
Mauritius	469.5	485.7	471.8	499.8	-16.2↓	-2.3	-30.3	-3.3	8573.1	7074.6	5954.9	6380.9	1498.5↑	2618.2	2192.2	21.2
Norway	174.3	168.9	164.8	173.1	5.4	9.6	1.3	3.2	4855.0	4723.9	4648.7	4799.4	131.1↑	206.3	55.6	2.8
Peru	317.5	176.6	172.9	180.4	140.9↑	144.6	137.1	79.8	6420.7	3901.9	3840.5	3963.6	2518.8↑	2580.2	2457.1	64.6
Poland	464.0	424.4	418.8	430.2	39.6↑	45.3	33.9	9.3	7142.9	5922.0	5815.8	6028.8	1220.9↑	1327.1	1114.1	20.6
Sweden	169.3	154.8	151.4	158.3	14.5↑	17.9	11.0	9.3	5292.3	4656.5	4589.7	4723.7	635.8↑	702.7	568.6	13.7
Ukraine	1395.0	1384.0	1243.0	1530.0	11.0	152.0	-135.0	0.8	8573.1	7074.6	6491.7	7673.9	1498.5↑	2081.4	899.2	21.2

*For all countries, the sum of observed and expected deaths is up to week 52, with the exception of England & Wales (starting from week 2 up to week 51), Kazakhstan and Mauritius (starting from week 2 up to week 52), Northern Ireland (up to week 50), and Slovenia (up to 51).
↑ Indicates statistically significant excess all-cause mortality using the sum of deaths for 2021.
↓ Indicates a statistically significant reduction all-cause mortality using the sum of deaths for 2021.
Due to the variability in the provided age groupings by countries, age-standardised mortality values are not entirely comparable between countries and direct comparisons between countries should be avoided.

Table S11. Cumulative observed and expected mortality rate for the whole year 2021 by age group.

Country	Observed mortality rate / 100,000 population*	Expected mortality rate / 100,000 population*	Lower limit of 95% CI of Expected mortality rate	Upper limit of 95% CI of Expected mortality rate	Difference (Observed -Expected mortality rate)	Difference using the Lower limit of 95% CI of Expected mortality rate	Difference using the Upper limit of 95% CI of Expected mortality rate	P-score (the ratio of the excess to the expected, expressed as a percentage)	Observed mortality rate / 100,000 population*	Expected mortality rate / 100,000 population*	Lower limit of 95% CI of Expected mortality rate	Upper limit of 95% CI of Expected mortality rate	Difference (Observed -Expected mortality rate)	Difference using the Lower limit of 95% CI of Expected mortality rate	Difference using the Upper limit of 95% CI of Expected mortality rate	P-score (the ratio of the excess to the expected, expressed as a percentage)
	<65								65+							
Australia	132.4	133.2	130.0	136.4	-0.8	2.4	-4.0	-0.6	3313.8	3159.4	3126.7	3192.1	154.5↑	187.1	121.7	4.9
Austria	185.7	166.2	162.7	169.8	19.4↑	23.0	15.8	11.7	4482.1	4149.3	4060.4	4239.0	332.7↑	421.7	243.1	8.0
Belgium	538.8	489.6	479.5	499.8	49.2↑	59.4	39.0	10.1	4243.2	4081.0	4000.7	4161.9	162.1↑	242.5	81.3	4.0
Brazil	379.1	269.7	265.2	274.3	109.4↑	113.9	104.8	40.5	5183.4	4151.5	4116.9	4186.2	1031.9↑	1066.5	997.2	24.9
Cyprus	138.0	126.1	117.4	134.9	11.9↑	20.5	3.1	9.4	4012.1	3483.9	3358.9	3610.4	528.2↑	653.2	401.8	15.2
Denmark	164.5	161.9	157.8	166.0	2.6	6.7	-1.5	1.6	4158.6	4039.1	3984.6	4093.9	119.4↑	174.0	64.6	3.0
England and Wales	196.1	168.6	164.9	172.3	27.4↑	31.1	23.7	16.3	4401.1	3912.5	3826.9	3998.7	488.6↑	574.2	402.4	12.5
Estonia	314.0	249.8	238.7	261.1	64.2↑	75.4	52.9	25.7	5576.1	4688.5	4579.4	4798.5	887.6↑	996.7	777.6	18.9

Georgia	455.6	345.2	337.1	353.4	110.4↑	118.5	102.3	32.0	8168.7	6013.0	5860.4	6166.9	2155.7↑	2308.3	2001.8	35.9
Greece	1296.2	1053.3	1034.1	1072.6	242.9↑	262.1	223.6	23.1	5297.6	4586.9	4489.1	4685.4	710.7↑	808.5	612.2	15.5
Israel	112.4	105.0	102.2	107.9	7.3↑	10.2	4.5	7.0	4009.5	3543.0	3486.0	3600.3	466.6↑	523.6	409.2	13.2
Italy	159.0	145.2	141.8	148.5	13.9↑	17.2	10.5	9.6	4275.2	3987.4	3909.5	4065.9	287.7↑	365.7	209.3	7.2
Northern Ireland	205.9	181.3	173.1	189.7	24.5↑	32.7	16.2	13.5	4410.9	3951.3	3825.9	4078.1	459.6↑	585.0	332.8	11.6
Norway	121.7	118.9	115.4	122.4	2.8	6.3	-0.7	2.4	3733.0	3556.5	3502.3	3611.0	176.4↑	230.6	122.0	5.0
Peru	308.4	156.1	152.5	159.7	152.3↑	155.9	148.7	97.6	5285.3	2971.9	2925.0	3019.0	2313.4↑	2360.2	2266.3	77.8
Poland	357.0	296.5	291.7	301.3	60.5↑	65.3	55.7	20.4	5650.7	4412.4	4336.5	4488.8	1238.3↑	1314.2	1161.9	28.1
Slovenia	206.1	182.0	175.1	189.0	24.1↑	31.0	17.1	13.2	4503.0	4037.5	3944.2	4131.4	465.5↑	558.7	371.5	11.5
Spain	930.4	833.3	824.1	842.6	97.0↑	106.3	87.7	11.6	4078.3	3766.6	3701.0	3832.6	311.7↑	377.3	245.7	8.3
USA	345.6	263.9	259.4	268.5	81.7↑	86.2	77.2	31.0	4423.9	3891.1	3861.5	3920.7	532.8↑	562.4	503.2	13.7
	<70								**70+**							
Cyprus	189.4	170.6	160.7	180.8	18.8↑	28.7	8.7	11.0	5308.5	4707.9	4532.5	4885.5	600.6↑	776.0	423.0	12.8
Denmark	238.6	235.3	230.6	240.1	3.2	8.0	-1.5	1.4	5214.4	4924.9	4852.4	4997.8	289.5↑	362.1	216.6	5.9
Estonia	355.8	351.0	339.2	362.9	4.8	16.6	-7.1	1.4	6376.7	5832.3	5691.5	5974.3	544.4↑	685.2	402.4	9.3
France	257.8	238.1	233.8	242.4	19.7↑	24.0	15.4	8.3	5100.4	4725.2	4645.8	4805.0	375.2↑	454.6	295.4	7.9
Georgia	613.0	457.3	447.6	467.0	155.7↑	165.4	146.0	34.1	10793.0	8170.3	7957.9	8384.6	2622.7↑	2835.1	2408.4	32.1
Italy	221.4	197.3	193.4	201.2	24.1↑	28.0	20.2	12.2	5360.1	4970.0	4869.7	5071.0	390.1↑	490.4	289.1	7.8
Kazakhstan	509.2	319.2	313.8	324.6	190.0↑	195.4	184.7	59.5	9532.4	6431.2	6307.9	6555.2	3101.2↑	3224.5	2977.1	48.2
Mauritius	471.0	499.7	485.5	514.1	-28.7↓	-14.5	-43.1	-5.7	5519.3	6126.8	5914.4	6341.6	-607.4↓	-395.1	-822.3	-9.9
Norway	171.0	163.9	159.8	168.1	7.0↑	11.1	2.9	4.3	4863.9	4554.3	4480.1	4628.8	309.7↑	383.8	235.1	6.8
Peru	371.1	182.7	178.8	186.7	188.4↑	192.3	184.5	103.1	6804.7	4036.3	3972.2	4100.7	2768.4↑	2832.5	2703.9	68.6
Poland	419.2	430.6	515.1	424.9	-11.5↓	-95.9	-5.7	-2.7	7375.2	5826.4	5720.4	5933.0	1548.9↑	1654.8	1442.3	26.6

Sweden	161.2	147.0	143.7	150.4	14.2↑	17.5	10.8	9.6	4741.2	4496.7	4430.6	4563.0	244.5↑	310.6	178.2	5.4
Ukraine	2419.0	1258.8	1124.0	1398.7	1160.2↑	1295.0	1020.3	92.2	8055.7	7125.3	6536.3	7730.9	930.5↑	1519.4	324.8	13.1

*For all countries, the sum of observed and expected deaths is up to week 52, with the exception of England & Wales (starting from week 2 up to week 51), Kazakhstan and Mauritius (starting from week 2 up to week 52), Northern Ireland (up to week 50), and Slovenia (up to 51).

↑ Indicates statistically significant excess all-cause mortality using the sum of deaths for 2021.

↓ Indicates a statistically significant reduction all-cause mortality using the sum of deaths for 2021.

Due to the variability in the provided age groupings by countries, age-standardised mortality values are not entirely comparable between countries and direct comparisons between countries should be avoided.

Table S12. The mean of sociodemographic determinants of excess mortality for each country 2020-2021

	Population density	Median age	% of population aged 65+	Life Expectancy	Hypertension prevalence (2019	Diabetes prevalence (2019)	Obesity prevalence (2019)	PM2.5 air pollution	GDP	HDI	IDHI	Gini index	Government Effectiveness	Government revenue	Hospital beds per 1,000 population	Medical Doctors per 1,000 population	Nursing Personnel per 1,000 population	UHC	Completeness of vital registration systems	Healthcare Access and Quality (HAQ)
Australia	3.359	36.806	16.42	83.2	29.3	6.4	29	8.550	49261.096	0.951	0.876	34.3	1.562	35.261	3.84	41.02	136.3	89.423	100	90.18
Austria	108.0	42.669	19.31	81.193	33.8	4.6	20.1	12.478	53054.781	0.916	0.851	30.2	1.646	49.379	7.05	54.10	104.9	86.370	100	87.97
Belgium	382.7	40.823	19.32	80.795	30	3.6	22.1	77.84	50359.236	0.937	0.874	27.2	1.121	49.930	5.519	48.60	191.0	87.301	99.8	86.6
Brazil	25.58	32.616	9.448	76.084	45	8.8	22.1	12.707	14307.155	0.754	0.576	48.9	-0.449	31.53	2.09	21.42	55.13	64.828	99.3	52.97
Cyprus	134.3	37.344	14.32	81.135	30.8	8.6	21.8	17.294	40579.396	0.896	0.819	31.2	0.806	42.44	3.4	53.75	42.82	99.897	90.7	86.17
Denmark	137.8	137.753	20.17	81.551	35.9	5.3	19.7	10.029	56740.62	0.948	0.898	27.7	1.943	54.094	2.552	42.64	101.6	84.140	100	85.54
England & Wales	276.8	39.543	18.83	80.902	26.4	6.3	27.8	10.473	43481.410	0.929	0.85	35.1	1.324	39.814	2.382	31.11	85.87	67.157	100	83.34
Estonia	30.58	41.423	20.28	78.346	40.2	6.5	21.2	6.732	37300.481	0.89	0.829	30.8	1.359	39.224	4.46	38.63	91.86	82.040	100	76.45
France	117.0	41.497	21.18	82.175	29.1	5.3	21.6	11.815	43613.133	0.903	0.825	32.4	1.253	52.510	5.73	33.24	118.5	90.766	100	88.02

Georgia	54.13	36.334	14.53	73.919	44.5	5.7	21.7	22.196	14726.493	0.802	0.706	34.5	0.132	25.42	2.89	51.32	58.17	55.953	94.3	57.71
Greece	80.08	44.545	22.36	81.088	31.3	6.4	24.9	16.218	28325.790	0.887	0.791	33.1	0.441	49.877	4.18	63.06	34.28	80.140	100	83.88
Israel	408.2	29.018	11.87	82.699	29.1	8.5	26.1	21.381	40706.568	0.919	0.815	38.6	1.190	41.605	2.915	36.22	53.84	81.384	100	83.08
Italy	200.6	46.626	23.54	82.344	33.8	6.4	19.9	16.751	40497.357	0.895	0.791	35.2	0.377	47.714	3.19	40.66	62.65	88.895	100	89.6
Kazakhstan	7.071	29.515	7.898	71.370	41.9	6.6	21	13.824	25736.019	0.811	0.755	27.8	0.101	14.94	6.06	40.28	66.55	59.237	88.3	59.47
Northern Ireland	276.8	39.543	18.83	80.902	26.4	6.3	27.8	10.473	43481.410	0.929	0.85	35.1	1.324	39.814	2.381	31.12	85.88	67.157	100	83.34
Norway	17.72	39.186	17.93	83.210	30.5	3.6	23.1	6.956	64605.088	0.961	0.908	27.7	1.883	57.567	3.4	51.30	181.9	94.241	100	90.4
Peru	26.19	28.076	8.289	76.947	20.7	4.8	19.7	24.787	11845.785	0.762	0.635	43.8	-0.262	21	1.59	16.46	19.89	75.759	64.4	60
Poland	125.3	40.701	18.62	76.600	49.2	6.8	23.1	20.878	33731.175	0.876	0.816	30.2	0.326	41.849	6.19	37.14	60.27	72.656	100	73.2
Slovenia	105.2	43.055	20.32	80.532	45.3	5.8	20.2	16.024	38567.302	0.918	0.878	24.4	1.168	44.028	4.28	32.79	103.9	89.834	94.8	87.8
Spain	94.42	43.688	19.80	82.334	27.2	10.3	23.8	9.698	36940.484	0.905	0.788	34.3	0.917	42.78317416	2.95	45.77	61.04	90.006	100	89.67
Sweden	25.59	39.502	20.07	82.407	30.2	5	20.6	6.184	52472.352	0.947	0.885	29.3	1.681	49.316	2.05	70.62	203	90.361	100	90.38
Ukraine	75.44	40.638	17.30	71.185	43.1	5.6	24.1	20.310	12675.702	0.773	0.726	25.6	-0.396	36.94	7.46	29.9	62.95	63.812	100	63.05
USA	36.7	37.575	16.4	77.28	31.	10.	36.	7.409	61918.78	0.92	0.81	41.	1.32	32.660	2.8	35.5	124.	82.13	99.	80.5

	9		7	0	6	7	2			1	9	5	3			5	7	8	9	8

*Recent data from reliable sources was not available for Mauritius. Peru and Kazakhstan are included here for descriptive purposes, but were excluded from the analyses of determinants of excess mortality due to a completeness of vital registration systems of <90%.

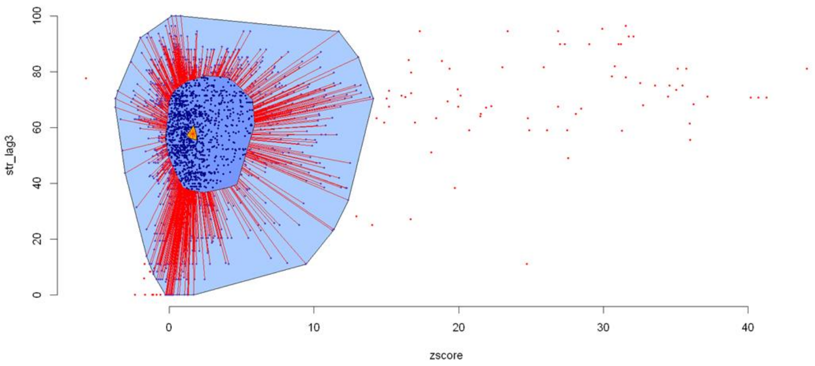

Figure S1. Bag plot of the observations in 2020 and 2021, regarding z-score and Stringency of control measures (3-week lag). In the bag plot, half of the data is in the dark blue polygon (interior polygon) and the outer polygon is used to identify outliers.

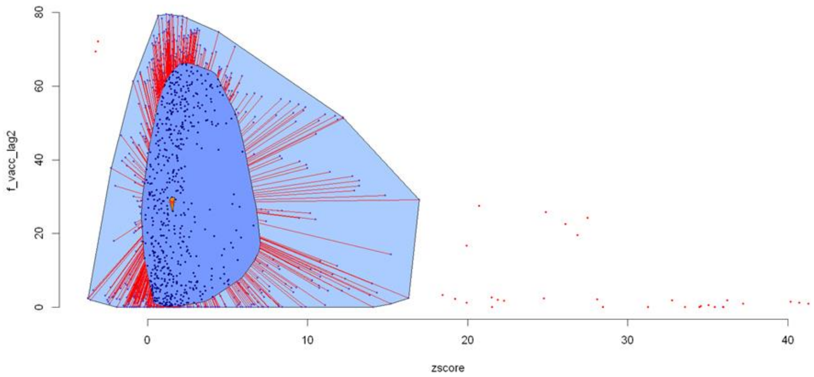

Figure S2. Bag plot of the observations in 2021, regarding z-score and fully vaccinated per 100 population (2-week lag).

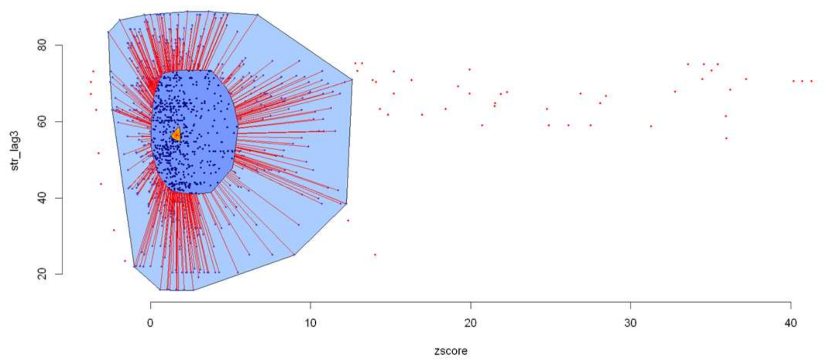

Figure S3. Bag plot of the observations in 2021, regarding z-score and Stringency of control measures (3-week lag).

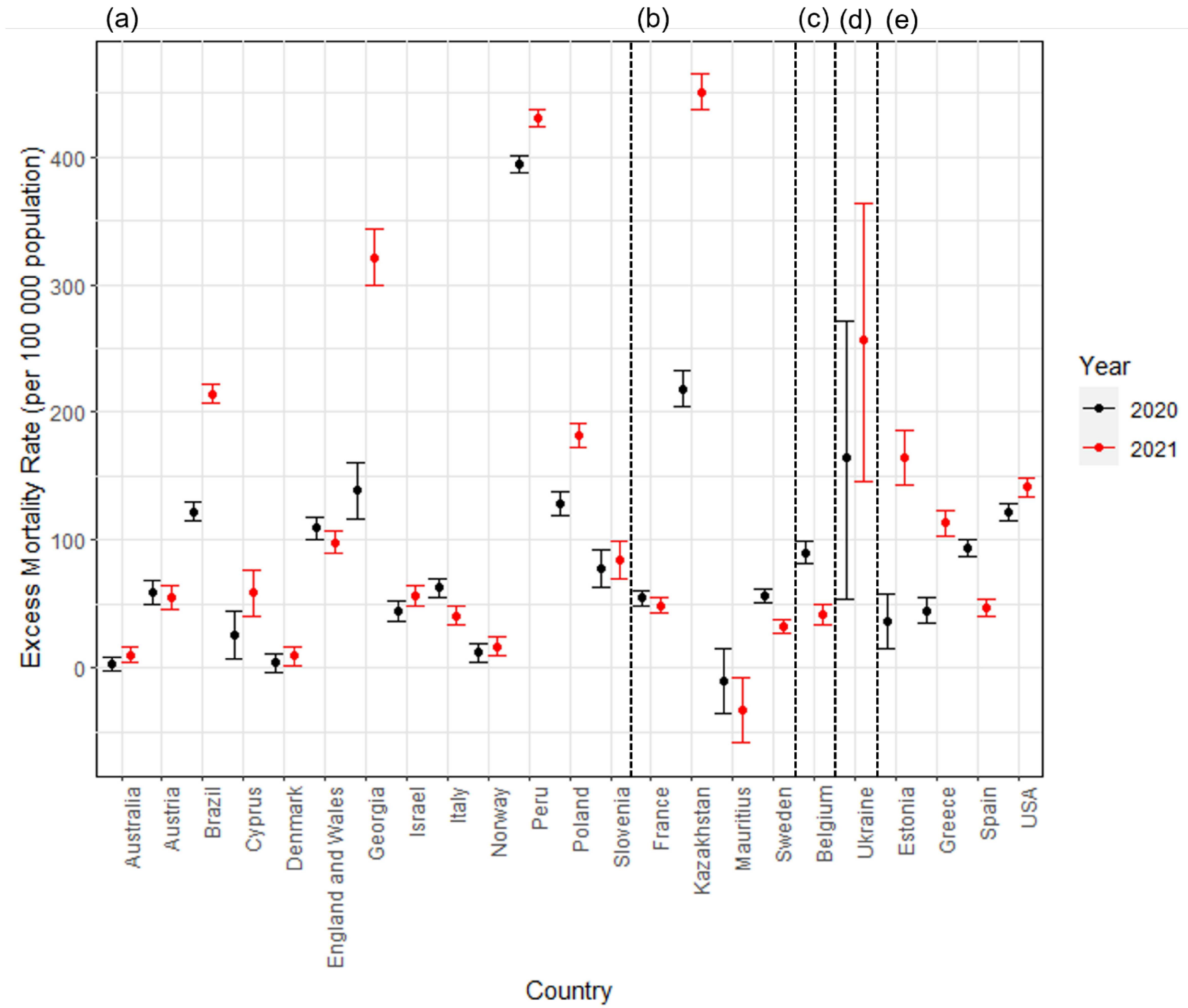
(a)
(b)
(c)
(d)
(e)
Excess Mortality Rate (per 100 000 population)
400
300
200
100
0
Year
2020
2021
Australia
Austria
Brazil
Cyprus
Denmark
England and Wales
Georgia
Israel
Italy
Norway
Peru
Poland
Slovenia
France
Kazakhstan
Mauritius
Sweden
Belgium
Ukraine
Estonia
Greece
Spain
USA
Country

Figure S4. Cumulative excess age-standardized mortality rate for males for 2020 and 2021. Plot letters correspond to the age groups in which countries have provided data and therefore the age groups used for age standardization: (a) age groups <15, 15-44, 45-64, 65+; (b) age groups <20, 20-49, 50-69, 70+; (c) age groups <45, 45-64, 65+; (d) age groups <20, 20-69, 70+; (e) age groups <15, 15-64, 65+. The plot was produced using R.

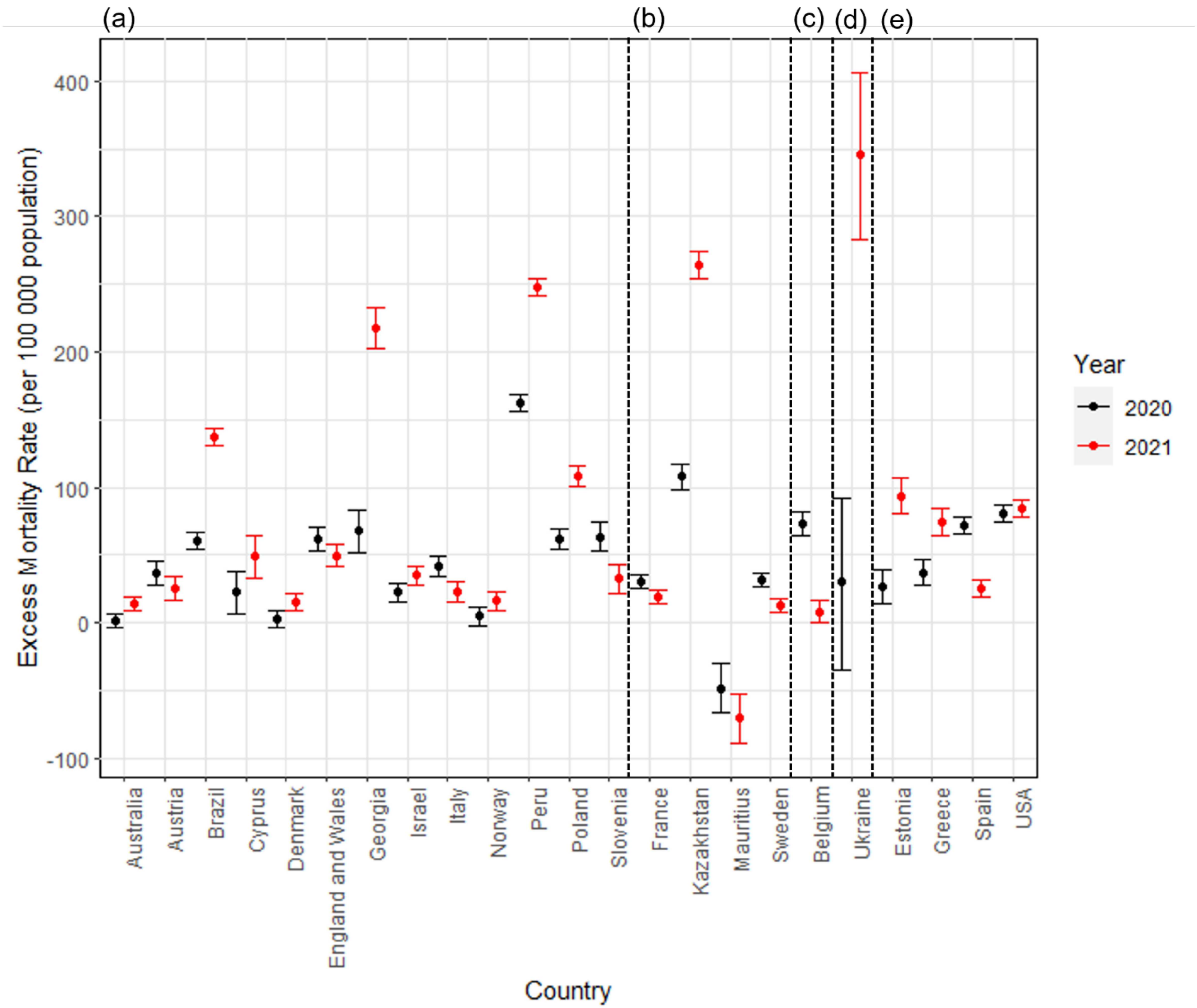
(a)
(b)
(c)
(d)
(e)
Excess Mortality Rate (per 100 000 population)
400
300
200
100
0
-100
Australia
Austria
Brazil
Cyprus
Denmark
England and Wales
Georgia
Israel
Italy
Norway
Peru
Poland
Slovenia
France
Kazakhstan
Mauritius
Sweden
Belgium
Ukraine
Estonia
Greece
Spain
USA
Country
Year
2020
2021

Figure S5. Cumulative excess age-standardized mortality rate for females for 2020 and 2021. Plot letters correspond to the age groups in which countries have provided data and therefore the age groups used for age standardization: (a) age groups <15, 15-44, 45-64, 65+; (b) age groups <20, 20-49, 50-69, 70+; (c) age groups <45, 45-64, 65+; (d) age groups <20, 20-69, 70+; (e) age groups <15, 15-64, 65+. The plot was produced using R.

Pallari CT, *et al. BMJ Glob Health* 2024; 9:e013018. doi: 10.1136/bmjgh-2023-013018

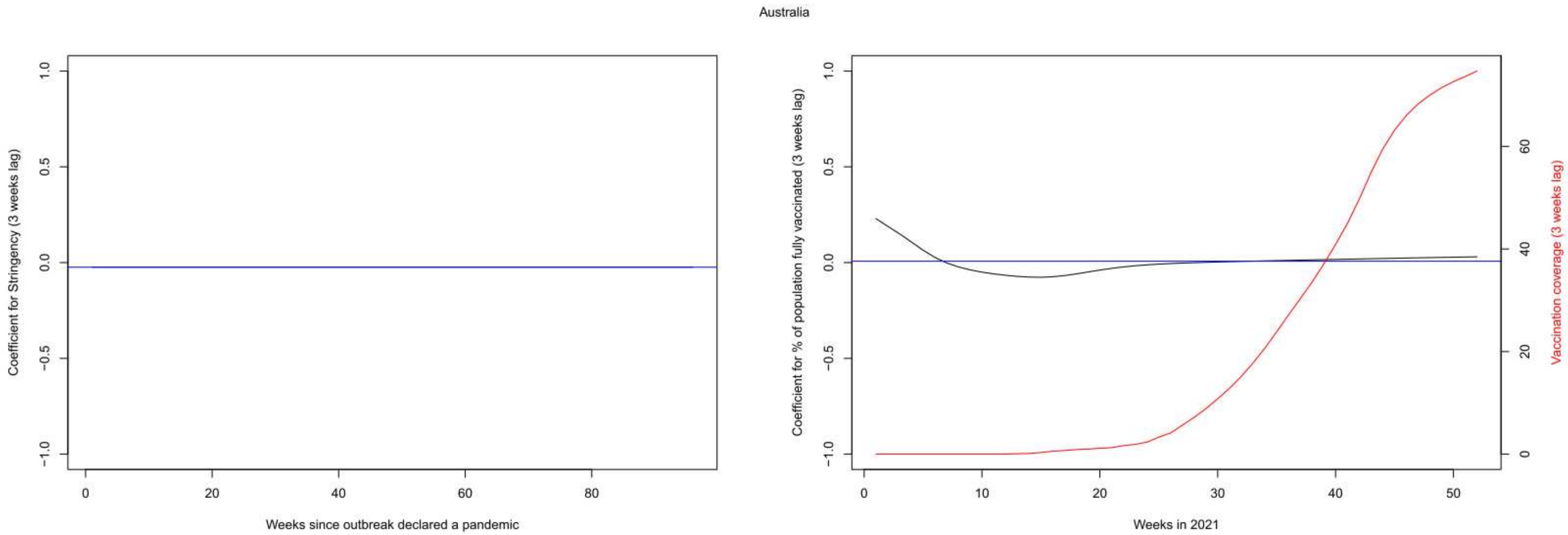

Figure S6 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for Australia.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Negative coefficients throughout. NB: blue line is superimposed on the black line.

Vaccination: Coefficients drop to negative values shortly after vaccine introduction (week 15), but then increase again to reach a plateau that is positive at the end of 2021.

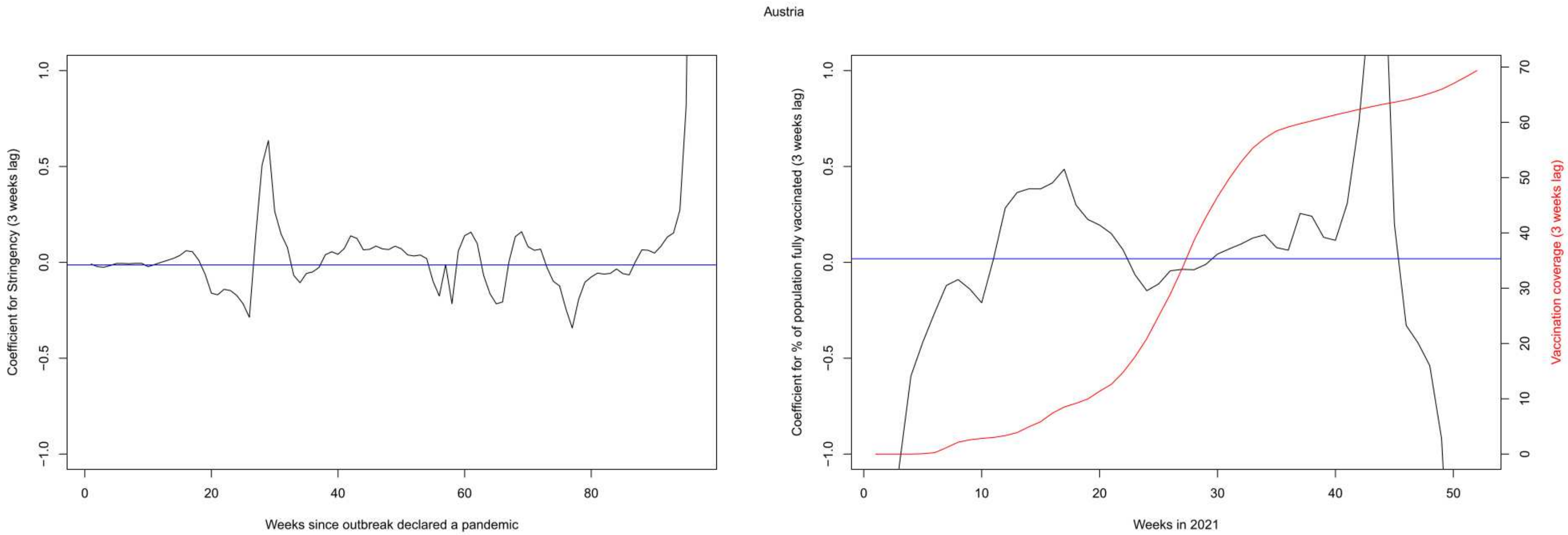

Figure S7 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for Austria.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Coefficients fluctuating between positive and negative values throughout 2020-2021

Vaccination: Coefficients start in the negative range. The coefficients then increase towards zero and weak positive values (weeks 15-35), but sharply increase between weeks 40-45, to drop to negative values again at the end of 2021.

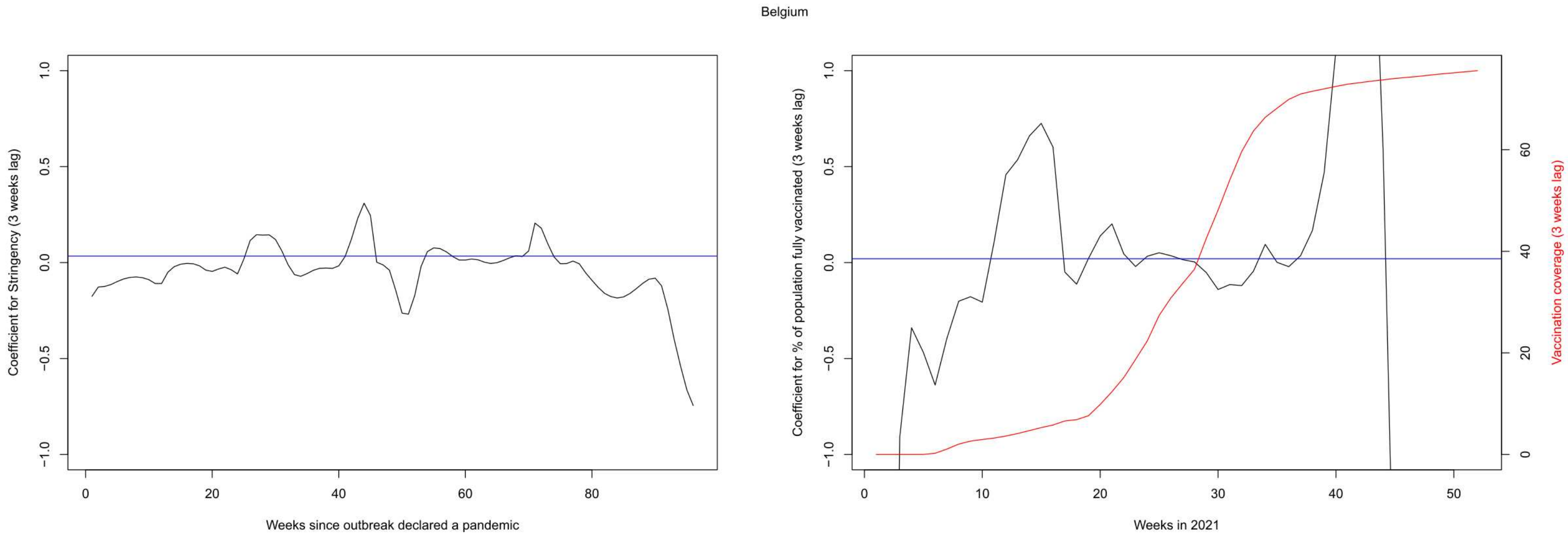

Figure S8 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for Belgium.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Coefficients fluctuating between positive and negative values throughout 2020-2021, but were in the negative range for most of the years.

Vaccination: Coefficients start in the negative range. The coefficients then increase towards zero and weak positive values in weeks 12-35. They then sharply increase until week 42, to drop to negative values again at the end of 2021.

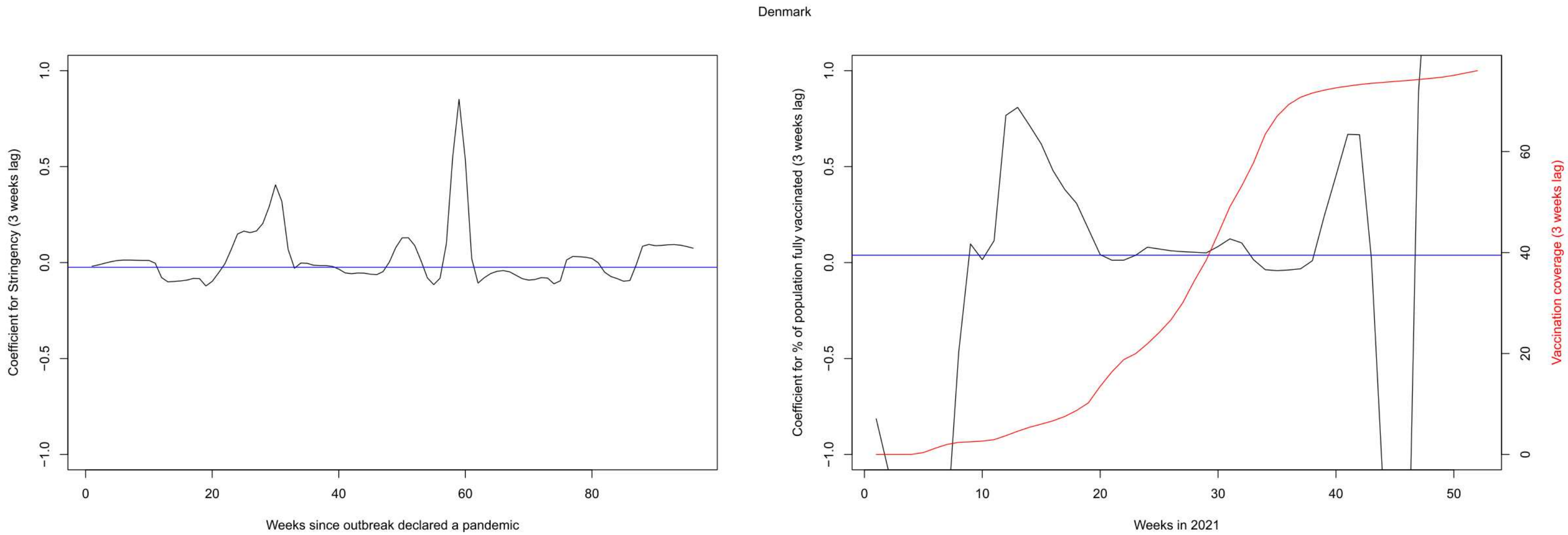

Figure S9 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for Denmark.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Coefficients fluctuating between positive and negative values throughout 2020-2021.

Vaccination: Coefficients start in the negative range. Then, coefficients increase towards zero (week 15). There are two sharp peaks between weeks 10-20 and weeks 38-42. The coefficients drop sharply to negative values between 42-48 weeks to increase sharply again at the end of 2021.

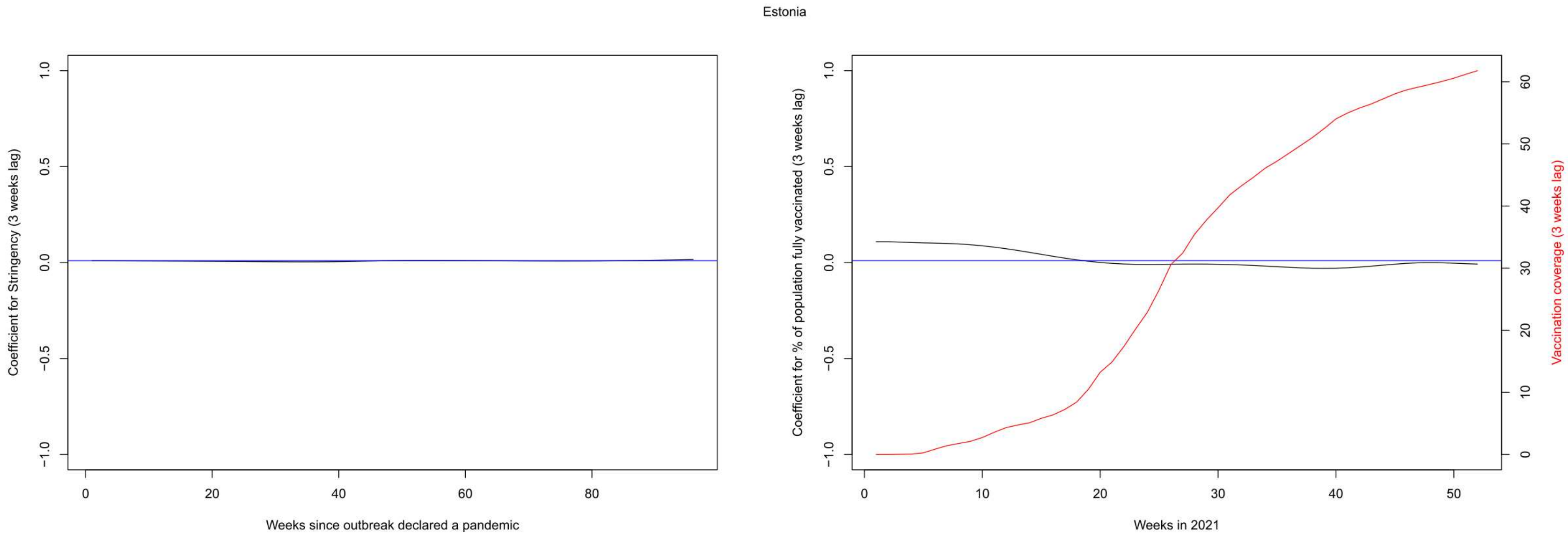

Figure S10 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for Estonia.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Positive coefficient throughout,. NB: black line is superimposed by the blue line.

Vaccination: Coefficients start positive and then drop to negative values around week 20, and remain in the negative range throughout the rest of the year. Despite still negative, the coefficients are slightly attenuated between weeks 40-50.

Pallari CT, *et al. BMJ Glob Health* 2024; 9:e013018. doi: 10.1136/bmjgh-2023-013018

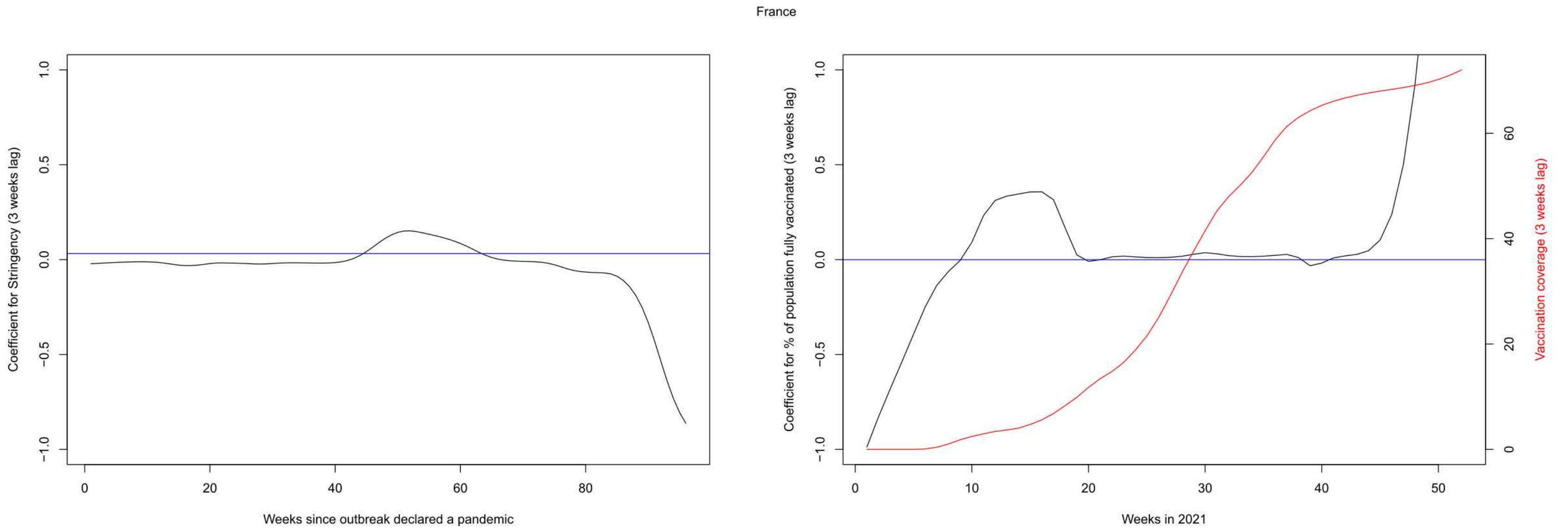

Figure S11 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for France.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Coefficients were negative for most of 2020-2021, with a brief increase to positive values in the first weeks of 2021.

Vaccination: Coefficients start in the negative range. Coefficients then increase towards zero and positive values (weeks 10-30). They then remain stable around zero until week 42 when they sharply increase and remain high until the end of 2021.

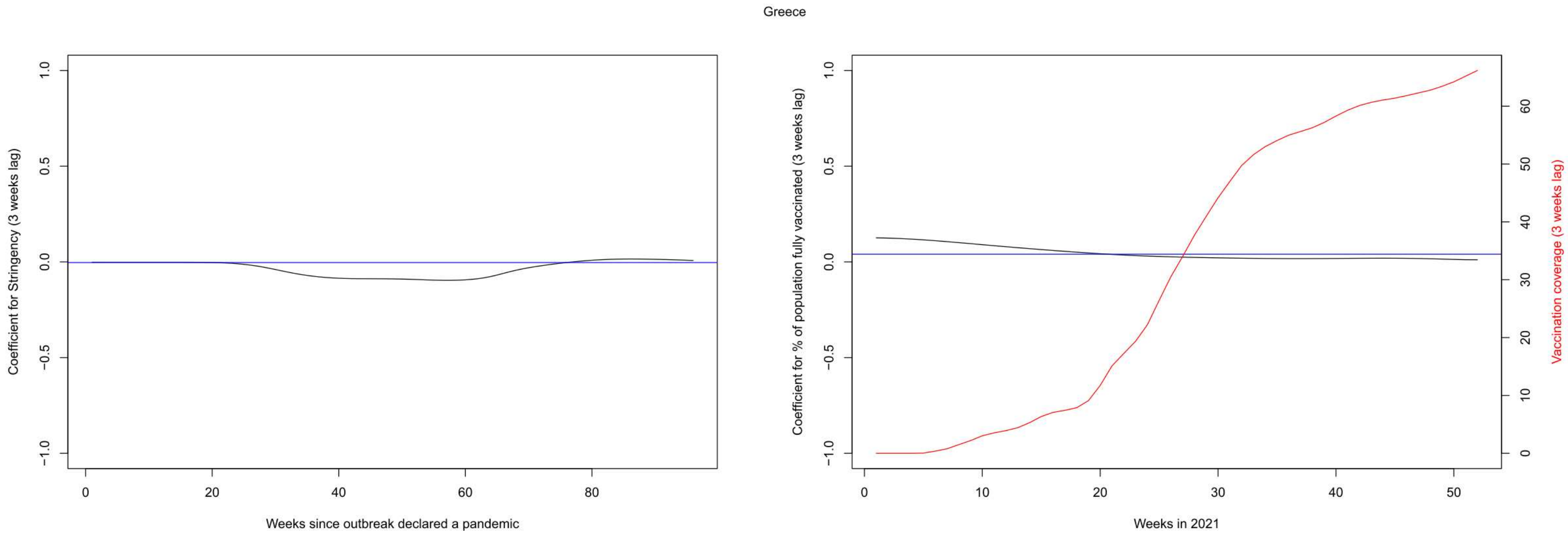

Figure S12 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for Greece.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Coefficients were negative for most of 2020-2021, with a brief increase to positive values during the last weeks of 2021.

Vaccination: Coefficients were positive and dropped to zero and negative values after week 20 and remained negative until the end of the year.

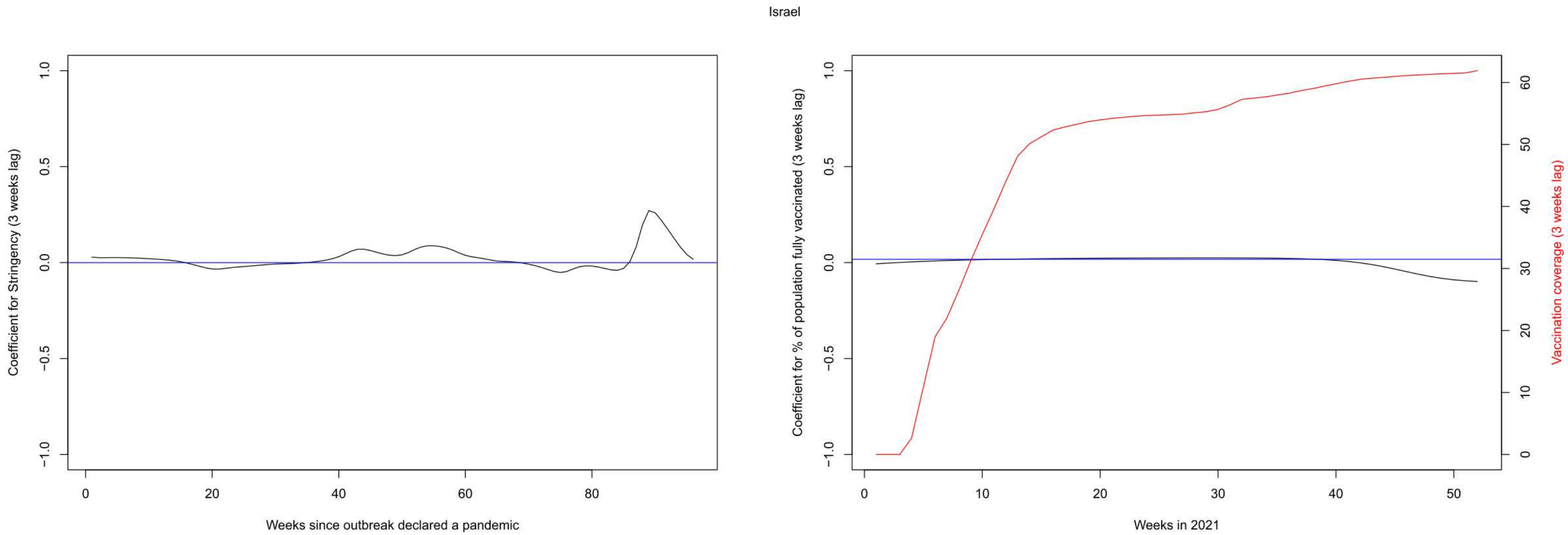

Figure S13 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for Israel.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Coefficients fluctuating between positive and negative values throughout 2020-2021.

Vaccination: Coefficients start in the negative range. The coefficients then increase slightly towards zero (weeks 10-35), and then drop to negative values again at the end of 2021.

Pallari CT, *et al. BMJ Glob Health* 2024; 9:e013018. doi: 10.1136/bmjgh-2023-013018

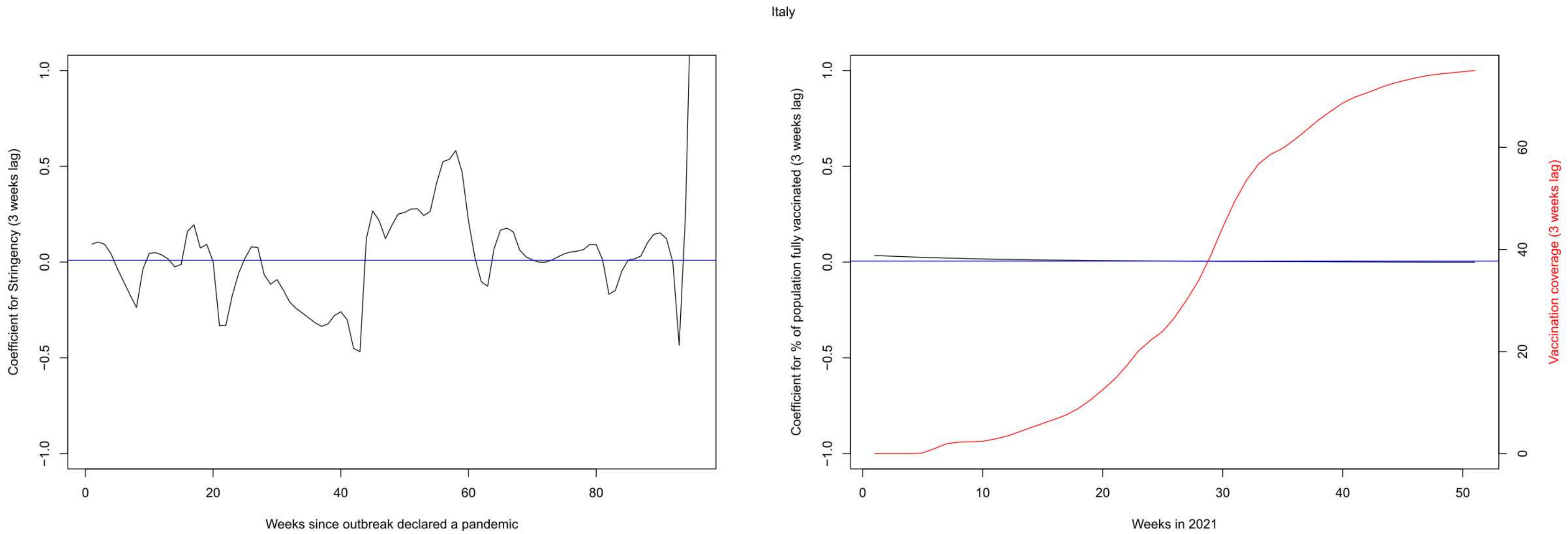

Figure S14 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for Italy.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Coefficients fluctuating between positive and negative values throughout 2020-2021.

Vaccination: Coefficients were positive and dropped to zero and weak negative values after week 20 and remained negative until the end of the year.

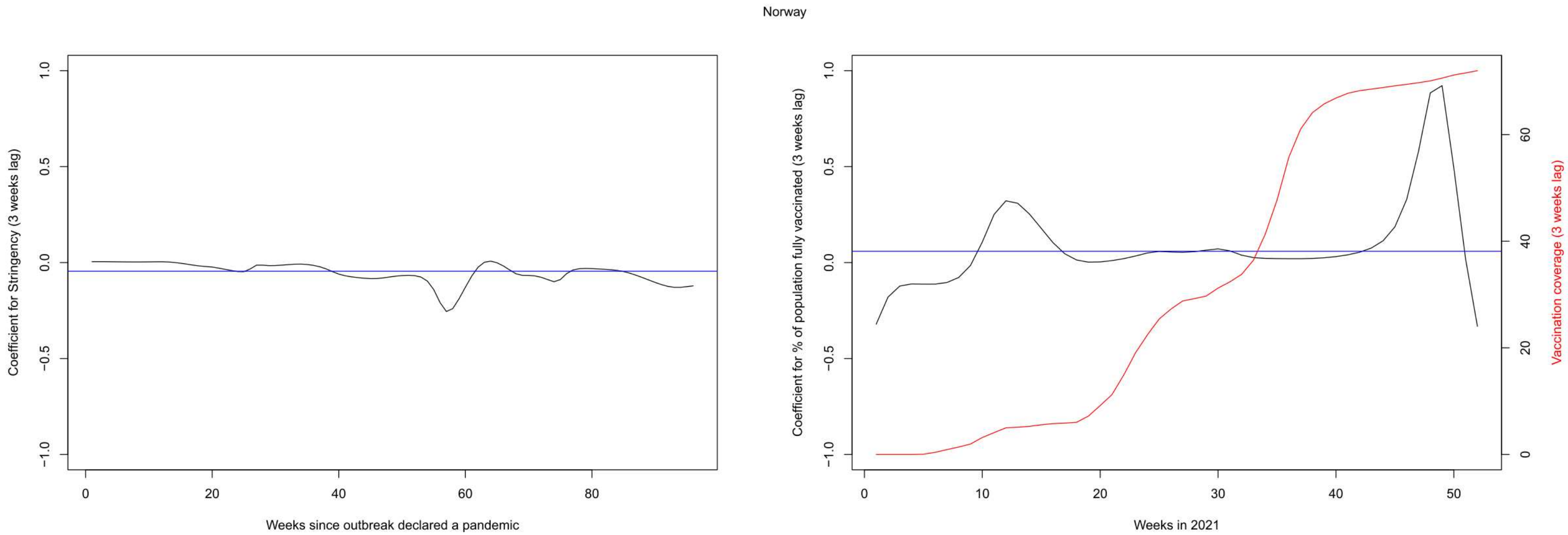

Figure S15 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for Norway.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Coefficients fluctuating but were negative values throughout 2020-2021

Vaccination: Coefficients start in the negative range. Then, coefficients increase towards zero (week 10), where they largely remain with the exception of two sharp peaks between weeks 10-20 and weeks 40-50.

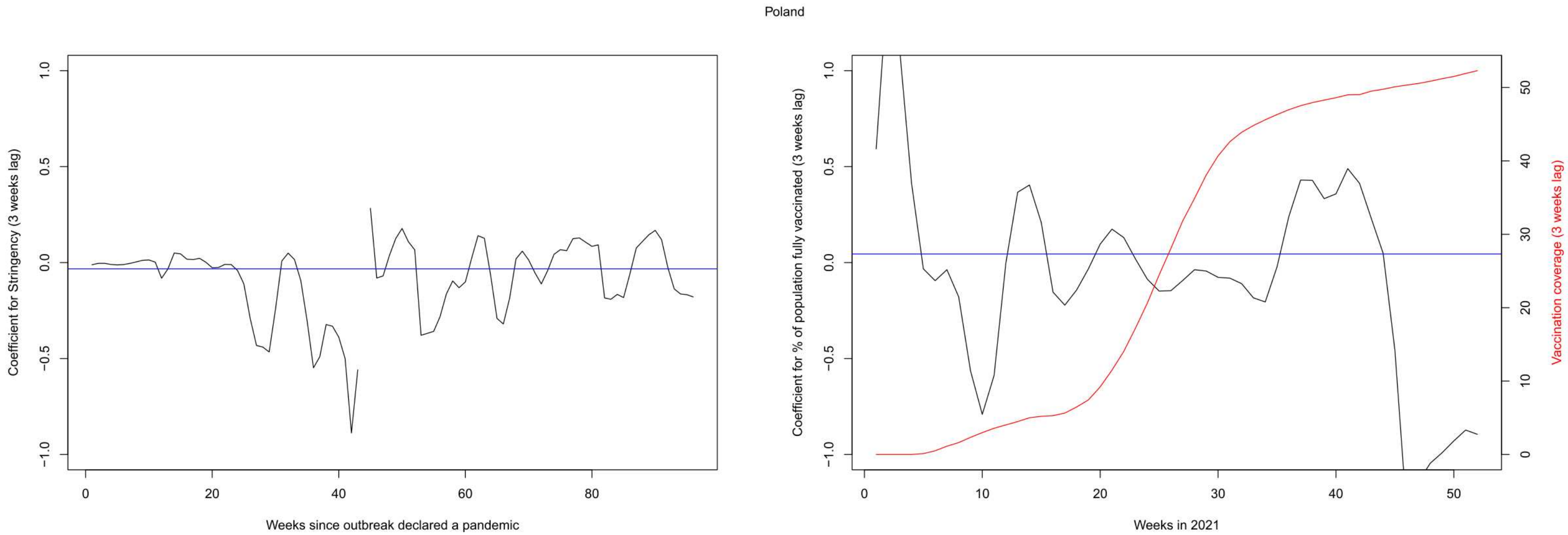

Figure S16 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for Poland.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Coefficients fluctuating between positive and negative values throughout 2020-2021, but were in the negative range for most of the years.

Vaccinations: Coefficients start in the positive range and from week 5 onwards fluctuate between positive and negative values. There is a brief sustained increase in the coefficients between weeks 35-45, but the coefficients then drop back to negative values.

Pallari CT, *et al. BMJ Glob Health* 2024; 9:e013018. doi: 10.1136/bmjgh-2023-013018

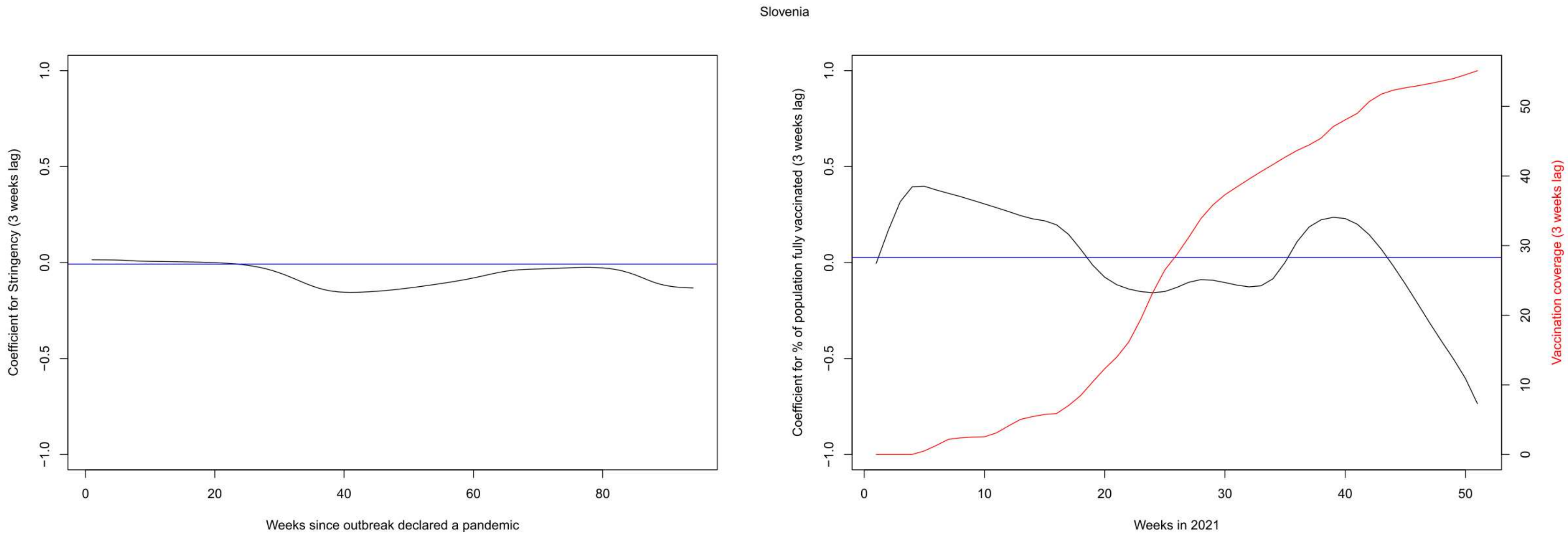

Figure S17 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for Slovenia.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Coefficients fluctuating throughout 2020-2021, but were in the negative range for most of the years.

Vaccinations: Coefficients start in the positive range but drop to negative values between weeks 20-35. There is a brief sustained increase in the coefficients between weeks 35-45, but the coefficients then drop back to negative values.

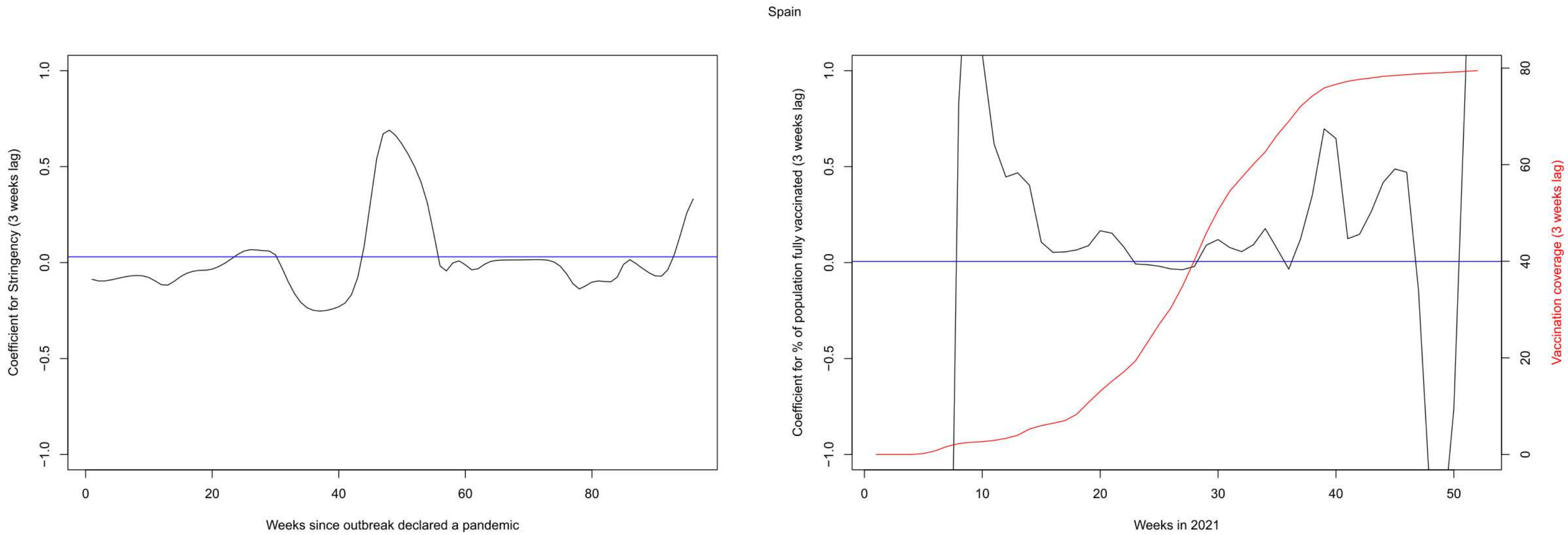

Figure S18 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for Spain.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Coefficients fluctuating throughout 2020-2021, but were in the negative range for most of the years.

Vaccination: Coefficients increase towards zero and positive values (weeks 10-35), but then decrease and sharply increase to positive values again at the end of 2021.

Pallari CT, *et al. BMJ Glob Health* 2024; 9:e013018. doi: 10.1136/bmjgh-2023-013018

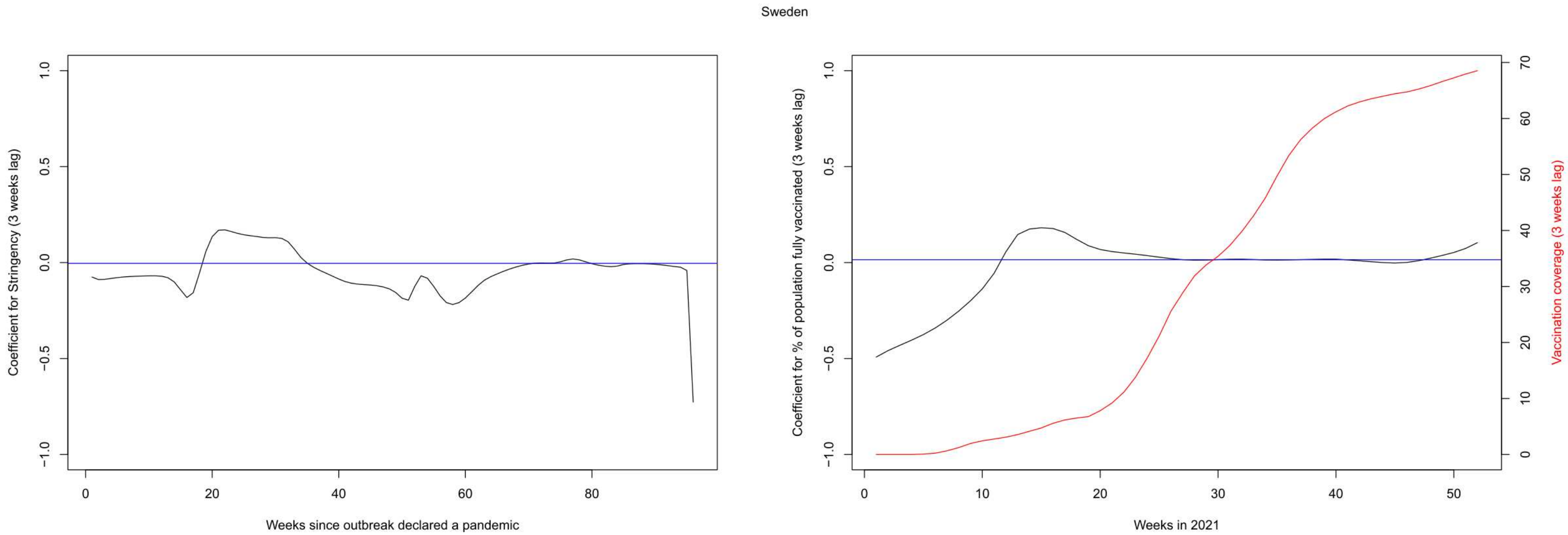

Figure S19 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for Sweden.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Coefficients fluctuating throughout 2020-2021, but were in the negative range for most of the years.

Vaccination: Coefficients start in the negative range indicating that the first vaccinations, that prioritised older and vulnerable portions of the population, managed to mitigate excess mortality. Then, coefficients increase towards zero and weak positive values (week 15), where they remain for the rest of the year.

Pallari CT, *et al. BMJ Glob Health* 2024; 9:e013018. doi: 10.1136/bmjgh-2023-013018

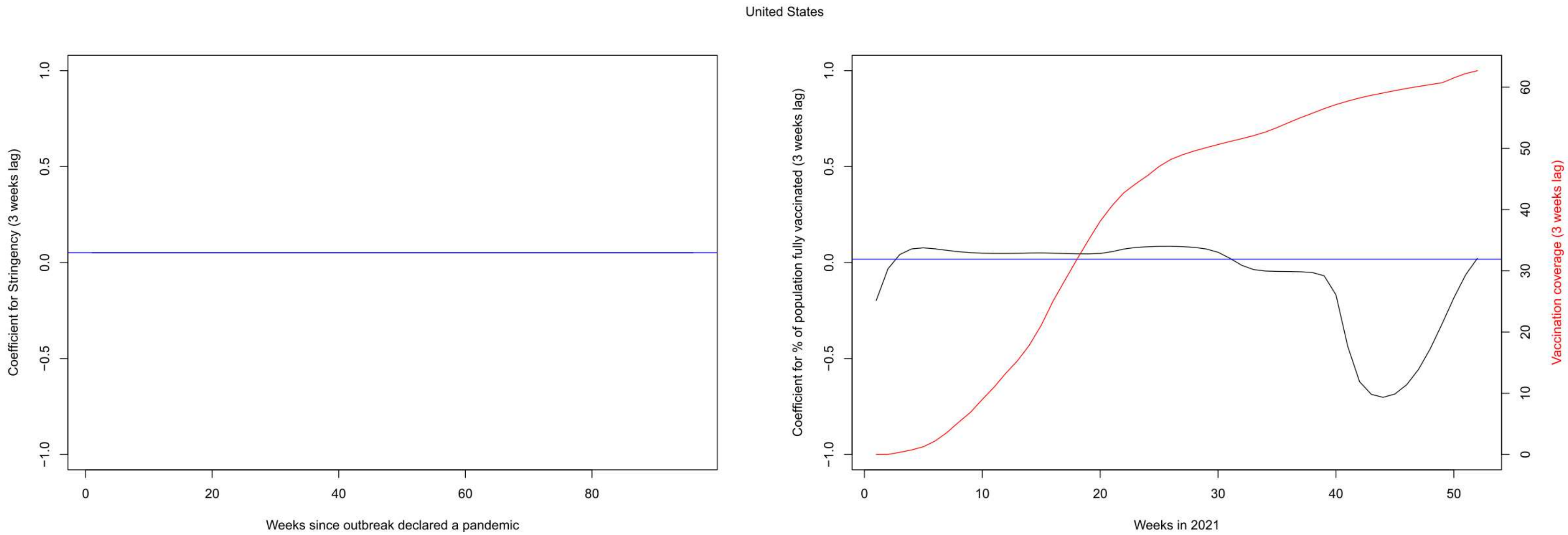

Figure S20 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for Australia.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Positive coefficients throughout. NB: black line is superimposed by the blue line.

Vaccination: Coefficients start negative but increase to positive values between weeks 5-30. The coefficients then drop to negative values between weeks 30-50, and then increase again to zero at the end of 2021.

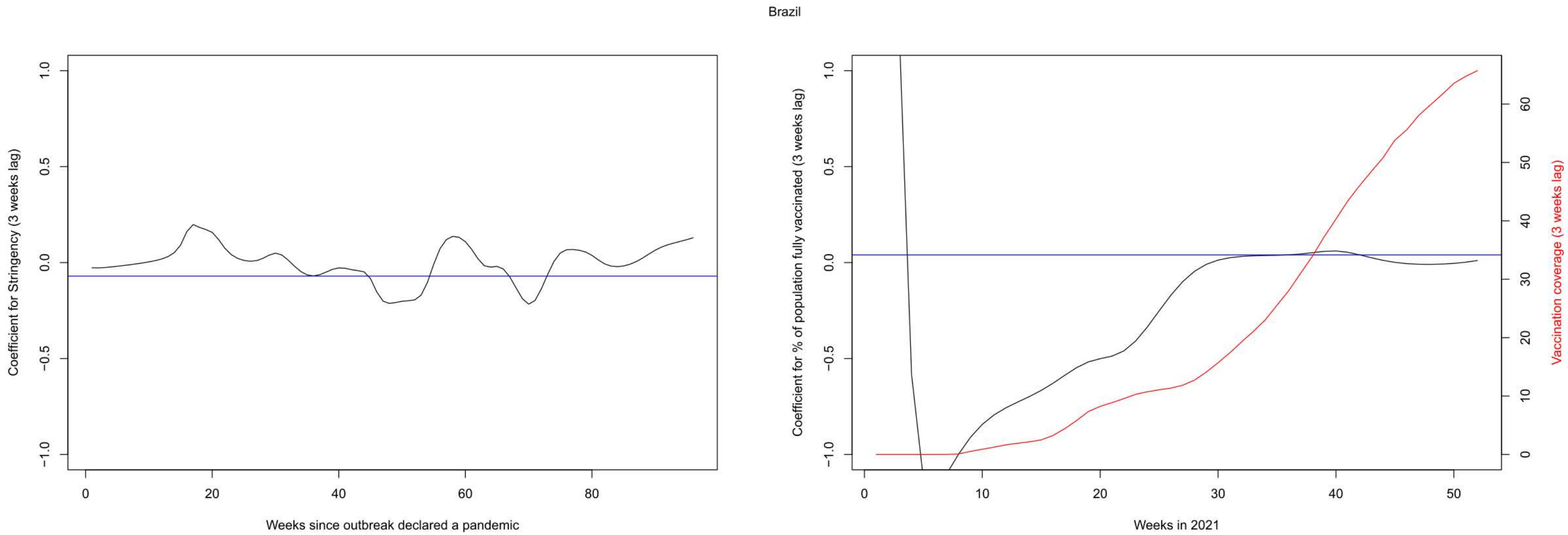

Figure S21 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for Brazil.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Coefficients fluctuating between positive and negative values throughout 2020-2021

Vaccination: Coefficients start positive and drop to negative values after vaccine introduction (weeks 5-30), but then increase again to reach a plateau around zero at the end of 2021.

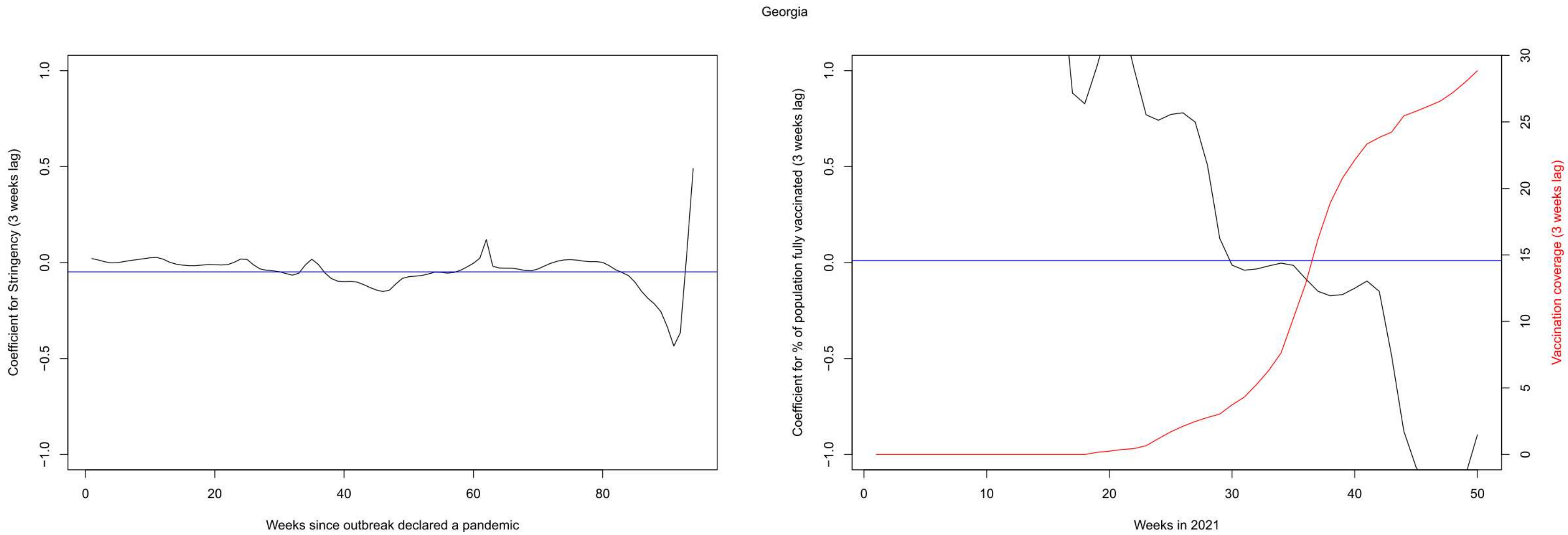

Figure S22 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for Georgia.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Coefficients fluctuating between positive and negative values, but were mostly negative in throughout 2020-2021

Vaccination: Coefficients start positive and then drop close to zero around week 30, and remain in the negative range throughout the rest of the year.

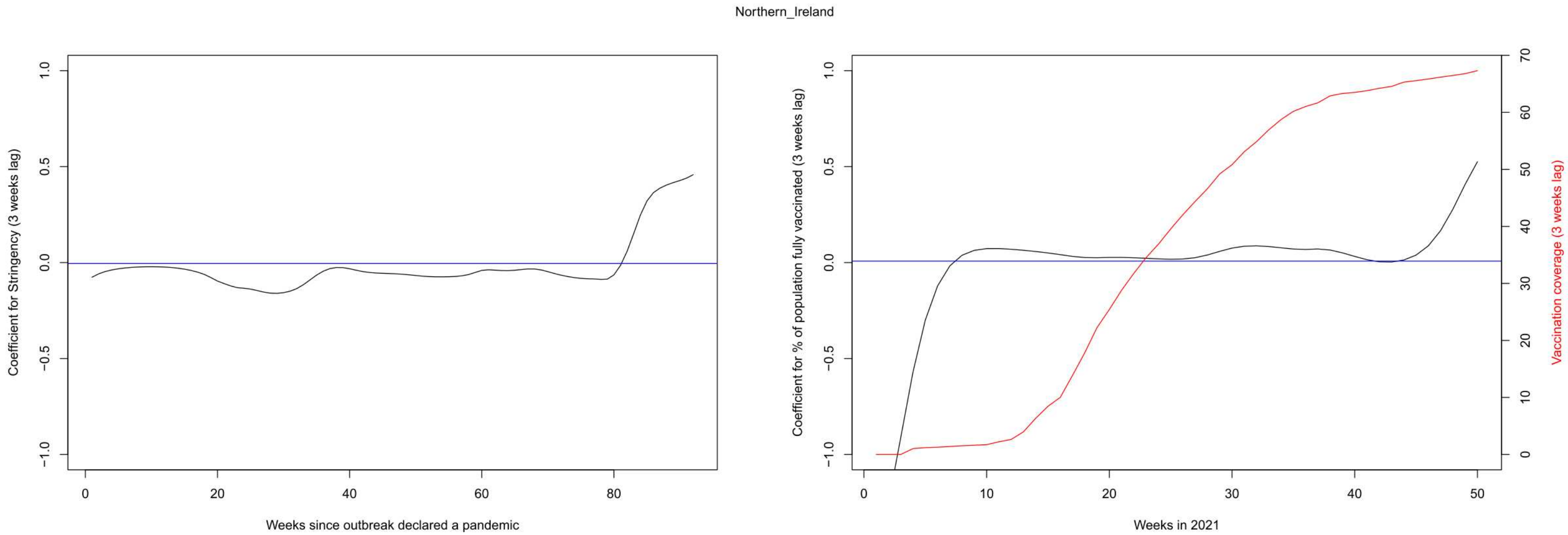

Figure S23 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for Northern Ireland.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Coefficients fluctuating throughout 2020-2021, but were in the negative range for most of the years.

Vaccination: Coefficients start in the negative range. Then, coefficients increase towards zero (week 7) where they remain until later in the year. There is one peak during the last 5 weeks of the year.

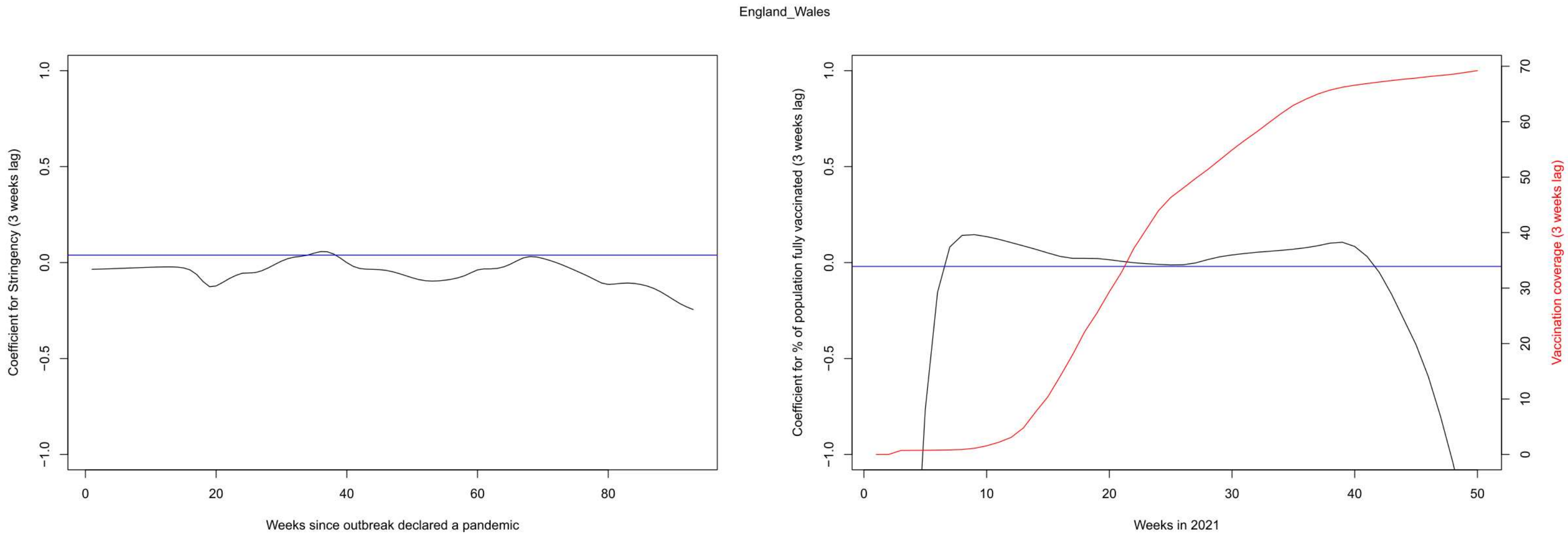

Figure S24 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for England and Wales.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Coefficients fluctuating throughout 2020-2021, but were in the negative range for most of the years.

Vaccination: Coefficients start in the negative range but quickly increase towards zero and weak positive values (week 8) where they remain until later in the year. There is a decrease in coefficients after week 40 of the year.

Pallari CT, *et al. BMJ Glob Health* 2024; 9:e013018. doi: 10.1136/bmjgh-2023-013018

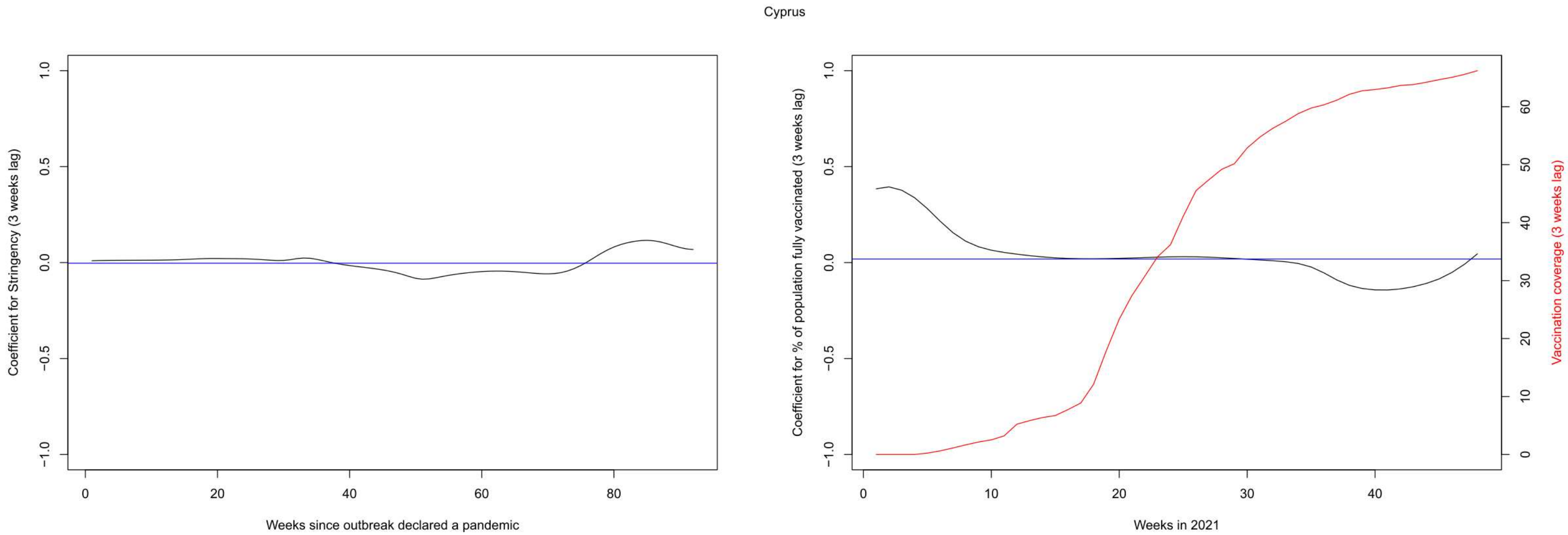

Figure S25 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for Cyprus.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Coefficients fluctuating between positive and negative values throughout 2020-2021

Vaccination: Coefficients start positive and then drop close to zero around week 15-30. They then remain in the negative range until the last few weeks of the year when they increase again to values close to zero.

Pallari CT, *et al. BMJ Glob Health* 2024; 9:e013018. doi: 10.1136/bmjgh-2023-013018

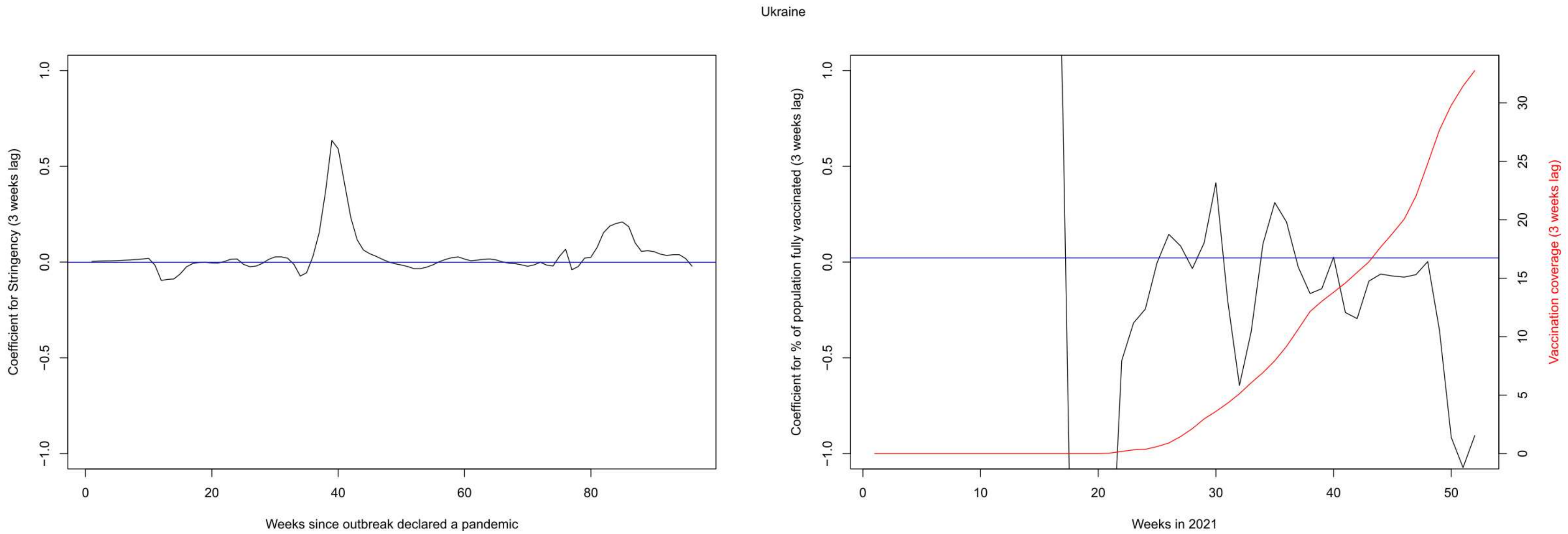

Figure S26 – Time varying coefficients for A) stringency index (3-week lag) and B) % population fully vaccinated (3-week lag) for Ukraine.

Black line marks coefficients obtained from a regression model with time-varying exposure against excess mortality z-scores, adjusting for weekly COVID-19 incidence. The x-axis represents number of weeks, during 2020-2021 for A and during 2021 for B. Blue line represents the coefficient from the corresponding non-time-varying linear regression model. Red line marks vaccination coverage as % of population fully vaccinated in 2021.

Stringency: Coefficients fluctuating between positive and negative values throughout 2020-2021

Vaccination: Coefficients were in the negative range, but increase towards zero wround weej 25 . The coefficients then fluctuate close to zero until the last 5 weeks of the year when they drop to negative values again.

Pallari CT, *et al. BMJ Glob Health* 2024; 9:e013018. doi: 10.1136/bmjgh-2023-013018

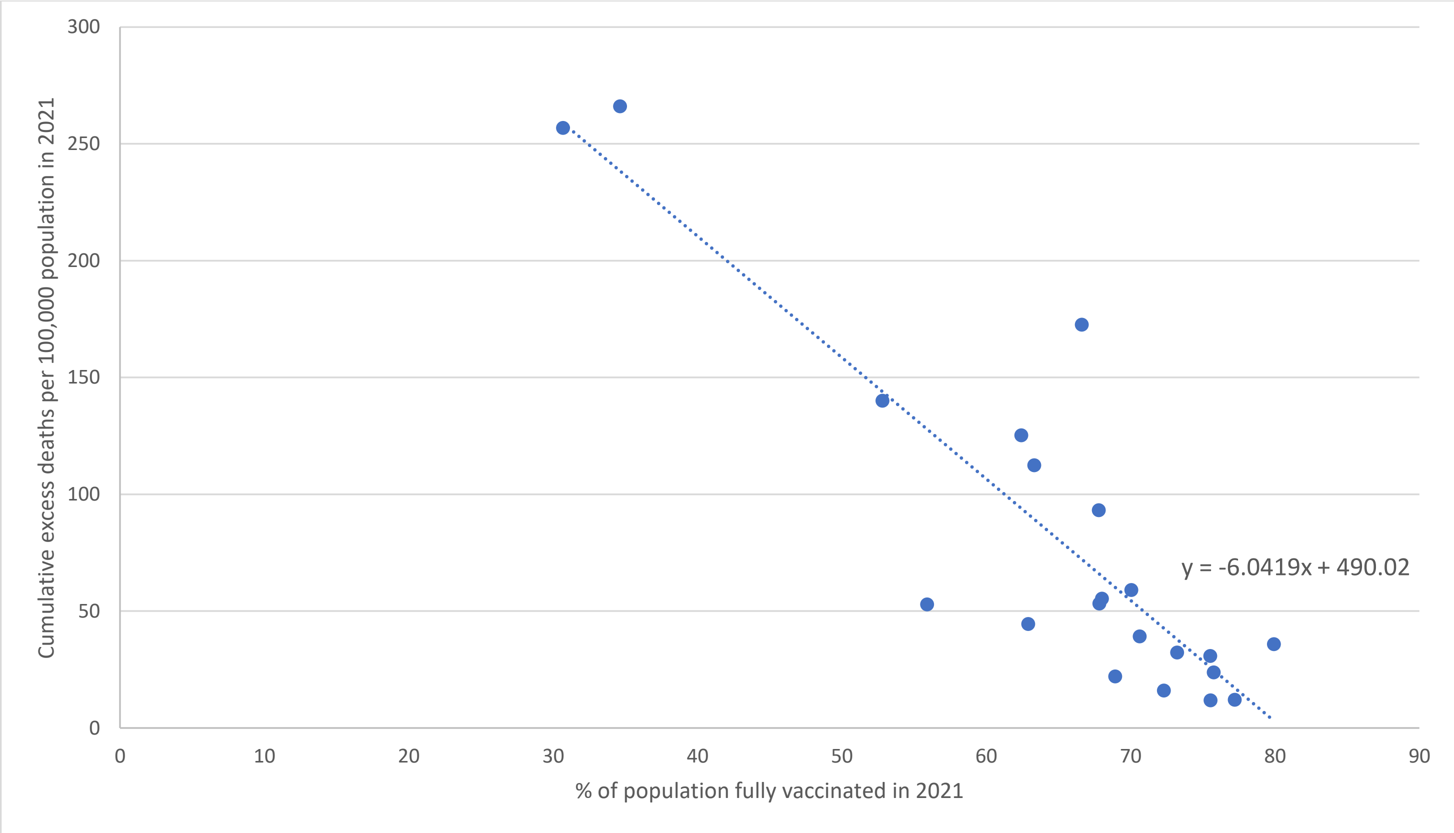

Figure S27. Scatterplot of cumulative excess deaths per 100,000 population and % of population fully vaccinated, across countries, in 2021. Kazakhstan and Peru are excluded due to a completeness of vital registration systems of <90%.