COVID-19: Analyzing All-Cause Mortality and Excess Deaths

DATA 601 PROJECT

PopHealth3

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Abstract

We are researching the patterns in all-cause mortality during the COVID-19 pandemic from 2020 to 2022, compared to pre-pandemic years, focusing on 38 OECD countries. The objective was to determine if the observed excess deaths were attributable to COVID-19. Excess mortality data, representing the difference between actual reported deaths and expected deaths in the absence of the pandemic, sourced from the OECD database.

Time series analysis was conducted to analyse the patterns of all-cause mortality, excess, and COVID-19 mortality. Pearson's correlation test, linear, and multiple regression models were used to estimate the correlation between excess all-cause mortality and COVID-19 mortality per 100,000. Separate analyses were conducted for each year - 2020,2021 and 2022 to capture temporal changes.

Statistical analysis for 2020 showed a strong correlation between excess deaths and COVID-19 deaths (correlation coefficient r of 0.80 and a coefficient of determination R^2 of 0.64). Excess deaths ranged from -40.98 to 253.92, and COVID-19 deaths varied from 0.51 to 172.23. In 2021, not only did the correlation increase (r = 0.89, R^2=0.79), with excess deaths ranging from -10.02 to 405.43, and COVID-19 deaths rose to a range of 0.45 to 301.77. However, 2022 saw a weakened correlation (r=0.64, R^2=0.41), suggesting an increasing influence of non-COVID factors on mortality, excess deaths ranged from -9.968 to 256.617, and COVID-19 deaths were recorded between 11.57 and 133.85.

Our findings indicate a significant rise in all-cause mortality rates from 2020 across the majority of the countries. The year 2020 witnessed substantial fluctuations in mortality, with countries like Mexico and Lithuania experiencing high excess deaths, contrasting with New Zealand and Australia, which reported negative excess deaths. The volatility continued in 2021, displaying diverse mortality trends. By 2022, the correlation between excess and COVID-19 deaths diminished, implying the influence of other factors on mortality rates.

Keywords: COVID-19, excess mortality, OECD countries, all-cause mortality, linear regression

Introduction

Initially, our original project idea centered around exploring the relationship between obesity and coronavirus disease 2019(COVID-19) mortality. For this, we conducted literature reviews, where we actively looked for a dataset that could address our primary question. After an exhaustive search, we unfortunately were not able to find a dataset that linked COVID-19 deaths with obesity. Although we successfully gathered data on obesity rates for countries before the COVID-19 pandemic and covid 19 mortality rates, we were unable to find the desired interrelated dataset.

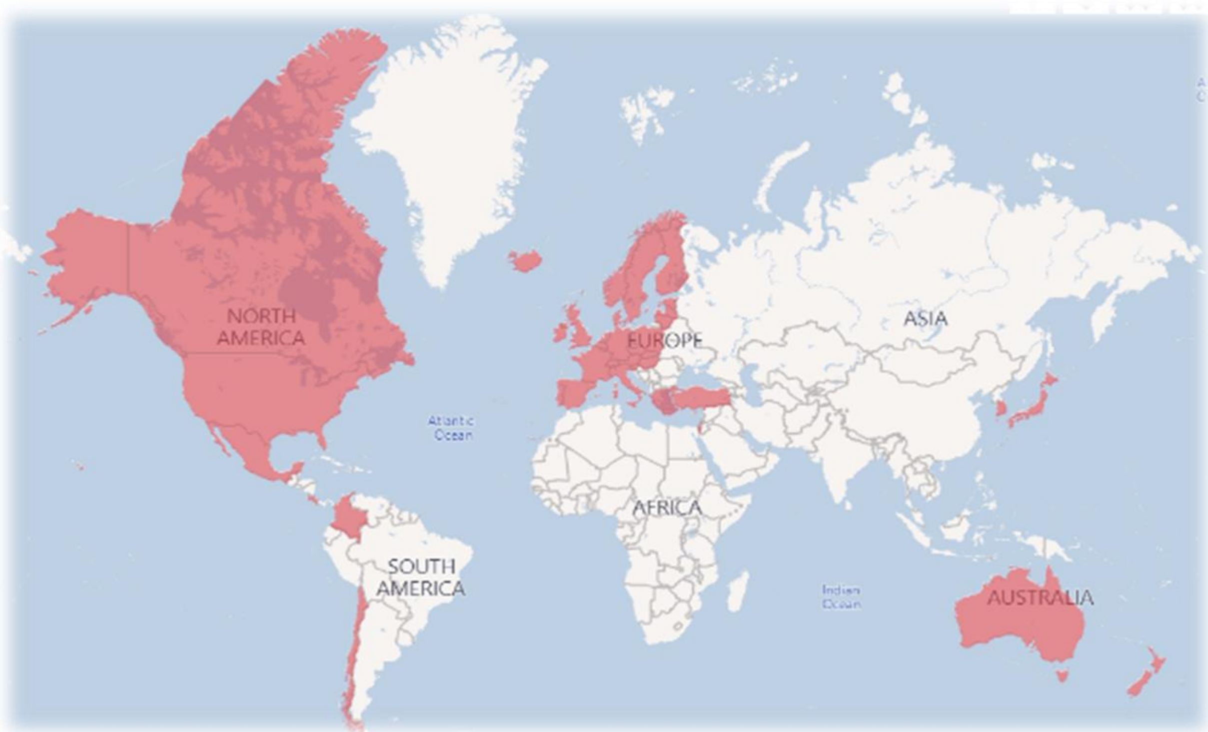

Figure 1: The 38 OECD countries are shown in red

After much discussion with our supervisor and co-supervisor, we decided to follow the research route of analyzing global COVID-19 mortality patterns. Therefore, our revised research question was now focused on understanding the mortality patterns before and during the covid 19 pandemic. Moreover, we wanted to understand any occurrences that could explain excess deaths. During our data search, we came across the OECD (The Organization for Economic Cooperation and Development) database, which emerged as our primary data source. With these datasets, we formulated two research questions:

- Are there differences in all-cause mortality during 2020-2022, compared to pre-pandemic years?
- And if there were changes, can we link this change (Excess mortality) to COVID-19 either directly or indirectly?

COVID-19

COVID-19 emerged in Wuhan in December 2019, and the disease rapidly spread across the world. The World Health Organization (WHO) declared the COVID-19 pandemic in March 2020. (Wuthrich, 2020) . The global impact of COVID-19 has affected nearly every country, resulting in significant losses in terms of life, health, and economic productivity.The pandemic has not only caused excess mortality but has also changed global trends in all cause mortality. As of January 9, 2024, the global COVID-19 situation, as reported by Worldometer (*COVID - Coronavirus Statistics - Worldometer,* n.d.) , indicates a total of approximately 701.2 million confirmed cases and 6.97 million deaths worldwide.

In this project, we aim to analyze the pattern of all-cause mortality, particularly focusing on how COVID-19 has influenced these trends from 2020 to 2022. In March 2020, the WHO declared COVID-19 a global pandemic, which officially ends on May 5, 2023. The pandemic has undoubtedly disrupted typical mortality patterns. Common sense might suggest an increase in mortality rates in countries heavily affected by the pandemic, but is this assumption accurate? To explore the impact on all-cause mortality, it's crucial to examine excess deaths, determining whether COVID-19 has had a direct or indirect effect on increased mortality rates.

Our interest lies in understanding the relationship between COVID-19 and excess deaths. This pandemic has touched everyone's lives in some way, and living in a diverse country like New Zealand, it becomes especially relevant to compare our situation with other nations. Gaining insights from this comparison could be invaluable if faced with another pandemic in the future. How different countries have managed the pandemic could offer key learnings. Moreover, a significant benefit of this analysis could be in identifying vulnerable groups and implementing effective interventions to protect them more efficiently. It also helps us think about developing more effective response strategies and improving preparedness for future challenges.

For our study, we have chosen to focus on OECD countries due to the availability of reliable data, and New Zealand's inclusion in this group adds a personal dimension to our research. The OECD is a collaborative platform for countries to address shared socio-economic challenges and work together on solutions. And their members comprise developed nations with high-income economies. However, we must acknowledge that comparing these countries can be challenging. Each nation has its unique policies, demographic profiles, healthcare systems, pandemic management strategies, and social structures. Understanding these differences will be crucial in our analysis of how various countries have navigated the complexities of the pandemic.

Data

Table 1: List of OECD Countries by Continent

Continent	Country
North America	Canada, United States, Mexico, Costa Rica
South America	Chile, Colombia
Europe	Ireland, Slovenia, Latvia, Lithuania, Estonia, United Kingdom, Switzerland, Sweden, Spain, Slovak Republic, Portugal, Poland, Norway, Netherlands, Luxembourg, Italy, Iceland, Hungary, Greece, Germany, France, Finland, Denmark, Czechia, Austria, Belgium
Asia	Türkiye, Korea, Japan, Israel
Oceania	Australia, New Zealand

Our primary data source, the OECD database, provides data for 38 countries on weekly all-cause mortality from 2015 to 2022, weekly COVID-19 deaths, and weekly excess deaths from 2020 to 2022. Our analysis focuses on 2020-2022 due to two key factors: ensuring complete yearly datasets for all variables (as 2023 data was incomplete when we began) and capturing the peak period of the pandemic (2020-2022) for insightful pattern analysis. The excess death data was directly obtained from the OECD database, and the methodology for calculating excess deaths is outlined in the Methodology section. Excess mortality is defined as the difference between the actual number of observed deaths from all causes within a specific timeframe and the expected number of deaths for that period. This expectation is typically based on historical data from recent years, often estimated using the average over several preceding years (Ramírez-Soto & Ortega-Cáceres, 2022). All-cause mortality refers to deaths caused by any reason, while COVID-19 deaths in our database include both deaths with COVID-19 and deaths from COVID-19. Deaths with COVID-19 imply that the individual tested positive for the virus. Still, another underlying condition might have caused their death, whereas deaths from COVID-19 indicate that the virus directly caused the death (INTERNATIONAL GUIDELINES FOR CERTIFICATION AND CLASSIFICATION (CODING) OF COVID-19 AS CAUSE OF DEATH Based on ICD International Statistical Classification of Diseases, n.d.). Our weekly mortality dataset includes data further broken down by age groups: 0-44, 45-64, and 65 and older. It is worth noting that for 2020, there are 53 weeks, while for 2021 and 2022, there are 52 weeks each.(“Glossary of Statistical Terms,” 2021)

Additionally, we should be aware that there is a difference in the methodology flag code for Week 53 excess deaths in 2020, which means that the 2020 Week 53 excess death calculation only compares it to Week 53 of 2015. The initiation of Week 1 of each year typically corresponds to the week containing January 4th or the first Tuesday of the year. Consequently, some years, including 2020, report a 53rd week that commences before the end of the calendar year and extends into the first few days of the subsequent year. Therefore, it's essential to be cautious when interpreting the Week 53 excess death figure for 2020 as it might not directly compare to other weeks due to this unique calculation method. (*OECD.Stat Metadata*, n.d.)

To understand the broader context of excess deaths and account for confounding variables, we incorporated a socio-economic factor, GDP per capita ("Glossary of Statistical Terms," 2021), which reflects the average economic output per person, calculated by dividing a country's total economic production (GDP) by its population, sourced from the World Bank for 2020 to 2022. We also considered the percentage of the population residing in urban areas obtained from Worldometer annually. Population density, calculated by dividing the total population by land area, was also included using data from the OECD (population) and Worldometer (land area) for 2020 to 2022. Demographic factors such as the percentage of the population aged 65 and older is considered. We specifically chose the population aged 65 and older as they are more vulnerable to COVID-19 and are known to have a higher excess mortality rate. Data for these factors were sourced from UN data for 2020 to 2022. Lastly, we sourced "access to quality healthcare " data from the Global Health Security Index, which provides a score of 0 to 100, with 100 being the best, covering 2020 to 2022. Access to quality healthcare, in this context, refers to a country's overall ability to provide its citizens with timely, effective, and equitable preventive, diagnostic, and therapeutic care services. It encompasses factors such as the availability and accessibility of healthcare infrastructure, the adequacy of medical professionals, and the affordability of healthcare for different populations.

Ethics

As our database (Table 2) are open-source databases, we didn't need any individual consent for our research.

Table 2: Sources and datasets used.

Data Type	source	Period /Coverage)
All-cause mortality	OECD database ("Glossary of Statistical Terms," 2021)	2015- 2022 (weekly)
COVID-19 deaths, Excess deaths	OECD database	2020-2022 (weekly)
GDP per capita	World Bank ("Glossary of Statistical Terms," 2021)	2020-2022 (Annual)
Urban population (%)	Worldometer	2020-2022 (Annual)
Population density	OECD, Worldometer	2020-2022 (Annual)
Age 65+ (%)	UN data (United Nation, 2022)	2020-2022 (Annual)
Access to quality healthcare	GHS Index (Report & Data -	2020-2022 (Annual)

GHS Index, n.d.)

Missing Data Handling

In the OECD database, we encountered missing values for countries such as Japan, Korea, and Costa Rica, where excess death data and all-cause mortality were unavailable for 2021 and 2022. We supplemented the OECD dataset from The Economist's COVID-19 Excess Deaths Tracker to address this gap.(*Covid-19-Excess-Deaths-Tracker/Output-Data/Excess-Deaths at Master · TheEconomist/Covid-19-Excess-Deaths-Tracker · GitHub*, n.d.)

Methodology

Regarding our study, we explored the statistical patterns of all causing deaths and cause-specific deaths during the COVID-19 (2020-2022) and then compared it to the baseline period i.e. before COVID-19 (2015-2019), taking into consideration cofactors such as age (percentage of 65 over), GDP per Capita, population density, urban population (%), excess to quality healthcare. With this analysis, we aimed to determine whether there were marked shifts or changes in mortality trends that align with the COVID-19 outbreak period. Also, we compared excess all-cause mortality and COVID-19 mortality of 38 OECD countries (Fig 1 and Table 1.) to determine whether most excess deaths in 2020 - 2022 could be attributed to COVID-19 or not.

The programming tools for this study included R (Team, 2021), Jupyter Notebook, and Power BI (Becker & Gould, 2019) to analyze and visualization. Data wrangling was conducted in R using Jupyter Notebook and in excel. The dataset was relatively clean. The initial steps involved widening the table to allocate variables into separate columns and renaming columns for clarity. Missing values for Japan, Costa Rica, and Korea were filled using a supplementary dataset. The main dataset encompassed data from 2015 to 2022.

After filling in the missing values, we created three tables for our analysis. The main table, with 235581 rows from 2015 to 2022, encompasses all-cause deaths, COVID-19 deaths, and excess deaths. Missing values in these tables are attributed to the availability of COVID-19 deaths and excess deaths only from 2020 onwards. This table is used for our all-cause mortality analysis and to replicate the excess deaths.

To specifically analyze excess deaths, we created a separate table focusing on data from the years 2020 to 2022. we converted the year and week column into a date format (d/m/y), with our timeline spanning from 30/12/2019 to 01/01/2023. This table contains 5928 rows from 2020 to 2022 and has no missing values. For regression analysis, we aggregated the data from weekly intervals to yearly summaries, yielding three distinct sets from each country to the years 2020,2021 and 2022. This summary table contains 114 rows where we added additional variables (Table 2).

Excess deaths calculation method.

Table 3: Calculation of Excess deaths as per OECD.

Excess Deaths Calculation Methodology (OECD) (Enki et al., 2016)
Excess mortality quantifies the difference between the actual reported deaths in a specific week or month (depending on the country) and the estimated deaths expected in the absence of the COVID-19 pandemic. Initially, the expected number of deaths is established by calculating a baseline using the average number of deaths for the same week over the preceding five years (2015-2019). This baseline serves as a reliable reference point, accounting for factors like population growth and an aging demographic. Next, the percentage Score (P-score) is computed using the formula: $\text{P-score} = \frac{\text{(Reported deaths - expected deaths)}}{\text{expected deaths}} * 100$ The P-score provides a percentage change, indicating whether the observed deaths exceed or fall below. the anticipated values. Excess deaths = Reported deaths - Expected deaths

In our analysis, we utilize the data calculated by the OECD database. However, we also attempted to reproduce this data. Using a methodology of OECD database (Table 3), we were able to generate expected death values and calculate excess deaths, which align closely with the OECD'S findings.

We developed a Power BI dashboard to conduct a time series analysis of excess deaths and COVID-19 deaths, offering an interactive and detailed visualization of the trends and patterns in the data.

Statistical Analysis

To analyze all-cause deaths by year and assess changes over time and between groups, we employed a combination of descriptive statistics and inferential tests. Mean, median, and standard deviation provided central tendency and dispersion metrics for year-on-year comparisons and identification of trends, such as increasing or decreasing mortality rates. To delve deeper into specific differences, we utilized the t-test ($p<0.05$) to compare mortality rates between two distinct periods: before and during the COVID-19 pandemic. Additionally, we calculated the percentage change in mean mortality rates from year to year to quantify fluctuations in health outcomes (Table 4).

Table 4: Calculation of Percentage of change.

Percentage of change
$$\text{percentage change} = \frac{\text{(current year mortality - previous year mortality)}}{\text{previous year mortality}} \times 100$$

Pearson's test and a linear regression model were used to estimate the correlation between excess deaths and COVID-19 deaths per 100,000. Multiple regression analysis was used while adjusting potential confounding factors (GDP per capita, urban population, access to quality healthcare, population density, and age (65 over %)). Our initial analysis revealed that the relationships between variables might not be the same across all years we studied. To get a more detailed picture, we decided to do a separate multiple regression analysis for each year (2020, 2021, and 2022).

Since our data features multiple observations for each country over three different years, it can be characterized as panel data. So, we attempted to apply panel ordinary data regression to our analysis. However, due to time constraints and a lack of previous knowledge, we were not successful. We also considered using Lasso regression, but it seemed unsuitable for our data due to the limited number of variables. Additionally, we conducted investigations into how each country handled the pandemic.

All relevant files, including data and coding, can be found at https://github.com/nbu52/Data601-popHealth3-COVID-19

How to read an "Excess deaths" chart

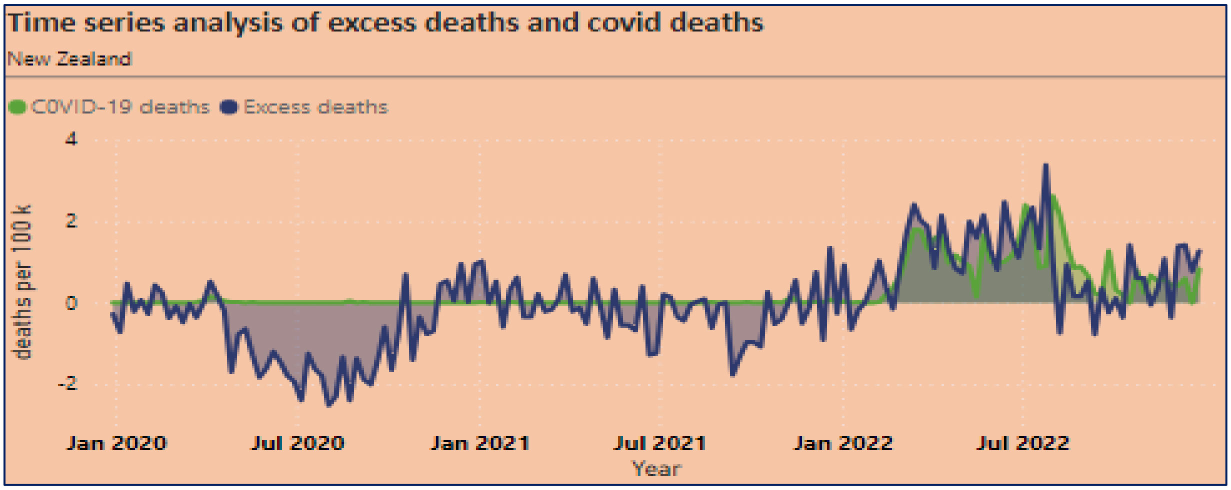

Figure 2: Comparing deaths attributed to COVID-19 and excess deaths

The zero baseline (From Figure 2) represents the 2015-2019 average of deaths from all causes. A number above zero means more than expected, and a number below Zero means fewer than expected. The shaded light green area represents the number of deaths attributed to COVID-19. And the purple shade represents the number of excess deaths.

Results

Impact of COVID-19 on all-cause mortality

Our initial analysis using time-series plots (Figure 3) revealed a marked increase in all-cause mortality rates across most of the 38 countries studied between 2015 and 2022.

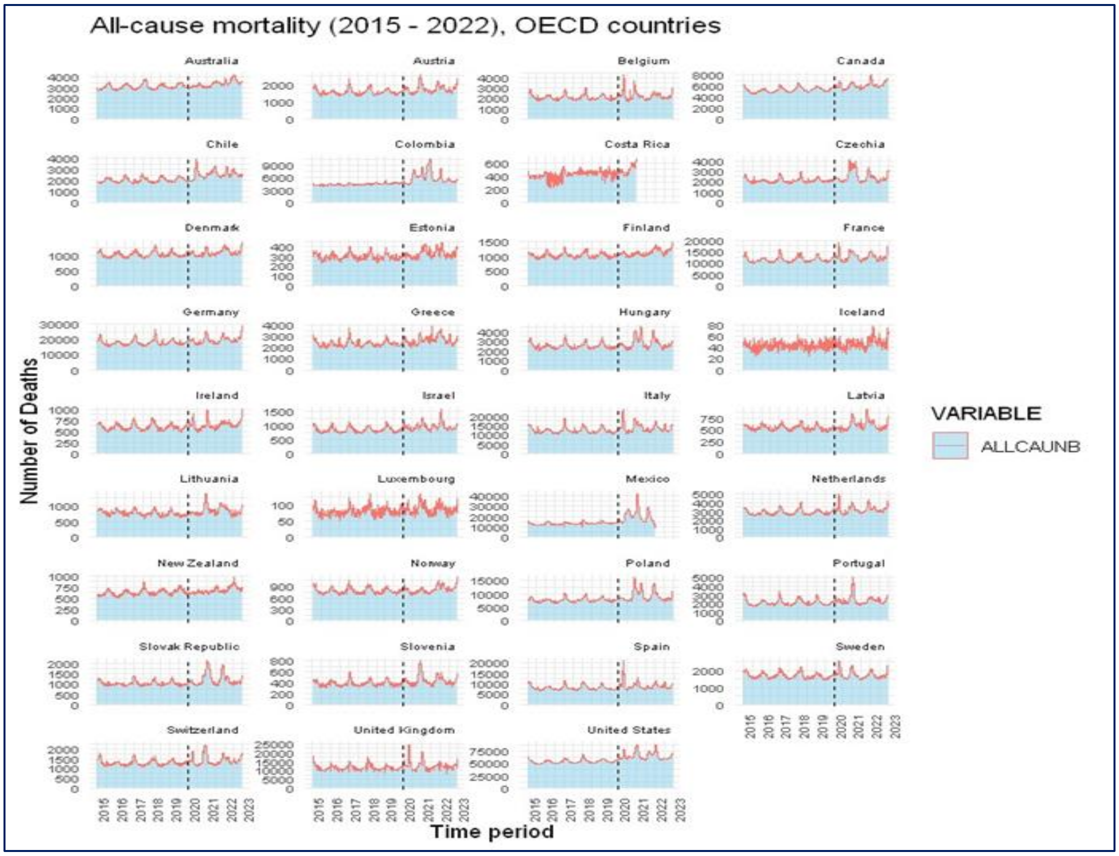

Figure 3: All-cause mortality of 38 OECD countries over the year (2015 - 2022)

This finding encouraged a deeper investigation of these trends. We utilized statistical methods such as calculating mean, median, and standard deviation to compare mortality rates across countries and years (Appendix A), allowing us to quantify the observed changes. Prior research has established clear seasonal patterns in mortality rates, with colder months often seeing a rise in deaths, particularly in northern hemisphere countries (Moore, 2006). Our comprehensive analysis, spanning from 2015 to the present, not only confirms the observed trends but also uncovers statistically significant shifts in death rates during key periods, particularly since 2020. Notably, significant increases in death rates were detected in various countries, demonstrating the profound impact of external factors such as the COVID-19 pandemic. For instance, Costa Rica faced a rise in death rates from 2019 to 2022, surging from 23,184 to 26,541 deaths. Similarly, Ireland had a notable increase in mortality rates, with deaths rising from 62,492 in 2019 to 70,352 in 2022. These trends reflect statistically significant deviations from prior mortality patterns, providing compelling evidence of the pandemic's impact.

The end of 2020 marked a decisive period where several countries showed marked increments in death rates, indicating significant shifts in mortality dynamics. Slovenia, for instance, saw a notable rise in deaths from 81,712 in 2019 to 97,620 in 2020, a statistically significant deviation from previous years. Similarly, Poland experienced a pronounced increase in mortality rates during this period, with deaths soaring from 1,630,496 in 2019 to 1,942,416 in 2020, underscoring the statistical significance of the observed trend.

The onset of 2022 revealed distinct patterns in death rates across various nations, further highlighting the dynamic nature of global health trends. Notably, Israel experienced a statistically significant surge in mortality rates, with deaths escalating from 91,636 in 2019 to 103,060 in 2022. Likewise, Canada witnessed a substantial increase in deaths, rising from 1,137,120 in 2019 to 1,348,295 in 2022, indicative of significant shifts in mortality dynamics during this period.

At the midpoint of 2022, New Zealand's mortality rates presented unique characteristics, reflecting its distinctive track during global health dynamics. Analyzing the data, we observed a shift in death rate trends. Initially, from 2019 to 2021, New Zealand experienced a consistent decrease in mortality rates, with numbers declining from 49,308 deaths in 2019 to 48,686 in 2021 (Summers, 2022). However, this trend saw a reversal in 2022, observed by a significant increase in deaths to 57,966 (Figure 4). While New Zealand's mortality figures may appear comparatively lower than those of larger nations, the statistical significance of this fluctuation emphasizes its impact on the nation's health landscape. These statistics highlight New Zealand's response to external factors, including the ongoing COVID-19 pandemic, and emphasize the importance of adapting public health strategies to address emerging challenges.

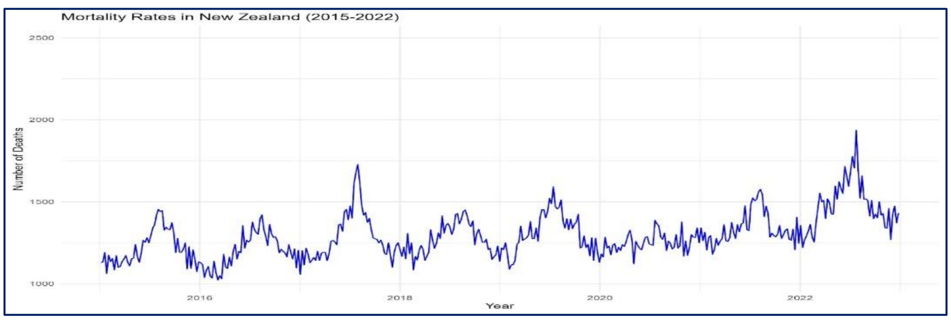

Figure 4: New Zealand all-cause mortality rate.

In contrast, several countries, including Estonia, Sweden, Norway, Luxembourg, Germany, Finland, Denmark, and Austria, maintained relatively stable mortality patterns, exhibiting statistically nonsignificant deviations from pre-pandemic levels. This finding underscores the varied paths that countries have followed in responding to and mitigating the impact of the COVID-19 pandemic.

For a more comprehensive analysis of mortality rate fluctuations, we calculated the average percentage (Appendix B.1) increase spanning the years 2020 to 2022 for each country. This calculation allowed us to quantify the rise in mortality rates since 2020. Notably, for Australia, the average percentage increase in mortality rates from 2020 to 2022 was approximately 7.52%. This approach was extended to all countries in our dataset, enabling us to identify those experiencing the most noticeable increases annually since 2015. The graphical representation of these findings emphasizes a significant observation: a strong rise in death rates initiating in 2020, coinciding with the arrival of the global pandemic. (Figure 5) serves as visual evidence of the impact of the pandemic on mortality trends, providing a clearer understanding of the evolving patterns over the specified time frame.

2020 saw significant volatility in mortality rates across countries driven in part by COVID19. Mexico, Colombia, Spain, Poland, Slovenia, and Belgium faced staggering increases exceeding15% compared to 2019. Mexico, with its 18.44% rise, stands as a grim example, its struggle amplified by one of the deadliest initial COVID-19 waves, claiming over 150,000 lives. Conversely, New Zealand (-2.63%), Australia (-0.24%), and Iceland (-0.59%) defied the global trend, demonstrating commendable declines in mortality rates, hinting at the potential for effective pandemic management to yield positive outcomes.

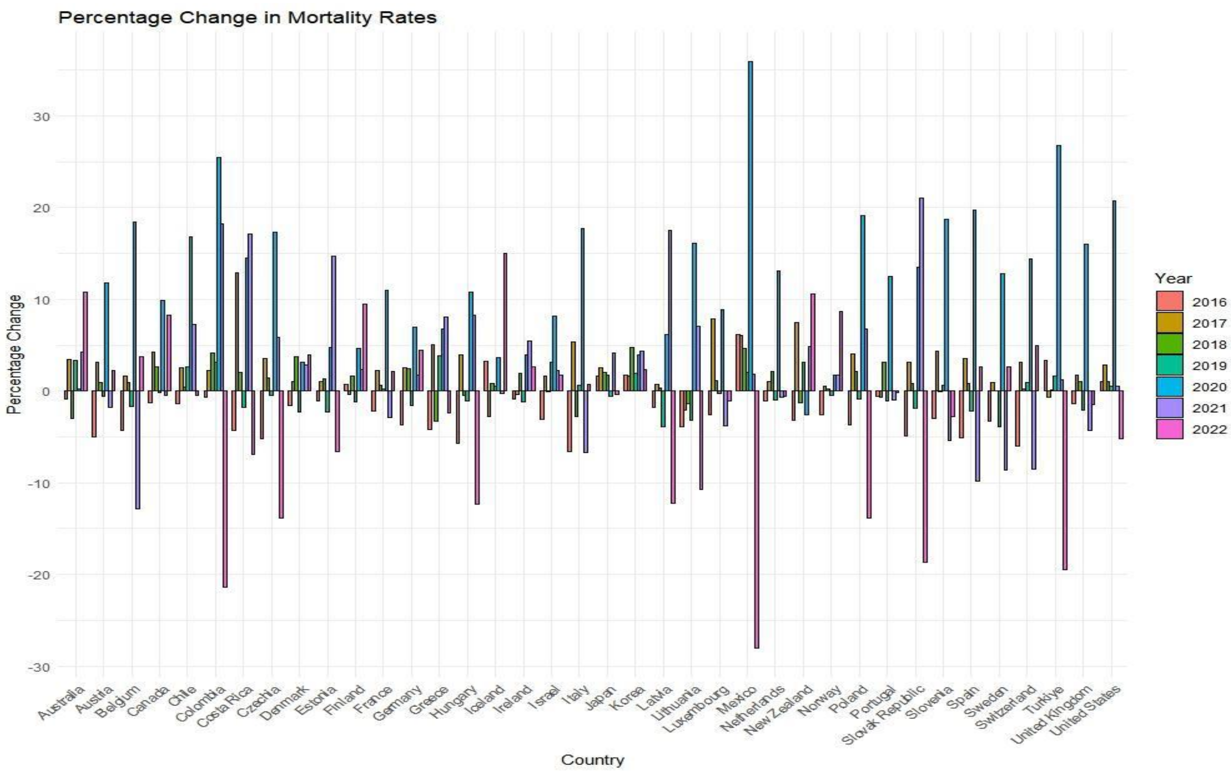

Figure 5: Percentage change of all-cause mortality rate

2021 witnessed a continuation of the volatile mortality trends seen in 2020, with both rises and falls across nations. While the Slovak Republic (21.07%), Colombia (18.22%), Latvia (17.49%), and Estonia (14.69%) faced substantial increases exceeding 15% compared to the previous year, several European nations experienced positive change. Belgium (-12.83%), Spain (-9.87%), Sweden (-8.65%), Switzerland (-8.54%), Italy (-6.69%), Slovenia (-5.39%), the United Kingdom (-4.26%), and Luxemburg (-3.81%) all saw declines in mortality rates.

This divergence highlights the ongoing impact of the pandemic on global mortality patterns. Notably, the Slovak Republic and Colombia, both grappling with sustained high COVID-19 cases throughout 2021, also experienced renewed significant increases in overall mortality exceeding 15% compared to 2020. This trend shows the link between effective pandemic control and positive outcomes for overall health.

Evolving patterns continued in 2022 (Appendix B.1). Iceland (15.01%), Australia (9.48%), and New Zealand (10.56%) registered increases exceeding 10% compared to 2021.
In New Zealand, COVID-19 mortality data from the Ministry of Health underscored disparities in risk, with certain demographic groups facing higher susceptibility to the virus. Peaks in daily COVID-19 deaths in July and August 2022 further highlight the ongoing impact of the pandemic on mortality dynamics (*Deaths Increase by Ten Percent in 2022 | Stats NZ*, n.d.) . This variant, first detected in Australia in November 2021, led to multiple waves of the pandemic throughout 2022. In Australia alone, there were 9,859 deaths due to COVID-19 in 2022, making it the third leading cause of death nationally and among the top 10 leading causes in every state and territory (*Causes of Death, Australia, 2022 | Australian Bureau of Statistics*, n.d.-a). In Iceland, Chief Epidemiologist Guðrún Aspelund attributes the excess mortality in 2022 primarily to COVID-19. Despite vaccinations reducing mortality, the number of deaths remained high due to a surge in infections (*Iceland: Deaths by Age 2022 | Statista*, n.d.). These trends also coincide with an increase in the population aged 65 and over, which could have contributed to the higher mortality rates observed (Liu et al., 2020a).

However, a broader group of countries, including Mexico (-28.06%), Costa Rica (-6.95%), Colombia (-21.39%), the Slovak Republic (-18.65%), Czechia (-13.86%), Poland (-13.81%), Hungary (-12.32%), Latvia (-12.20%), Lithuania (-10.71%), Estonia (-6.59%), Slovenia (-2.81%), Greece (-2.36%), the United Kingdom (-1.51%), Luxemburg (-1.04%), the Netherlands (-0.60%), Chile (-0.45%), and Portugal (-0.14%), displayed negative percentage changes, suggesting improvements in mortality rates.

Looking at some countries with improvement in mortality rates, in the case of Mexico, a significant reduction in COVID-19 mortality rates can be explained by the pandemic's behavior. During the first quarter of 2021, there was a surge in infections, and the vaccination process had not yet covered a significant portion of the population. However, by the first quarter of 2022, the vaccination process had progressed significantly, resulting in a notable reduction in mortality due to COVID-19 (*México Mejora Cifras de Mortalidad: Entre Enero y Marzo Se Registraron 255,448 Defunciones*, n.d.).

In Colombia, a similar pattern was observed, with a significant decrease in COVID-19 mortality rates from the first quarter of 2021 to the first quarter of 2022. This reduction can be attributed to the advancement of the vaccination process, which covered a larger portion of the population by 2022, thereby reducing the severity and impact of the virus(*Muertes En Colombia Segundo Semestre de 2022 | Economía | Portafolio*, n.d.).

The lower death rates in Slovakia can be attributed to several factors. Firstly, the overall death rate in Slovakia dropped to 2%, which is lower than the five-year average before the pandemic. COVID-19 dropped to the eighth place in the ranking of the most common causes of death, with only 81 people dying from the infection in November. This decrease in COVID-19-related deaths contributed to the lower overall death rate. Additionally, diseases of the circulatory system and tumors, which are among the most common causes of death, accounted for a significant portion of deaths in November but were consistent with the average for the years 2015-2019 (*Demography – Deaths and Causes of Deaths in the SR in November 2022*, n.d.).

Following the percentages of change and to statistically validate the observed increases in all-cause mortality rates for New Zealand, Australia, and Iceland, we conducted paired t-tests (Appendix C) comparing mortality rates before and during the COVID-19 pandemic. The results, presented in the table below (Table 5), provided compelling evidence for statistically significant increases for all three countries, confirming the substantial impact of the pandemic on overall mortality trends. Notably, while Australia and Iceland experienced more moderate surges in 2020-21, New Zealand's 2022 increase of 2.78% coincided with a significant jump in COVID-19 deaths to 2280, highlighting the direct influence of the virus on its mortality trend.

Table 5. Percentage of change before and during COVID. (full table on appendix)

Countries	t value	degrees of freedom	p value
Australia before COVID-19 vs. during COVID-19	-2.925	3669.144	0.0035
Iceland before COVID-19 vs. during COVID-19	-2.847	3687.339	0.0044
New Zealand before COVID-19 vs. during COVID-19	-3.482	926.999	0.0005

These countries began recording notable increases in total deaths, prompting us to explore deeper into the underlying factors behind this puzzling divergence. To better understand this phenomenon, we turned to existing research, exploring data (*Causes of Death, Australia, 2022 | Australian Bureau of Statistics*, n.d.-b). These studies highlighted a crucial factor: the growing population over 65 in these countries. While the growing 65-and-over population (Appendix C.2), as exemplified by a 21.4% increase in New Zealand between 2016 and 2022 (Table 5), is a crucial factor in understanding the observed divergence in mortality rates, it's critical to acknowledge the significant role of the COVID-19 pandemic. Studies link age with higher susceptibility to severe COVID-19 outcomes and data from New Zealand (reference here), where the 2022 surge in overall mortality (2.78%) coincided with a dramatic increase in COVID-19 deaths among the 65+ (from 26 to 2280), reinforces this connection.

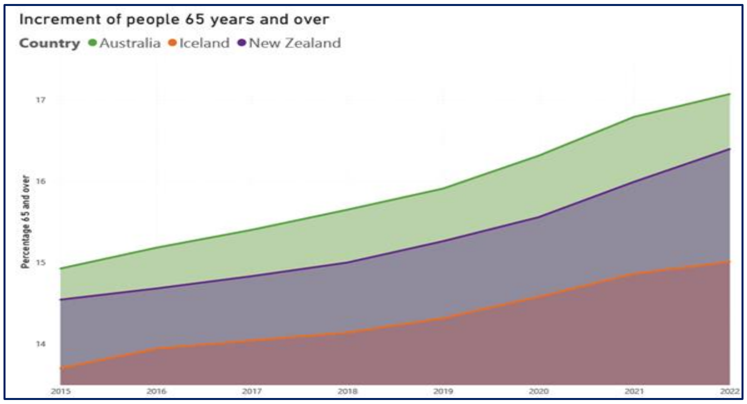

Figure 6: Percentage change of population 65 and over

Our analysis shows a significant surge in mortality rates, fueled in part by the COVID-19 pandemic, has disproportionately affected the 65 and over demographic in the examined countries. This observation underscores the undeniable role of age and the virus in shaping the dynamics of mortality trends.

Impact of COVID-19 on excess deaths

Across OECD countries, over 39.9 million lives were lost between 2020 and 2022, with COVID-19 claiming 3.2 million of those. This period also saw a concerning rise in excess deaths, exceeding expected trends by nearly 5 million.

After the initial year of the pandemic, overall deaths (total deaths) saw a modest increase of 1.11% from 2020 to 2021, followed by a slight decline of 2.91% in 2022. While deaths attributable to COVID-19 rose by a more substantial 29.13% from 2020 to 2021, highlighting the virus's devastating toll, a significant drop (-47.33%) in 2022. Excess deaths also increased by 17.06% in 2021, However, by 2022, the trend reversed, with a notable decrease of 24.99% (Table 5).

Table 5. Percentage of change in total, COVID and excess deaths in OECD countries

Year	All-cause deaths	COVID-19 deaths	Excess deaths	Total deaths % change	COVID deaths % change	Excess deaths % change
2020	13331989	1073706	1609603	_	_	_
2021	13480068	1386513	1884220	1.11	29.13	17.06
2022	13088433	730308	1413362	-2.91	-47.33	-24.99

2020

The year 2020 started with lower excess death rates but demonstrated considerable variability, as indicated by long error bars in the Heterogeneity plot (Figure 7). The range of excess deaths varied widely among countries, from -40.98 to 253.92 per 100k. Notably, countries like New Zealand, Japan, Australia, and Iceland reported fewer deaths than expected. On the other hand, the maximum excess death rate was observed in Mexico and Lithuania at 253.92 per 100k. (From Appendix D)

The year reported a lower rate of COVID-19 deaths, with a range of 0.51 to 172.23 per 100k. Despite this, there was a large error bar, indicating high variance (From figure 7). The data was skewed towards higher numbers, with a median of 67.7 and a mean of 64.09. Countries like New Zealand, Korea, Japan, Australia, Iceland, and Norway reported fewer deaths.

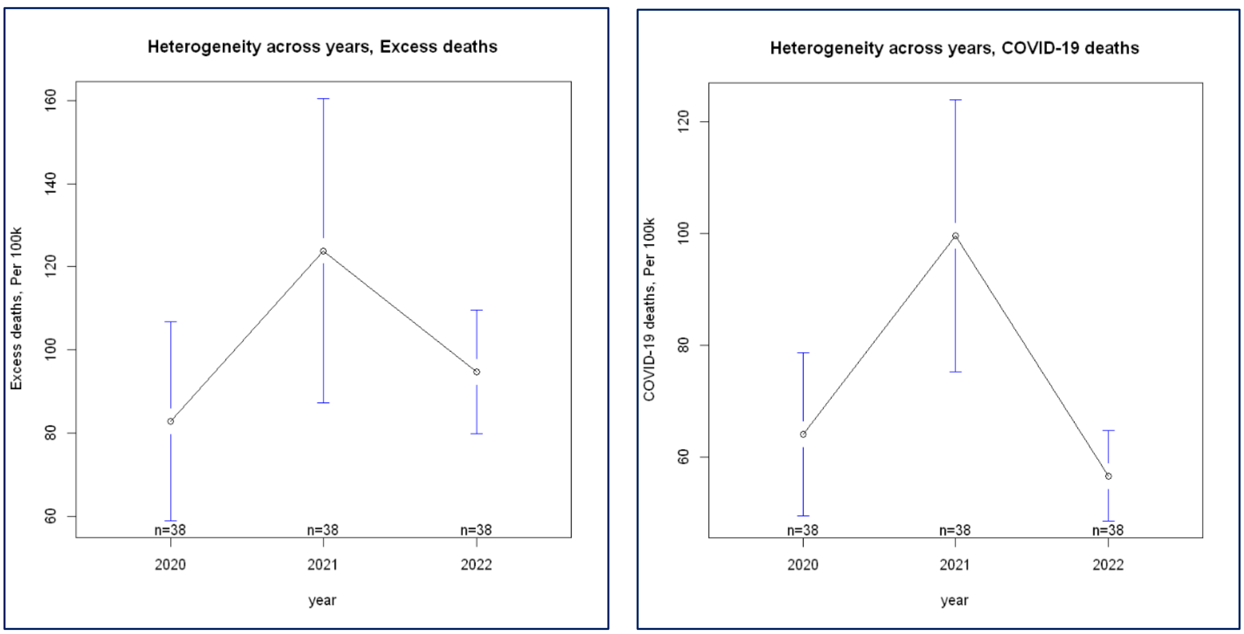

Figure 7: Heterogeneity across years (excess deaths on left and covid deaths on right)

Conversely, Belgium experienced very high death rates, with Slovenia, the United Kingdom, Italy, Czechia, and Spain also reporting high numbers. (From Appendix D)

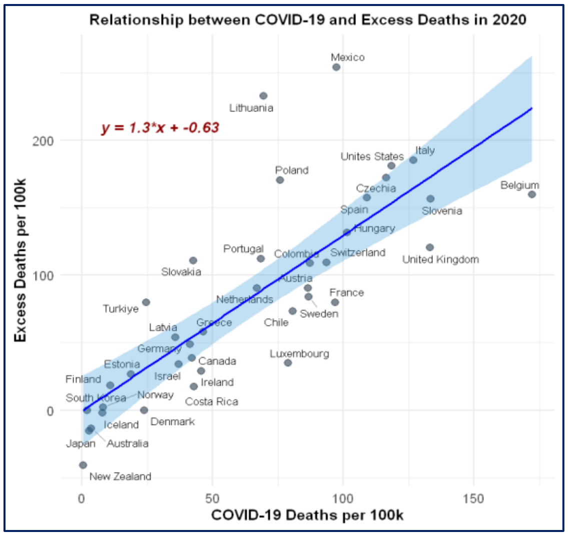

Figure 8 : Excess deaths and COVID-19 deaths for year 2020

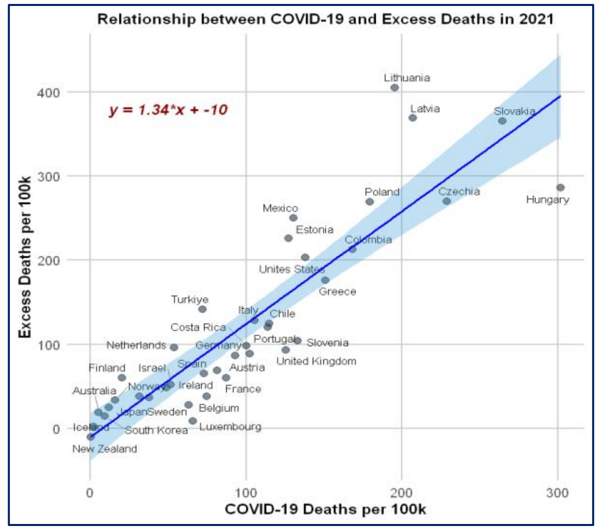

Figure 9: Excess deaths and COVID-19 deaths for the year 2021

There was a correlation between the all-cause excess deaths and the COVID-19 deaths (r = 0.80; y=1.3x−0.63; $R2$ = 0.63) (Figure 8). Adjusted for other variables in multiple regression (Appendix E) the model was statistically significant (F (6,31) = 16.15, p-value = 2.485e-08, Adj. $R2$ = 0.71).

2021

This year marked an even broader range of excess deaths, spanning from -10.02 to 405.43 per 100k. The median excess death rate increased to 91.07, and the mean escalated significantly to 123.88, indicating a year of exceptionally high excess death rates in many countries. The peak rate spiked to 405.43, which was substantially higher than the previous year's maximum, with severe impacts in countries like Hungary, Slovakia, Czechia, Latvia, Lithuania, Poland, Colombia, Greece, Mexico, and Estonia. Interestingly, New Zealand continued to exhibit negative excess death. (From Appendix D).

This year saw a peak in the death rate, alongside a large error bar, suggesting continued variability across countries (From figure 7). The range widened to 0.45 to 301.77 per 100k, with an increased median of 49.51 and mean of 99.61. New Zealand, Korea, Japan, and Australia continued to report fewer deaths. However, Hungary, Slovakia, and Czechia experienced very high death rates (From Appendix D).

There was a correlation between the all-cause excess deaths and the COVID-19 deaths (r = 0.89; y=1.34x−10; $R2$ = 0.79). Adjusted for other variables in multiple regression (Appendix F) the model was statistically significant (F (6,31) = 27.28, p-value = 4.479e-11, Adj. $R2$ = 0.81). Factors like GDP per capita, Age 65 over percentage, urban population percentage, and

population density does not show a significant unique effect, whereas access to quality healthcare shows a trend towards significance.

2022

There was a notable decline in excess deaths, accompanied by shorter error bars, suggesting reduced variability and potentially more precise measurements (From figure 7). The range of excess deaths was lower than in 2021, extending from -9.968 to 256.617 per 100k. The negative minimum indicates a continued trend of fewer deaths than expected in some countries, such as Luxembourg. However, Lithuania experienced high excess deaths this year. (From Appendix D)

The death rate significantly decreased, and the error bar narrowed (Figure 7), indicating more uniformity in reported data. The range was lower at 11.57 to 133.85 per 100k, with the median and mean being closer at 55.48 and 56.64, respectively. An interesting pattern emerged where countries like the Netherlands and Turkey, which previously had medium-high COVID-19 death rates, reported low rates. In contrast, Greece and Finland saw very high death rates. Notably, countries like New Zealand, Australia, Japan, and Korea, which had previously low death rates, experienced a significant increase in 2022 compared to previous years (From Appendix D).

There was a correlation between the all-cause excess mortality and the COVID-19 mortality rate (r = 0.64; y=0.85x+45.11; $R2$ = 0.41) (Figure 10). Adjusted for other variables in multiple regression (Appendix G) the model was statistically significant (F (6,29) = 5.897, p-value = 0.0004075, Adj. $R2$ = 0.46). It's important to note that in 2022, Lithuania and Luxembourg were identified as outliers using the interquartile range method and subsequently removed from the analysis. This decision was based on Lithuania's unusually high excess deaths and Luxembourg's exceptionally low excess deaths, which skewed the overall data. The multiple regression model's R-squared value indicates a moderate fit, explaining about 46% of the variance in excess deaths. Population density emerges as a significant factor, and GDP per capita shows a marginal positive association with excess deaths.

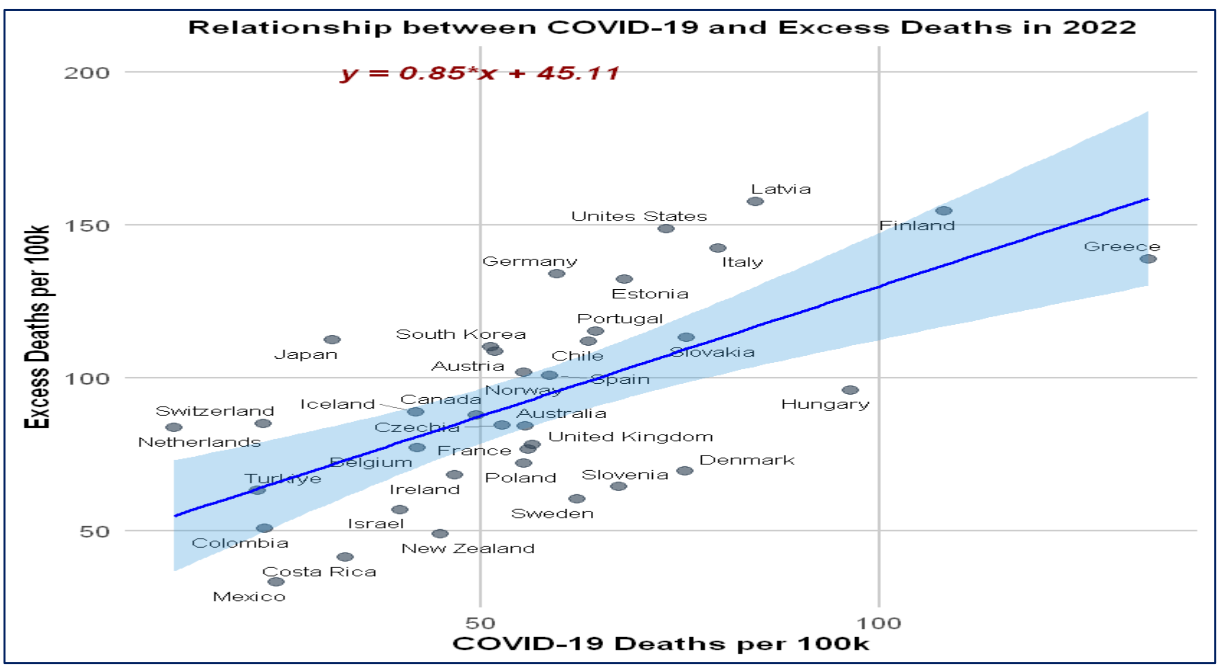

Figure 10: Excess deaths and COVID-19 deaths for year 2022

For the years 2020, 2021 and 2022, the data shows a consistent positive correlation between excess deaths and covid deaths, with the strength of this relationship varying each year. In 2020 and 2021, the correlation was strong (0.7954 and 0.8919, respectively), indicating a significant association between COVID-19 mortality and excess mortality. The correlation weakened in 2022(0.64), suggesting other factors might have increasingly influenced excess deaths. The R squared values for both simple and multiple regressions show a similar trend: higher in 2020 and 2021, indicating a better model fit, and lower in 2022. The P-values for all years were below the conventional threshold ($P < 0.005$), confirming the statistical significance of the findings.

Discussion &Conclusions

The observed decrease in correlation and R Squared values in 2022 compared to 2020 and 2021 could be attributed to a variety of factors. It suggests that while COVID-19 was a significant contributor to excess deaths in the earlier years of the pandemic, its impact relative to other factors may have diminished in 2022. This could be due to increased vaccination rates, improved treatment protocols, or changes in the virulence of the virus. Additionally, the introduction of other variables in the multiple regression model slightly improved the explanatory power, indicating the influence of socioeconomic and healthcare-related factors on excess mortality.

A. Difference in mortality varies over time.

We observed different phases of the pandemic, each impacting mortality rates differently. Various factors contributed to these variations. Initially, the inadequate preparedness of some countries for the pandemic likely led to an increase in COVID-19 deaths compared to previous years. Then, the emergence of the Delta variant in 2021, whose deadliness wasn't fully understood at the time, might have further affected mortality rates. However, as countries became more aware of COVID-19 and vaccination rates increased, this likely contributed to a decrease in COVID-19 deaths compared to the period between 2020 and 2021.

I. Initial response to the pandemic (2020)

In 2020, New Zealand and Australia quickly used their advantage as isolated island nations to fight the pandemic. They implemented early and strict lockdowns, border closures, and aggressive testing and tracing strategies. These measures, along with their natural isolation, helped them control COVID-19 spread, leading to lower COVID-19 and excess death rates. Furthermore, indirect effects such as a decrease in traffic accidents, reduction in other communicable diseases as people due to lockdown and social distancing, may have also contributed to the lower expected mortality observed during this period.

Luxembourg, while not implementing strict lockdowns like New Zealand and Australia, adopted a phased and ambitious mass screening strategy early in the pandemic. This gradual escalation in testing, from PCR tests for symptomatic individuals to widespread antigen and antibody testing, positioned Luxembourg as a notable example of effectively managing the pandemic through extensive testing.(Msemburi et al., 2023)

Japan's response to the pandemic was marked by early emphasis on avoiding "Three Cs" - closed spaces, crowded places, and close-contact settings.(Sayeed & Hossain, 2020). Despite not imposing stringent lockdowns like some other countries, Japan relied on a high level of public compliance with government advisories and a culture of mask-wearing. This societal discipline, combined with contact tracing and cluster-focused strategies, may have contributed to their relatively lower mortality rates.

Mexico's response to the pandemic has been criticized for being delayed and inadequate in terms of testing and contact tracing. The country also faced challenges with healthcare capacity and resources. The high excess and COVID-19 death rates in Mexico could be attributed to these factors.

Lithuania initially responded with strict lockdown measures during the early stages of the pandemic. However, the country faced challenges during subsequent waves of the virus. Factors contributing to higher mortality rates could include the strain on the healthcare system, public fatigue leading to reduced compliance with safety measures over time .(Kojala & Balticum, n.d.)

II. The delta variants effect (2021)

The emergence of the Delta variant in late 2020 indicated a significant turning point in the COVID-19 pandemic. Its increased transmissibility promoted a rapid global spread, with over 100 countries reporting cases within months. ((Liu et al., 2020b) The UK, due to its close travel connections with India, presented a particularly severe impact. Despite ongoing vaccination efforts, the Delta variant became the dominant strain by April 2021, triggering a devastating wave of infections and accounting for over 95% of new cases. This surge extended beyond the UK, significantly impacting other European countries.

On a global scale, the Delta variant's toll was unquestionable. South America faced the full impact, accounting for 21% of all reported deaths, followed by North America and Eastern Europe with over 14% each. The Delta variant's dominance in 2021, marked by its presence in 187 WHO member countries and its devastating impact on numerous regions, underscores the continued threat this highly transmissible strain poses to global public health. While declining cases in some areas offer promising signs, ongoing vigilance and robust vaccination efforts remain crucial in mitigating its lingering effects.

III. Vaccination rollout (2020 - 2022)

As vaccinations rollout began at the end of the 2020, many OECD countries had significantly vaccinated a significant portion of their population by 2021. This widespread vaccination coverage likely played a key role in the decrease of the COVID-19 deaths rate observed in 2022 compared to previous years. Vaccines works my training the immune system to recognize and fights the virus, reducing the severity of the risk of death even if infected. However, this trend in mortality wasn't uniform across all countries. Interestingly, countries like New Zealand, Australia and Japan, which has been successfully controlling COVID-19 deaths and reducing excess mortality in the earlier years of pandemic, experienced higher mortality rates at the beginning of 2022.

B. Differences in Mortality Rates Across Countries:

The study found that there were significant differences in both COVID-19 mortality rates and excess all-cause mortality rates among the OECD countries. These differences imply that the impact of the COVID-19 pandemic on mortality was not uniform across these countries. The variation in impact could be due to several factors such as the effectiveness of each country's response to the pandemic, the quality and accessibility of healthcare systems, demographic differences (like age distribution of the population), socioeconomic factors, and the degree of adherence to public health measures.

C. Consistent Influence of COVID-19 on Excess Deaths:

Despite these differences, a common finding across most OECD countries was that COVID-19 had a notable influence on the increase in excess deaths like Mexico, USA, Chile, Lithuania.

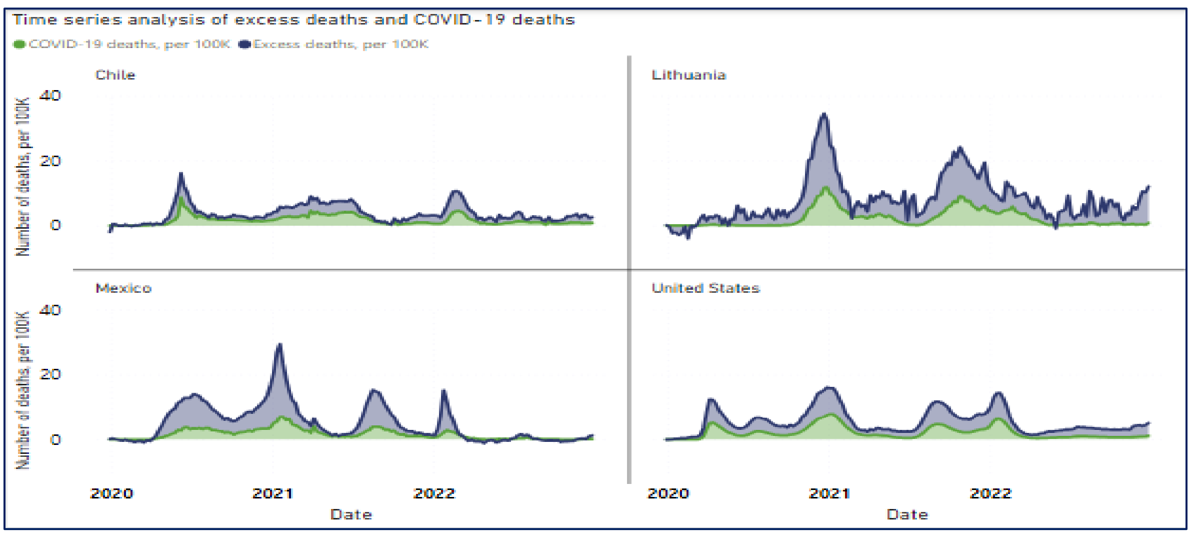

Figure 11: Time series analysis of countries Chile, Lithuania, Mexico and United States

This means that, regardless of the country-specific variations in the mortality rates, the presence and spread of COVID-19 generally contributed to a higher number of deaths than would typically be expected in a normal year without the pandemic.

D. Indirect Effects Leading to Reduced Excess Deaths:

While COVID-19 generally led to an increase in excess deaths, there were also instances where indirect effects of the pandemic resulted in a reduction of excess deaths in some OECD countries like New Zealand, Australia, Iceland. This phenomenon can be attributed to several factors:

I. Public Health Measures: Strict lockdowns, social distancing, and other public health measures not only helped in controlling the spread of COVID-19 but also led to a decrease in other causes of death. For instance, reduced traffic and lower rates of accidents during lockdown periods contributed to a decrease in mortality from these causes.(Ebrahim Shaik & Ahmed, 2022)

II. Lower Incidence of Other Communicable Diseases: Measures like mask-wearing and social distancing also reduced the spread of other infectious diseases, such as seasonal flu, which in some cases led to a lower overall mortality rate than expected.

III. Healthcare access -- The access to healthcare and urban population density might play a dual role. While better healthcare access potentially mitigated mortality, high population density in urban areas could have posed challenges in implementing effective social distancing. Prolonged lockdowns may have indirectly influenced mortality rates through increased mental health issues and obesity rates, highlighting the broader health implications of the pandemic response.

Interestingly, in 2022, a marginal significance was observed in high GDP countries, which are usually assumed to have lower excess deaths due to better healthcare quality. These could be attributed to factors like these countries likely performed a larger number of COVID-19 diagnostic tests and reported data more transparently and accurately, contributing to the observed trends in mortality rates.(Bayati, 2021)

E. Age as a Risk Factor:

The vulnerability of individuals over 65 to COVID-19 was a consistent finding, aligning with global observations. Countries with larger older populations experienced higher mortality rates, underscoring age as a significant risk factor. Across OECD countries, approximately 75% of COVID-19 deaths occur in individuals aged 65 and above. (Figure 12)

This age-related vulnerability can be attributed to a combination of factors, including weakened immune systems, pre-existing health conditions, and potential social isolation. While this trend holds true for most OECD nations, Mexico presents a unique exception. With a significantly younger overall population and a comparatively lower percentage of citizens above 65, Mexico exhibits a lower proportion of COVID-19 deaths within this age group.(Mexico's Response to COVID-19: A Case Study, n.d.)

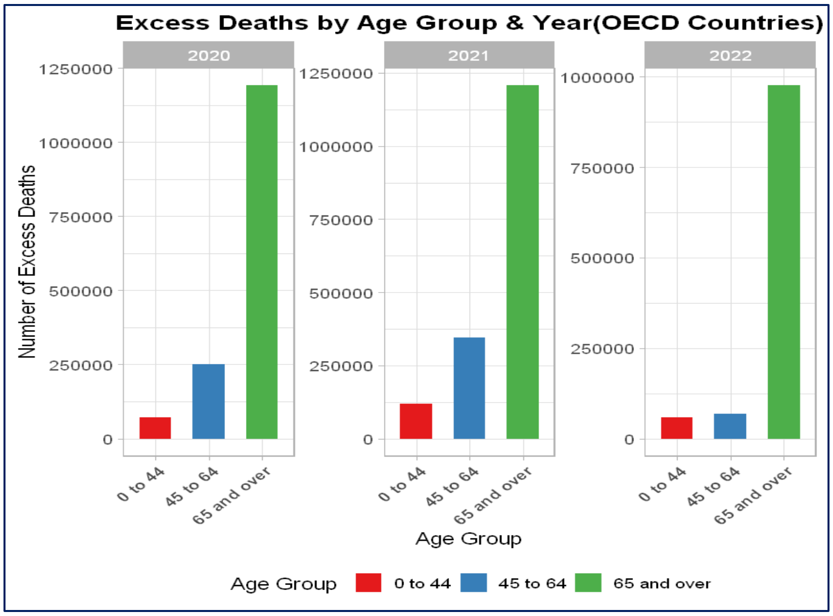

Figure 12: Excess deaths of OECD countries by age group and year

Conclusion

Overall, Considering the Variations in mortality during the peak of the pandemic in OECD countries, we can observe the complexity of the situation. It wasn't just about the COVID-19, it also depended on how prepared the countries were, how they responded, and how their healthcare systems managed the crisis.

Our analysis indicates that excess all-cause mortality across OECD countries is directly or indirectly related to COVID-19 deaths. Despite varying patterns among the countries, the impact of COVID-19 on excess deaths is somehow there.

Difficulties & Limitations

Cross-country comparisons of COVID-19 death data face challenges due to varying reporting practices. Differences include where deaths occurred, testing availability, and coding methods. Some countries improved reporting for non-hospital deaths, while others faced testing limitations early in the pandemic. Coding practices differ, with some countries counting suspected cases alongside confirmed ones. Additionally, variations exist in counting deaths solely caused by COVID-19 as a secondary cause.

This analysis focused on OECD countries, characterized by high income and developed healthcare systems. Therefore, the findings may not directly translate to developing or low-income countries facing different socio-economic and healthcare infrastructure contexts.

As we attempted panel data analysis, we faced limitations due to time constraints and our lack of prior study in this area. We may not have conducted these analyses properly, which could be considered for future work. Additionally, we experimented with LASSO for feature selection, but given the limited number of variables in our data, we concluded that this might not be the best approach for our analysis.

Future work

Development of a Predictive Model for Expected Deaths

An extension of this research could involve the creation of a model to estimate expected deaths based on historical data. This model could be trained using the OECD database, and then adapted to include low-income and developing countries. Such an expansion would provide a more comprehensive understanding of the pandemic's impact across a diverse range of nations, especially those not represented in the OECD dataset.

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Report writing**:** Budhathoki N, Gonzalez P

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Appendices

Appendix A. Statistical analysis comparison between two time periods "before COVID-19" and "during COVID-19".

	Mean		Median		SD	
Country	before COVID	during COVID	before COVID	during COVID	before COVID	during COVID
Australia	644611.2	702424.667	639662	686870	11181.6441	52843.7919
Austria	325393.6	363088	326228	364784	6152.70711	4343.85267
Belgium	438396.8	475368	437112	464552	7529.87724	34257.4619
Canada	1105644	1280031.67	1109545	1249140	34015.7492	58165.1576
Chile	424234	535149.333	424368	545910	8792.53013	20806.6232
Colombia	460755.8	634164.333	453545	611453	18491.3879	79774.6754
Costa Rica	22363	28855	23134	28931	1341.76786	2276.95147
Czechia	444849.6	520682.667	448160	525976	9447.82328	38835.5073
Denmark	214389.2	229057.333	213740	228164	3756.49134	7631.31688
Estonia	61829.6	68898.6667	61904	68804	595.110746	4718.71225
Finland	214780	235816	214604	230312	1660.32768	14430.0004
France	2413032.8	2672470	2417238	2684650	29160.9287	39841.6955
Germany	2784945.4	3070448	2796296	3043061	51396.0928	96891.2639
Greece	487994.4	555891.333	493296	561128	11267.3432	21872.3254
Hungary	521142.4	578947.333	522478	572894	11262.1045	38550.1102
Iceland	9009.6	9829.33333	9000	9380	114.10872	802.638981
Ireland	62560.4	67939.3333	62492	68518	464.037498	2748.0803
Israel	89362	101184.667	88850	101364	1602.14981	1989.07248
Italy	2584378.4	2899165.33	2571856	2845048	68028.2173	111547.355
Japan	1463195.2	1552011.33	1465484	1569228	46845.0911	35030.5125

Korea	292852.4	332747.333	288980	334822	12457.2659	10940.5414
Latvia	113958.4	125424.333	114636	121051	2062.38813	10943.3003
Lithuania	160813.6	178886.667	159960	177288	6493.16786	10259.842
Luxembourg	16663.2	18131.3333	17004	17956	645.491441	473.980309
Mexico	812343.8	1093008.67	821156	1192302	60971.5191	190750.01
Netherlands	601710.4	680826.667	599172	680736	7226.13346	4236.72767
New Zealand	65611.4	70984.6667	66118	69604	2286.74918	5414.66909
Norway	163093.6	171632	162564	167732	1751.44877	9382.96414
Poland	1608219.2	1935142.67	1610132	1942416	37150.8227	143432.376
Portugal	443290.4	498114	442632	496678	5277.10648	3100.3503
Slovak Republic	214228.8	256781.333	214808	241060	4067.27073	30429.7887
Slovenia	80937.6	93246.6667	81712	92356	1562.76319	4003.01753
Spain	1674780.8	1872509.67	1682356	1839149	33924.8831	102275.474
Sweden	355904.8	368529.333	357612	363524	8143.65343	17319.2334
Switzerland	267632.8	295925.333	267552	296380	6013.59753	13195.8759
Turkiye	412024.8	501311	412734	531994	6690.6359	58906.3038
United Kingdom	604473.4	673580.333	604706	667043	6372.92494	20652.1637
United States	5571073.6	6784198.33	5615114	6881392	128663.973	198031.35

Appendix B. Percentage of change.

B.1 All-cause mortality from 2020 to 2022.

Country	**PercentageChange 2020**	**PercentageChange 2021**	**PercentageChange 2022**
Australia	0.23663672	4.21268874	10.8361116

Austria	11.818728	-1.8180622	2.28282964
Belgium	18.4403704	-12.8285785	3.73539605
Canada	9.85120304	-0.42509246	8.30459146
Chile	16.8587771	7.27865312	-0.4489653
Colombia	25.5027165	18.2154638	-21.391416
Costa Rica	14.4798137	17.1508233	-6.95333355
Czechia	17.3634416	5.82231889	-13.8569889
Denmark	3.13525371	2.817333	3.914728
Estonia	4.72867206	14.6914118	-6.59752389
Finland	4.69709945	2.3845511	9.49841954
France	10.988101	-2.84087548	2.15718656
Germany	6.93424444	1.76787624	4.43711119
Greece	6.77367937	8.04586031	-2.35648285
Hungary	10.7975028	8.25143918	-12.3167023
Iceland	3.62350862	-0.29850746	15.0128315
Ireland	3.93010305	5.49670506	2.6766689
Israel	8.15836571	2.27217693	1.69093564
Italy	17.7145221	-6.6870843	0.70966372
Japan	-0.59947883	4.19381043	-0.37292823
Korea	3.94105263	4.33257094	2.29375609
Latvia	6.16676317	17.4989774	-12.2042675
Lithuania	16.0747957	7.08677406	-10.7093947
Luxembourg	8.8386194	-3.81401328	-1.03586545
Mexico	35.9239748	1.78880854	-28.0592932
Netherlands	13.0660664	-0.63814756	-0.60228929
New Zealand	-2.63381728	4.83477423	10.5626113
Norway	1.69043976	1.76183658	8.70674648

Poland	19.1303751	6.81542986	-13.8128012
Portugal	12.5127837	-0.99547114	-0.13811765
Slovak Republic	13.4613574	21.0719323	-18.6489228
Slovenia	18.7764637	-5.39233764	-2.80653125
Spain	19.7416814	-9.87369798	2.68379972
Sweden	12.8165146	-8.64775658	2.61386988
Switzerland	14.3775457	-8.54031235	4.91030343
Turkiye	26.8153029	1.23084095	-19.5240111
United Kingdom	15.9978889	-4.25815619	-1.50739907
United States	20.7620651	0.48626789	-5.18456355

B.2 People 65 and over from 2015 to 2022

Country	2016	2017	2018	2019	2020	2021
Australia	3.31842746	3.1427318	3.14877787	3.1851648	3.81865506	3.06949711
Austria	1.37942107	1.20036055	1.34793628	1.42585368	1.5610848	1.48005619
Belgium	1.57599893	1.63539185	1.66142408	1.72072727	1.46048609	1.46251419
Canada	3.47295996	3.615017	3.59477699	3.84636928	3.70293378	3.47359682
Chile	4.16263849	4.28449558	4.5585852	4.38884258	4.35328919	4.24329352
Colombia	4.11025701	4.21318655	4.65431554	4.79052419	5.49600244	3.67879308
Costa Rica	4.48001414	4.91725335	4.98096831	5.13851036	5.29645382	5.22973002
Czechia	2.86654735	2.73361603	2.43575338	2.21826584	1.72888401	0.67958622
Denmark	2.08472956	1.82356743	1.89372463	1.79117061	1.77804824	1.7357643
Estonia	1.63568055	1.59667828	1.43743492	1.50318129	1.66499385	1.10758845
Finland	2.64548496	2.47295073	2.35557162	2.17938942	2.09735669	1.92038623
France	2.63552085	2.38512357	2.23012788	2.16682473	1.8892334	1.72217393
Germany	1.22420947	1.17649364	1.06143731	1.07031542	1.07887857	0.95101182
Greece	1.1106274	1.0256706	0.93422566	0.97877382	0.93867276	-0.27196189

Hungary	1.79740104	1.52780422	1.67735905	2.41239791	2.26272706	1.22758875
Iceland	3.19597413	3.11410544	3.42452967	3.49564799	3.50353648	3.64892442
Ireland	3.20792436	3.1801374	3.61376076	3.4041125	3.42633178	3.07328704
Israel	4.25893118	4.1164579	3.90341109	3.64385664	3.34130943	3.11552197
Italy	1.05722626	0.91087928	0.85567468	1.07835549	0.90126051	0.69177599
Japan	2.04230729	1.52629698	1.11745785	0.77571313	0.76127886	0.5207703
Korea	3.30086309	4.57263881	4.24600131	4.38372623	6.01994227	5.14581506
Latvia	0.36778141	0.29309535	0.13800881	0.32860482	0.60482579	0.02623836
Lithuania	0.28166186	0.29761742	0.19727839	0.37838376	0.42170871	0.67779433
Luxembourg	2.64901481	2.56258956	2.4633376	2.62642236	2.4564812	2.40739328
Mexico	3.30876485	3.43937761	3.54243822	3.64169642	3.73016273	3.80561062
Netherlands	2.49414245	2.46288049	2.41215109	2.34151132	2.14014338	1.9400913
New Zealand	3.23610593	3.16790473	2.9585633	3.38512613	4.20998605	3.2341984
Norway	2.39788139	2.38843691	2.48594767	2.50045723	2.52029121	2.49880475
Poland	3.65854272	3.48298053	3.37876284	3.27609948	3.26129843	1.65448364
Portugal	1.88771815	1.99134706	2.0043898	2.33999138	2.50166513	2.16239217
Slovak Republic	3.74996349	3.81078384	3.59502842	3.50866172	3.24277576	2.0106695
Slovenia	2.95977441	2.60833256	2.95832712	2.72455215	2.73019924	2.51107932
Spain	1.41167711	1.44309652	1.53961968	1.79212853	1.35311129	1.51840196
Sweden	1.65746658	1.50144441	1.47767791	1.46506734	1.27737146	1.28548123
Switzerland	1.9416164	1.83227251	1.7652705	1.77244103	1.64537715	1.71573006
Turkiye	3.61392304	3.04368807	3.94703022	4.65389075	5.20698468	4.47876155
United Kingdom	1.74761073	1.4832888	1.469933	1.72128576	1.08022159	0.22698714
United States	3.25795962	3.14815664	3.14625745	3.21295519	1.46157609	2.55825634

Appendix C. T-test comparison before and during COVID-19

Countries	t_value	df	p_value
Australia before COVID-19 vs. during COVID-19	-2.9251836	3669.144196	0.003463636
Austria before COVID-19 vs. during COVID-19	-3.606607294	3607.502105	0.000314429
Belgium before COVID-19 vs. during COVID-19	-2.629373251	3623.490642	0.008590391
Canada before COVID-19 vs. during COVID-19	-5.118682546	3516.677808	3.24E-07
Czechia before COVID-19 vs. during COVID-19	-5.158308219	3341.927208	2.64E-07
Denmark before COVID-19 vs. during COVID-19	-2.143975882	3712.780359	0.032099576
Finland before COVID-19 vs. during COVID-19	-3.081182772	3631.422325	0.002077246
France before COVID-19 vs. during COVID-19	-3.385594188	3597.183054	0.000717857
Germany before COVID-19 vs. during COVID-19	-3.103222672	1818.14783	0.001943721
Greece before COVID-19 vs. during COVID-19	-4.241439347	3550.699101	2.28E-05
Hungary before COVID-19 vs. during COVID-19	-3.597177657	3522.659567	0.000326108
Iceland before COVID-19 vs. during COVID-19	-2.847351206	3687.339053	0.004432853
Italy before COVID-19 vs. during COVID-19	-3.639543325	3571.293017	0.000276989
Luxembourg before COVID-19 vs. during COVID-19	-2.902342143	3679.337418	0.003725845
Netherlands before COVID-19 vs. during COVID-19	-4.038064259	3536.623663	5.50E-05
New Zealand before COVID-19 vs. during COVID-19	-3.481949778	926.9989168	0.000521021
Norway before COVID-19 vs. during COVID-19	-1.645200899	3781.241671	0.100011505
Poland before COVID-19 vs. during COVID-19	-6.345971933	3239.228003	2.52E-10
Portugal before COVID-19 vs. during COVID-19	-3.747060011	3545.033151	0.000181768
Slovak Republic before COVID-19 vs. during COVID-19	-6.204445237	3236.923656	6.19E-10
Spain before COVID-19 vs. during COVID-19	-3.643621116	3534.639802	0.000272692
Sweden before COVID-19 vs. during COVID-19	-1.066656598	3810.016833	0.286194517
Switzerland before COVID-19 vs. during COVID-19	-3.221822825	3583.665209	0.001285179
United Kingdom before COVID-19 vs. during COVID-19	-5.464740517	221.0650207	1.25E-07

United States before COVID-19 vs. during COVID-19	-4.719615803	1123.120215	2.66E-06
Chile before COVID-19 vs. during COVID-19	-8.386416004	3231.550923	7.39E-17
Estonia before COVID-19 vs. during COVID-19	-3.694005649	3583.642677	0.000224043
Israel before COVID-19 vs. during COVID-19	-5.356996782	881.1670661	1.08E-07
Latvia before COVID-19 vs. during COVID-19	-3.338213439	3588.952731	0.000851786
Lithuania before COVID-19 vs. during COVID-19	-3.715487964	3555.854091	0.00020593
Slovenia before COVID-19 vs. during COVID-19	-4.58854334	3397.67713	4.62E-06
Mexico before COVID-19 vs. during COVID-19	-13.95508999	1606.613568	7.32E-42
Colombia before COVID-19 vs. during COVID-19	-12.01663665	674.4155589	2.81E-30
Ireland before COVID-19 vs. during COVID-19	-3.527317727	905.9190148	0.00044087
Costa Rica before COVID-19 vs. during COVID-19	-6.993906307	64.94491852	1.79E-09

Appendix D: Summary statistics and observations of COVID-19 deaths and Excess deaths for years 2020 - 2022

Year	**Range of Excess Deaths per 100k**	**Median**	**Mean**	**Notable Observations**
2020	-40.98 to 253.92	79.86	82.87	Fewer deaths than expected in New Zealand, Japan, Australia, and Iceland. Highest excess deaths in Mexico and Lithuania.
2021	-10.02 to 405.43	91.07	123.88	Median at 91.07, mean at 123.88. High impact in Hungary, Slovakia, Czechia, Latvia, Lithuania, Poland, Colombia, Greece, Mexico, Estonia. Negative excess deaths in New Zealand.
2022	-9.968 to 256.617	86.43	94.72	Decrease in excess deaths. Fewer deaths than expected in Luxembourg. High excess deaths in Lithuania.
Year	**Range COVID-19 Deaths per 100k**	**Median**	**Mean**	**Notable Observations**
2020	0.51 to 172.23	67.7	64.09	Fewer deaths in New Zealand, Korea, Japan, Australia, Iceland, Norway. High deaths in Belgium, Slovenia, UK, Italy, Czechia, Spain.

2021	0.45 to 301.77	49.51	99.61	Continued lower rates in New Zealand, Korea, Japan, Australia. Very high deaths in Hungary, Slovakia, Czechia.
2022	11.57 to 133.85	55.48	56.64	More uniform data. Lower rates in the Netherlands, Turkey. High rates in Greece, Finland. Increased deaths in New Zealand, Australia, Japan, Korea.

Appendix E: Multiple regression analysis of all-cause excess deaths and COVID-19 deaths year 2020

Variable	Coefficient (Estimate)	Std. Error	t value	p value
(Intercept)	252.6	107.3	2.353	0.0251
covid_deaths_per_100k	1.222	0.1534	7.965	< 0.0001
GDP_per_capita	-0.0005553	0.0003014	-1.842	0.0751
Age_65_over_percentage	-2.609	2.039	-1.280	0.2102
urban_pop_percentage	-0.8458	0.6393	-1.323	0.1955
Pop_density	0.01104	0.0521	0.212	0.8336
Access_to_quality_healthcare	-1.717	1.341	-1.280	0.2100

Appendix F: Multiple regression analysis of all-cause excess deaths and COVID-19 deaths year 2021

Variable	Coefficient (Estimate)	Std. Error	t value	p value

(Intercept)	395.9	189.0	2.094	0.0445
covid_deaths_per_100k	1.002	0.1884	5.321	< 0.0001
GDP_per_capita	-0.0004666	0.0003460	-1.349	0.1873
Age_65_over_percentage	-4.109	2.518	-1.631	0.1129
urban_pop_percentage	-0.5023	0.9017	-0.557	0.5815
Pop_density	-0.01425	0.06381	-0.223	0.8248
Access_to_quality_healthcare	-3.511	1.970	-1.782	0.0846

Appendix G: Multiple regression analysis of all-cause excess deaths and COVID-19 deaths year 2022

Variable	Coefficient (Estimate)	Std. Error	t value	p value
(Intercept)	175.2	70.10	2.499	0.0184
covid_deaths_per_100k	0.9776	0.2302	4.246	0.0002
GDP_per_capita	0.0003915	0.0001910	2.049	0.0496
Age_65_over_percentage	-2.952	1.489	-1.983	0.0569
urban_pop_percentage	-0.2122	0.4010	-0.529	0.6008
Pop_density	0.0786	0.03542	2.219	0.0344
Access_to_quality_healthcare	-1.427	0.9028	-1.581	0.1247

Appendix G Excess deaths of OECD countries over the years (2020 –2022)