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EVALUATING THE PREVALENCE OF TOTAL AND CAUSE-SPECIFIC MORTALITY IN EUROPE AND ASIA DURING COVID-19 PANDEMIC: A TIME-SERIES ANALYSIS

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STATEMENT OF ORIGINALITY

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I declare that the text and the work presented in this document are original and that no sources other than those mentioned in the text and its references have been used in creating it.

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ABSTRACT

This study provides an empirical analysis of total and cause-specific mortality rates in Germany, Hungary, Estonia, Slovenia, Taiwan, and Singapore. Utilizing time series models such as ARIMA and SARIMA, predicted values are generated. They establish the criteria for determining the presence of excess mortality. The analysis identifies considerable excess mortality in all four European countries during different time periods. The examination of cause-specific mortality for 2020 reveals no substantial change for the majority of causes, with the exception of declines in deaths from pneumonia in most nations. In terms of under- or over-reporting of COVID-19 deaths, the result indicates that Hungary and Estonia under-reported cases in 2020.

Keywords: ARIMA, Seasonal ARIMA, COVID-19, Excess mortality, All-cause mortality, cause specific mortality, anti-COVID policies, and Zero COVID policy.

1. INTRODUCTION

COVID-19 has produced major pandemics throughout the world. WHO (2022) estimates that by June 2022, COVID-19 had caused more than 5 million deaths. It is more than a public health disaster, and governments around the world are increasingly concerned with balancing numerous socioeconomic factors with mortality.

This research aims to estimate excess/reduced mortality using the latest available all-cause and cause-of-death mortality data and reveal direct and indirect mortality caused by the pandemic. It can provide valuable information for governments, medical institutions, and healthcare systems worldwide to design a better solution for co-existence with COVID-19.

2. LITERATURE REVIEW

Because it is often used as a measurement of contagious disease, the reported death numbers could contain bias (Lau et al., 2021). In the early stage of the pandemic, Beaney et al. (2020) identified two major reasons for a potential bias: the lack of testing and different death categorization guidance worldwide. The paper suggested and discussed a better standard for impact measurement via excess death. In addition to overcoming testing and identification issues, excess mortality takes into account direct and indirect death and provides feasibility for comparison between nations. Incorporating various advantages, excess mortality is a strong foundation for COVID-19-related investigations.

Several empirical studies had suggested that COVID-19-related deaths were under and overestimated in the first wave of the pandemic. Kung et al. (2021) compared the weekly all-cause mortality in 2020 with the 5-year historical data for 22 countries. For the countries that had extra deaths, the proportion of COVID-19-related death to excess death ranges from 30% to 197%. The considerable variation supports the theoretical argument from Beaney et al. (2020) and presents a heuristic compendium on the issue. Furthermore, the article found that the increase in excess mortality sometimes precedes death from COVID-19. It is a strong indication that the pandemic indirectly impacted mortality. More detailed examinations are required to reveal the underlying relationship.

Over time, cause-of-death mortalities are available for deeper analysis. Liu et al. (2021) did a meticulous investigation for the very first wave in Wuhan and compared cause-specific mortality with expected mortality based on age groups, locations and genders. The all-cause mortality nearly tripled in Wuhan, attributed to not only death from (COVID-19 related) pneumonia, but also increases in mortality from other diseases such as myocardial infarction and diabetes. It provides empirical evidence for indirect excess mortality as a consequence of the reduced availability of medical resources. Countries with more abundant medical resources are affected as well. Buja et al. (2022) concluded that excess mortality is significantly correlated with the density of licensed physicians in Italy. The two articles agreed on the fact that COVID-19 and the anti-COVID policies have both direct and indirect impacts on mortality.

The indirect impact of the pandemic on excess mortality differs worldwide. El-Shal et al. (2022) examined variables that correlate to maternal and infant mortality during a public health crisis. The model suggests that GDP per capita is the most important mitigator: a 1% increase corresponds to a 26% reduction in maternal mortality. More efforts are needed to analyze excess mortality in countries with different economic levels.

In previous research, the expected mortality is commonly based on averaging the historical mortality. However, Yun and Son (2016) suggested that mortality changes from year to year, both from changes in age-group mortality and from changes in age structure. It is reasonable to conduct the mortality forecast using more optimal methods for accurate estimations.

Apart from empirical research, there are a few efforts on directly modeling the bias. Ioannidis (2021) proposed a mathematical model that takes the properties of the virus, natural mortalities of counties, and human response factors into the account. It discovers that with expansion in testing, rising vaccine coverage, and mutation of the virus itself, most countries are overestimating the COVID-19 mortality. The model is hard to estimate empirically, but its results are valuable for better understanding the reported number of deaths, especially at the later stage of the pandemic.

Based on the concept of excess mortality, both empirical research and theoretical simulations suggested that under- or over-reporting of COVID-19 death can occur in many countries during different stages of the pandemic. Detailed investigation of the very first cause-of-death data implied that the consequence and response to the pandemic could lead to the indirect impact that causes extra death in addition to mortality from the virus itself. Furthermore, the degree of this indirect variation depends on the economic and healthcare factors of the country.

3. METHODOLOGY

3.1. *Data*

3.1.1. *Mortality Data*

The all-cause and cause-of-death mortality for six countries were obtained directly from respective official government websites or statistical bureaus. It is important to mention that for most countries, all-cause mortality is updated weekly or monthly, and later corrections on the data are frequent. In comparison, the cause-of-death mortality is often yearly data and only available later in the next year. In this thesis, the monthly all-cause mortality data and the yearly cause-of-death mortality data will be used.

One of the difficulties in this research is that for many countries, the cause-of-death data in the past years and during the COVID-19 pandemic are not available now. After searching, the mortality data from Germany (Statistisches-Bundesamt, 2022), Hungary (Központi-Statisztikai-Hivatal, 2022), Slovenia (Statistični-urad, 2022), Estonia (Statistikaamet, 2022), Taiwan (MHW-(ROC), 2022), and Singapore (of Statistics, 2022) were selected for the investigation. (HMD, 2022)

Country	All Cause Mortality	Cause Specific Mortality
Germany	The Human Mortality Database	Statistisches Bundesamt
Estonia	(University of California, Berkeley &	Statistikaamet
Hungary	Max Planck Institute)	Központi Statisztikai Hivatal
Slovenia	(This table has hyperlink)	Statistični urad Republike Slovenije
Taiwan	National Statistics (ROC)	Ministry of Health and Welfare (ROC)
Singapore	Department of Statistics Singapore	(Same)

Most countries implemented the ICD-10 (International Classification of Diseases and Related Health Problems) standard for the classification, so the data can be compared directly. In the case when the classification methods are different, data are recategorized and trimmed.

Note that the different updating frequencies of all-cause and cause-of-death mortality require different models for the forecasting. Therefore, the prediction models of each piece of data are different and the model-building process will consider the data pattern.

3.1.2. *COVID-19 and Variants Data*

The COVID-19 confirmed cases data used in the investigation is from the World Health Organization (WHO, 2022). The COVID-19 variants data is from Global Initiative on Sharing Avian Influenza Data (GISAID). For the European countries, it is retrieved directly from European Centre for Disease Prevention and Control official website (ECDC, 2022).

3.2. *Procedure*

Forecasts of the all-cause mortality for all countries will be conducted first. The predicted mortality will be used to compare with the real mortality to calculate the excess mortality. Considering the long period that all-cause mortality is available, the excess mortality can give a first glance at the severity of the pandemic at different stages.

One of the most important concepts in this research is to what extent the COVID-19 death is accounted for the total excess mortality. Under the best-case scenario, where there is no under- or over-reporting of the COVID-19 death, and the infectious disease has a negligible impact on any other social aspect including the healthcare system (which is impossible), the actual mortality will lie inside the interval constructed from the summation of the mortality prediction and reported COVID-19 death. In the meantime, it entails that otherwise, the under- or over-reporting may have happened.

As mentioned in the theoretical framework, many past studies suggest that during the first wave of the COVID-19, there are huge gaps between those two numbers. To further investigate the driving factors and dynamics behind those gaps, the cause-of-death mortality will be analyzed. Predictions of the cause-of-death mortality in 2020 and 2021 (only for Singapore) will be made, and the forecasts will be treated as the baseline to compare with the real numbers. In case the actual number lies outside of the constructed prediction interval, we are able to say during the pandemic the cause-of-death mortality is significantly different. There are many possibilities behind this: for example, misclassification (increase in pneumonia), lack of medical resources (increase in overall and especially chronic disease), or effect during lockdown (increase in suicide, decrease in traffic accidents) can be a potential reason. Taking into consideration of politics, structures of healthcare systems, and varying levels of lockdown, explanations, and interpretations will be made case by case.

3.3. *Explanation of the Model*

3.3.1. *ARIMA and SARIMA models*

As shortly mentioned in the data part, the model for each piece of data is not fixed and will undergo a model selection process. AutoRegressive Integrated Moving Average (ARIMA) (Box et al., 2015) and Seasonal ARIMA (SARIMA) models will be considered in this research for the forecasting. ARIMA is a common and widely used technique to analyze time-series data. SARIMA is a version of ARIMA that can better adapt to seasonal trends. The reason for considering SARIMA is that in most countries the numbers of monthly deaths display some monthly varying patterns. The utilization of SARIMA in monthly and seasonal data sets will theoretically yield a more accurate forecast.

For yearly data:

$$\text{ARIMA(p,d,q)}: \phi_p(L)(1-L)^d y_t = \alpha + \theta_q(L)\varepsilon_t$$

For monthly data:

$$\text{SARIMA(p,d,q)(P,D,Q)}_{12}: \phi(L_P^{12})\phi_p(L)(1-L^{12})^D(1-L)^d y_t = \theta_Q(L^{12})\theta_q(L)\varepsilon_t$$

For the model selection process, the information criteria will be the main consideration. In specific, the Akaike information criterion (Akaike, 1973) will be used to determine the optimal ARIMA or SARIMA model. The reason behind this is that the information criteria are relatively easy to compare. Also, Research by Billah et al. (2006) indicated that the AIC performs the best in selecting exponential smoothing models. The limited lengths of data also make validation of prediction capability to be unstable and therefore difficult.

The ARIMA and SARIMA model will be chosen by **auto.arima()** (Hyndman et al., 2022, Hyndman and Khandakar, 2008) using softward R (R Core Team, 2022) automatically.[2] The package "ggplot2" (Wickham, 2016) is deployed for the graphs.

3.3.2. *Box-Jenkins method*

During each model estimation, the method combines the well-established Box-Jenkins method (Box et al., 2015). The Box-Jenkins method includes three steps:

[2]One can replicate all works in this thesis at My GitHub repository

1. Model identification & model selection: Checking the stationarity and seasonality, and using a plot of auto-correlation (ACF) and Partial auto-correlation (PACF) to determine the p, q term of ARIMA.
2. Parameter Estimation: Using the maximum likelihood or non-linear least squares to obtain the optimal parameter values.
3. Model Checking: Checking if the resulting model is adequate for the requirements to be a stationary univariate process.

The model used in this thesis replaces the first process with a grid-search-like process that uses the Akaike information criteria as the optimization goal for obtaining the optimal hyper-parameter p, d, q, P, D, Q, s.

4. RESULT

4.1. *Excess Mortality*

This part focuses mainly on the detection of excess mortality and its relationship to COVID-19 in different countries.

The formats of the graphs are the same. The actual mortality and predicted mortality are shown in the side-by-side graph, or it will be one graph if the variant information of the country is unknown. The black line represents the actual mortality, whereas the predicted mortality and the 95% confidence interval are shown in blue color. The vertical dotted lines represent time points when excess mortality happened.

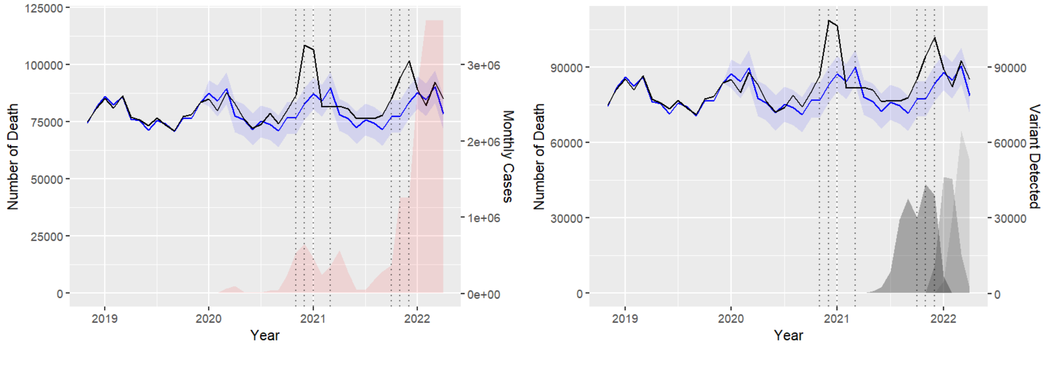
The red area in the left graph shows the monthly cases of Covid-19 confirmed cases (For the Omicron variant, part of the data is too large to be displayed). And in the right graph, a more detailed graph including the delta variant and two omicron variants (BA.1 and BA.2) are shown in the darkened area. Note that GISAID categorizes the original COVID-19 virus. So the impact due to the original virus can only be observed in the left graph.

4.1.1. *Germany*

The Seasonal ARIMA model: $ARIMA(2,0,1)(0,1,2)_{12}$ is selected.

Graph 1 shows the predicted and actual mortality in Germany. The model forecast indicates that for Germany, excess mortality is detected from November 2020 to January 2021 ($p < 0.005$), and from October 2021 to December 2021 ($p < 0.025$). Table I provides values for the forecast model in 2021, and the full table (Table VIII) is in the appendix.

FIGURE 1.—Germany excess mortality



The original variant leads to the first surge in deaths, with a delay of about two months. It was mainly due to the fact that COVID-19 requires time to replicate itself to be deadly.

TABLE I

ACTUAL MORTALITY AND PREDICTED MORTALITY IN GERMANY (2021)

	actual	forecast	ε	p-value
Jan 2021	106457.43	87342.65	3579.46	0.00***
Feb 2021	81619.29	84248.73	3585.22	0.23
Mar 2021	81719.14	89923.68	3586.31	0.01**
Apr 2021	81798.14	78037.68	3586.65	0.15
May 2021	80837.00	76348.62	3586.72	0.11
Jun 2021	76333.86	72425.25	3586.74	0.14
Jul 2021	76667.43	76002.64	3586.75	0.43
Aug 2021	76587.00	74584.51	3586.75	0.29
Sep 2021	77802.29	71578.57	3586.75	0.04*
Oct 2021	85195.14	77272.98	3586.75	0.01**
Nov 2021	94191.43	77367.36	3586.75	0.00***
Dec 2021	101727.14	83555.78	3586.75	0.00***

Note: *p$<$0.05; **p$<$0.025; ***p$<$0.005

One-sided p-value, adjusted for the direction.

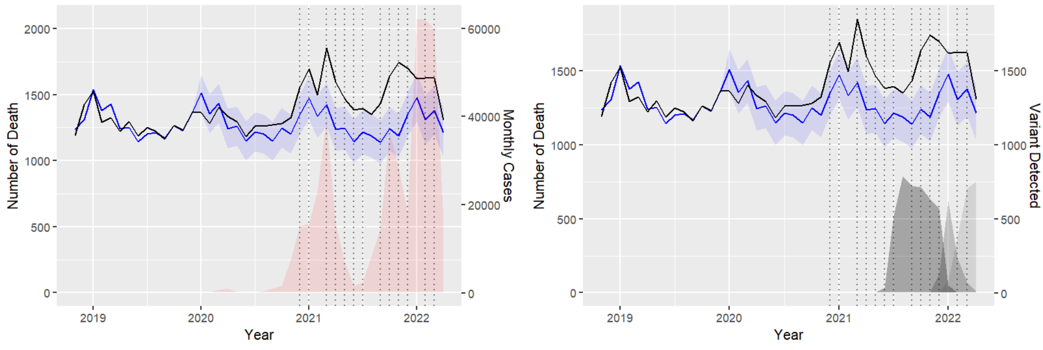
In the first half of the delta variant wave, there is not enough evidence to confirm the presence of excess mortality. Later on, the delta wave resulted in the excess mortality that was less severe than in the first wave, even though the confirmed cases were times higher. It is a representative example showing the catastrophic impact of the highly contagious virus: The exponentially increased confirmed cases will cause a repaid increase in mortality. Moreover, the decreased fatality rate can be explained by the increased vaccination coverage, death of venerable people in the first wave, and better response and management in hospitals and the CDC.

Despite the exponential increase in infection number, at the start of the Omicron wave, the excess mortality is not presented. In addition to the reasons stated above, the virus itself is suspected to be less harmful. (In the right graph, the "variant detected" number for two omicron variants is just a bit higher than that for the delta variant. It could be due to a limited capacity for sequencing. The dominant variant can be found both in the graph or from the data directly.)

4.1.2. *Estonia*

The Seasonal ARIMA model: $ARIMA(2,0,2)(2,1,0)_{12}$ is selected.

FIGURE 2.—Estonia excess mortality



Being a relatively less (but still) developed and much smaller country, the situation in Estonia is a bit different from that of Germany. Starting from November 2020 till the latest data available time (April 2022), excess mortality is always detected ($p < 0.005$ for $\frac{12}{17}$ months). The values are in the Appendix (table IX).

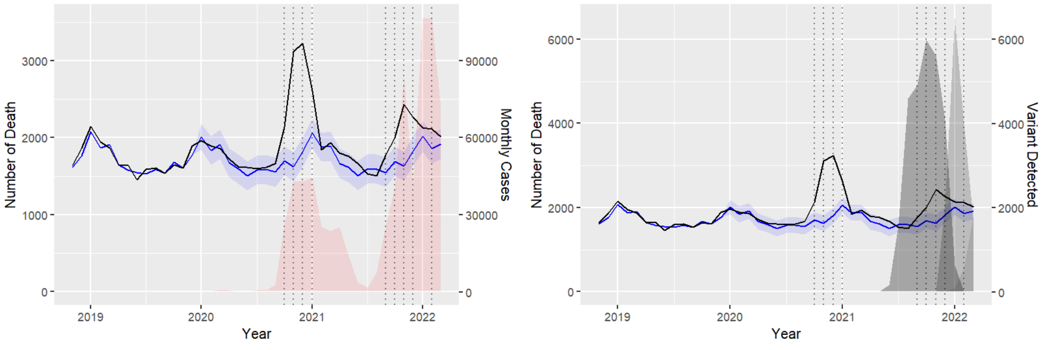
The two sharpest increases in mortality were again in the first wave and the Delta wave. In the Omicron wave, excess mortality decreased. In the middle of 2021, the infection number dropped to a low level, but the excess mortality was still significant. The cause of death analysis (unfortunately only for 2020) will reveal more information.

4.1.3. *Slovenia*

The Seasonal ARIMA model: $ARIMA(3,0,0)(1,1,2)_{12}$ is selected.

Slovenia's pandemic has a similar pattern as Germany. The excess mortality happened only in the first wave, from October 2020 to January 2021 ($p < 0.005$), and the delta wave, from October 2021 to December 2021 ($p < 0.005$). Compared to Germany, the excess mortality in the first wave was much more severe. In addition, Slovenia did a better job in sequencing variants, and the Omicron BA.2 variant arrives later than other countries.

FIGURE 3.—Slovenia excess mortality

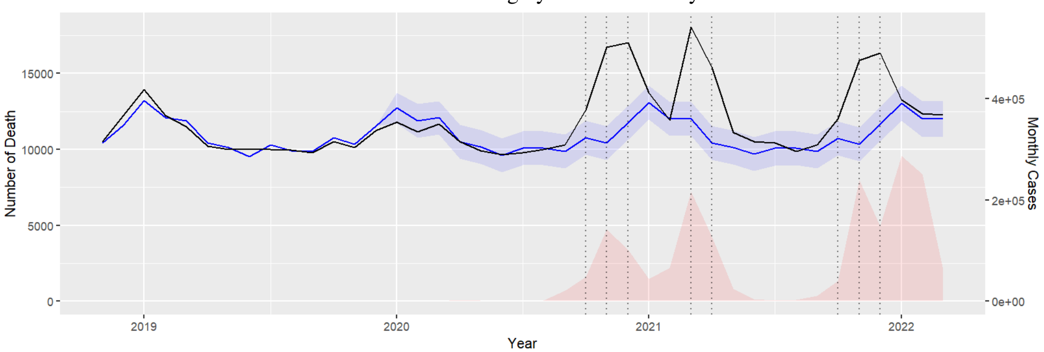


The values are provided in the appendix (Table X).

4.1.4. *Hungary*

The Seasonal ARIMA model: $ARIMA(1,0,1)(0,1,2)_{12}$ is selected.

FIGURE 4.—Hungary excess mortality



Hungary had experienced three waves of COVID-19. The first wave from October 2020 to December 2020 ($p < 0.005$), the variant wave Alpha in March 2021 and April 2021 ($p < 0.005$), and the delta wave from October 2021 to December 2021 ($p < 0.025$). The delay in mortality w.r.t. the increasing cases is detected as well. In the Omicron BA.2 (assume to be) wave, there is not enough evidence to identify the existence of excess mortality.

The values are provided in the appendix (Table XI).

4.1.5. *Singapore and Taiwan*

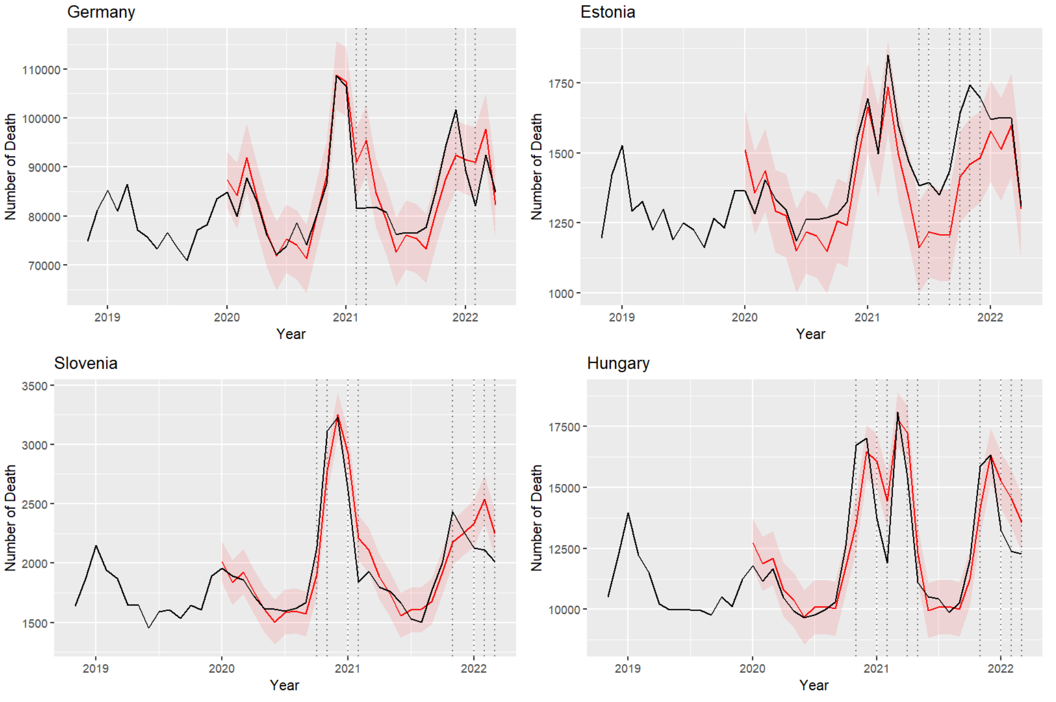
Singapore and Taiwan are two countries that implemented the "zero COVID policy" until the Omicron wave. In the official statistics, the death from COVID figure is nearly 0. In the light of this fact, they will be mentioned in this thesis only in the part of the cause of death mortality.

Worth mentioning, that one major difference between Taiwan and Singapore during the COVID pandemic is that, Taiwan basically has no confirmed cases until the Omicron wave, whereas Singapore had two very small waves in March 2020 and the delta wave.

4.2. *Over or Under estimation*

The graph 5 shows the "predicted mortality + death registered as COVID death (95% confidence interval)"-the red line and area; and the actual mortality-the black line. The vertical dots indicate the time points when the actual mortality deviates significantly from the predicted mortality.

FIGURE 5.—Actual mortality and predicted mortality with COVID-19 death



4.2.1. *Before and during the first wave*

Before September 2020, when no significant excess mortality is detected, there is no significant difference between the two series. During the outbreak phase of the first wave, Estonia and Germany data fit perfectly for the curve, whereas for Slovenia and Hungary, the actual mortality deviated from the predicted plus COVID death.

For Germany, Slovenia and Hungary, the actual value is lower than the forecast value in the second half of the first wave. Part of it can be explained by the effects of anti-COVID policies: in Germany, the hard lockdown was implemented from December 6, 2020, to March 7, 2021, Slovenia from October 19, 2020, to March 16, 2021, and Hungary from November 11, 2020, (Wikipedia contributors, 2022a,c,b). When the actual COVID death increased, mortality from other transmissible viruses would decrease. In addition, COVID may have "accelerated" death: from graph 1, the data show that the transmission of the virus remained to be high during the lockdown. During the first wave, people from venerable groups were affected most. As a result, the death after the sharp wave was lower than normal.

For Slovenia and Hungary, the data pattern can be explained in two ways. From one perspective, the actual mortality was always higher than the forecasted mortality during the outbreak. It is an important indication of the possible under-reporting. On the other hand, actual mortality exceeded forecast mortality for about a month. In Slovenia, the amplitude fits perfectly, so it is likely to be caused by administrative, statistical, or medical issues. And for Hungary, the highest point of the actual mortality is higher than that of the forecasted mortality.

4.2.2. *In between two waves*

For Germany, Slovenia, and Hungary, there is no significant evidence for the excess mortality. So the predicted numbers did not deviate from the actual numbers. In comparison, for Estonia, the death numbers from COVID were low. With the existence of excess mortality, the actual figures are sometimes significantly higher than expected. This is fairly unusual, and it is a strong sign of under-reporting of deaths from COVID. To confirm this, more details are examined in the cause-specific mortality analysis.

4.2.3. *During the Delta-Omicron wave*

Although the data for the Omicron wave is not complete, there is still some information. For Germany and Estonia, the actual data increased significantly higher in the Delta wave and then went back into the prediction interval in the Omicron wave. For Slovenia and Hungary, actual values are significantly lower than the forecast values plus COVID deaths in the Omicron wave. In addition to the stated reasons, the change in the fatality rate of the Omicron variants would possibly lead to more "die with COVID" cases being misclassified as "die from COVID".

The data table (table II) for Germany in 2021 is presented. The full table (Table XII) and the table for the other 3 countries (table XIII, XIV, and XV) can be found in the Appendix.

TABLE II

GERMANY PREDICTED MORTALITY WITH DEATH FROM COVID (2021)

	actual	forecast	ε	p-value
Jan 2021	106457.43	107411.65	3579.46	0.39
Feb 2021	81619.29	90983.73	3585.22	0.00***
Mar 2021	81719.14	95462.68	3586.31	0.00***
Apr 2021	81798.14	84788.68	3586.65	0.20
May 2021	80837.00	79142.62	3586.72	0.32
Jun 2021	76333.86	72719.25	3586.74	0.16
Jul 2021	76667.43	76166.64	3586.75	0.44
Aug 2021	76587.00	75457.51	3586.75	0.38
Sep 2021	77802.29	73344.57	3586.75	0.11
Oct 2021	85195.14	80740.98	3586.75	0.11
Nov 2021	94191.43	87540.36	3586.75	0.03
Dec 2021	101727.14	92434.78	3586.75	0.00

Note: *p$<$0.05; **p$<$0.025; ***p$<$0.005

One-sided p-value, adjusted for the direction.

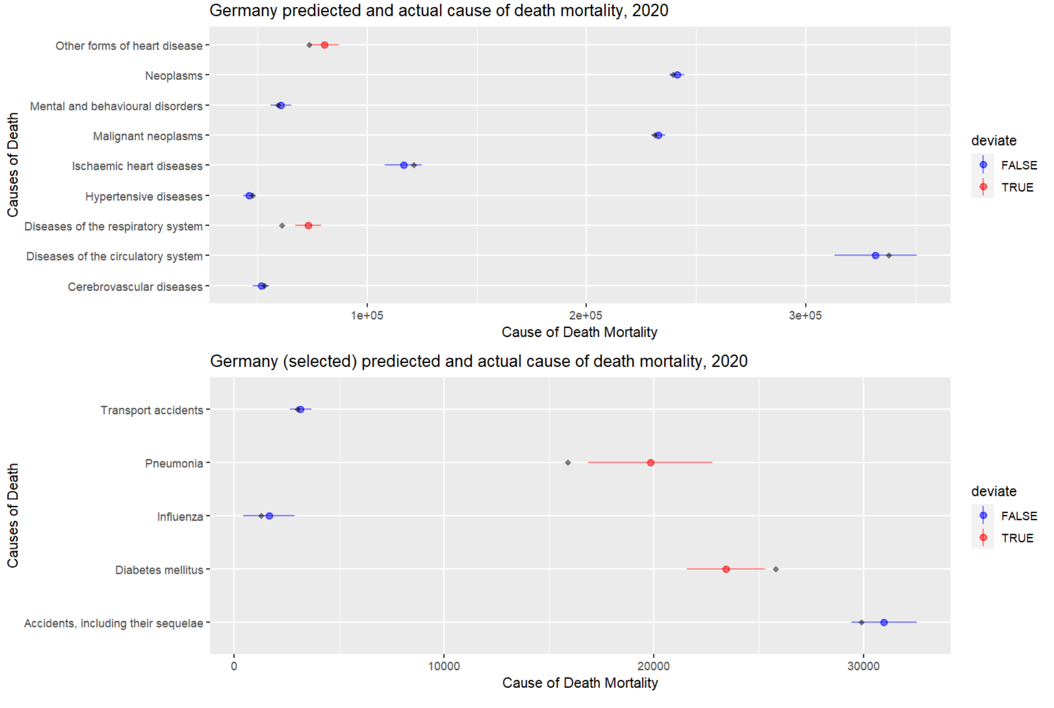
4.3. *Cause of Death Mortality*

The cause-specific mortality is first presented by each country. Result for Germany, Estonia, and Taiwan are explicitly shown in this section, whereas the graphs and tables for Slovenia, Hungary, and Singapore can be found in the Appendix.

4.3.1. *Germany*

The predicted and actual cause of death mortality of Germany in 2020 is shown in the graph 6 and table III. The error bar represents the 95% confidence interval for the point estimation. The error bar is shown in red if there exists a significant difference.

FIGURE 6.—Germany cause of death mortality

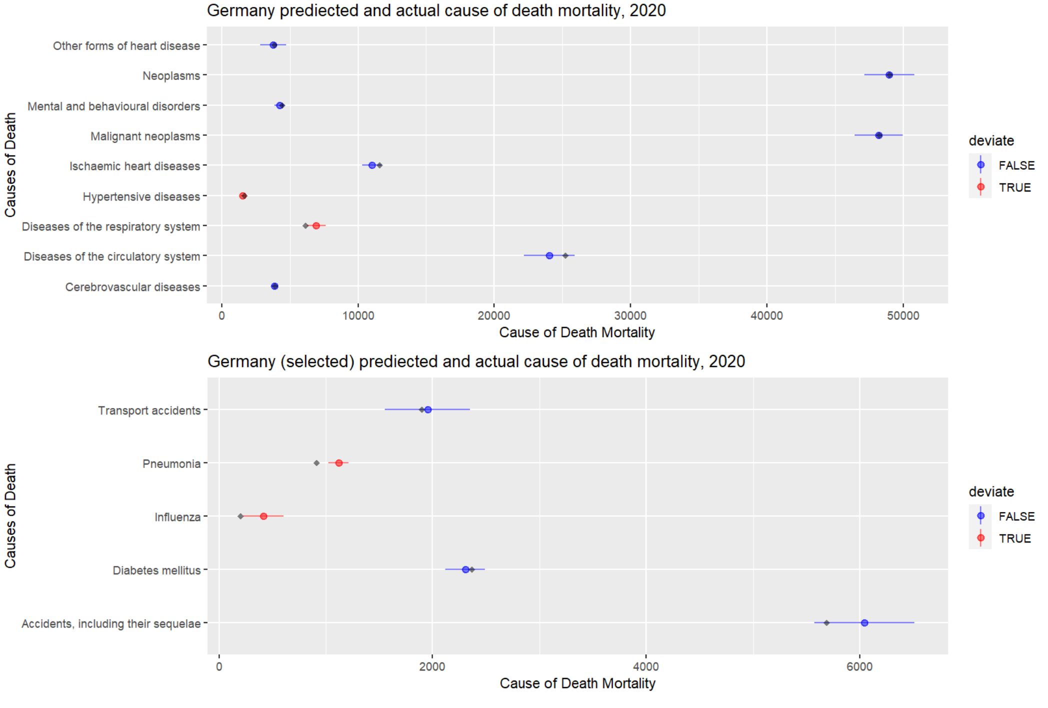


In the top 9 causes of death in 2020, only "Other forms of heart disease" and "Diseases of the respiratory system" deviate significantly from the prediction. And they are both significantly lower.

In selected causes of death, "transportation accidents" and "accidents, including their sequelae" do not show significant change. "Pneumonia" death decreased significantly and "diabetes mellitus" increased significantly.

Germany provides data with age groups, and the graph 7 shows if the age is restricted to 15 to 65. Now only "Pneumonia" and "Influenza" under/and "Diseases of the respiratory system" are significantly lower.

FIGURE 7.—Germany cause of death mortality (young age)



For Germany, current data shows that the COVID during 2020 did not have an impact on the medical services that was huge enough to rise the mortality of other causes of death. This is expected, as the data in excess mortality graphs fit perfectly. In addition, the peak in COVID-19 transmission started in October, and the "hard lockdown" started only in December; the impact of them might not be significant yearly.

The decline in pneumonia death across all age groups could be an indication of misclassification: some patients who died from Pneumonia may be categorized wrongly to die from

COVID. Another more plausible cause is that increased mask coverage successfully reduced the transmission of Pneumonia.

Table III gives the statistics for the point forecast and related p-value for Germany (total population) in 2020 for further examinations.

TABLE III

GERMANY'S PREDICTED AND ACTUAL CAUSE OF DEATH MORTALITY, 2020

	real	forecast	up.95%	low.95%	ε	p-value
Other forms of heart disease	73558.00	80430.32	87129.96	73730.68	3418.25	0.02**
Respiratory system	61348.00	73159.52	79109.97	67209.08	3036.00	0.00***
Circulatory system	338001.00	331713.08	350551.02	312875.14	9611.37	0.26
Neoplasms	239552.00	241223.21	244671.48	237774.94	1759.35	0.17
Malignant neoplasms	231271.00	232835.20	236076.08	229594.32	1653.54	0.17
Ischaemic heart diseases	121462.00	116527.17	124858.45	108195.88	4250.73	0.12
Mental and behavioural disorders	59613.00	60617.50	65382.48	55852.52	2431.15	0.34
Cerebrovascular diseases	53308.00	51698.33	55345.94	48050.73	1861.06	0.19
Hypertensive diseases	47900.00	46013.11	48677.93	43348.30	1359.63	0.08

Note: One-sided p-value, adjusted for the direction. *p<0.05; **p<0.025; ***p<0.005

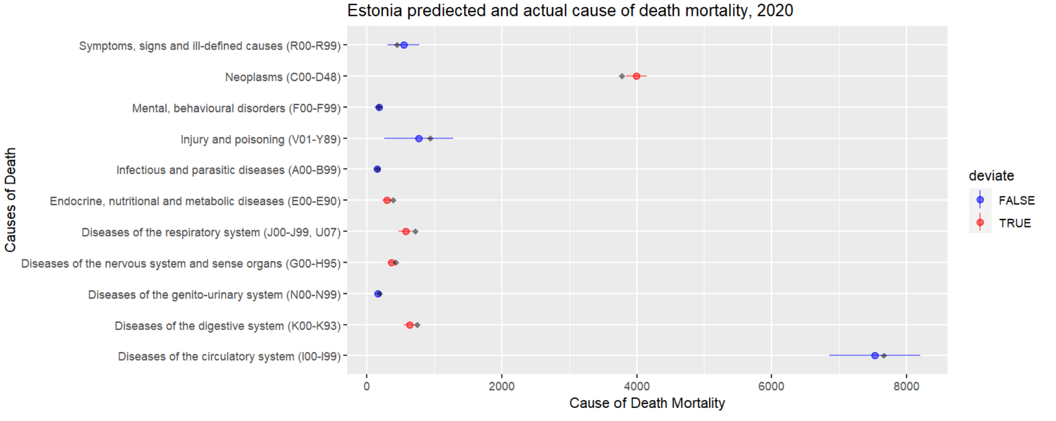
4.3.2. *Estonia*

Estonia is investigated for explaining the high excess death. The table IV and the corresponding graph 8 show the cause of death mortality forecast in Estonia in 2020.

It can be seen that the two major causes of death in Estonia did not increase in 2020. However, there were significant increases in some causes that accounted for a smaller proportion of mortality.

In specific, for two main causes, deaths from circulatory system stayed the same ($p = 0.35$), and deaths from neoplasm decreased ($p < 0.005$). Death from "Endocrine, nutritional and metabolic" ($p < 0.005$), "Respiratory system" ($p < 0.005$), "Digestive system" ($p < 0.005$), "Skin and subcutaneous tissue" ($p < 0.0025$), and "Nervous system and sense organs" ($p < 0.005$) increased.

FIGURE 8.—Estonia cause of death mortality



The prediction of the cause of death mortality is different from the total death forecast. The significant excess mortality observed in the total death forecast is not presented here. There is a chance that it happened due to differences among data sources. Otherwise, it is strongly skeptical that the death from COVID19 statistics in Estonia is (severely) underestimated.

TABLE IV

ESTONIA PREDICTED AND ACTUAL CAUSE OF DEATH MORTALITY, 2020

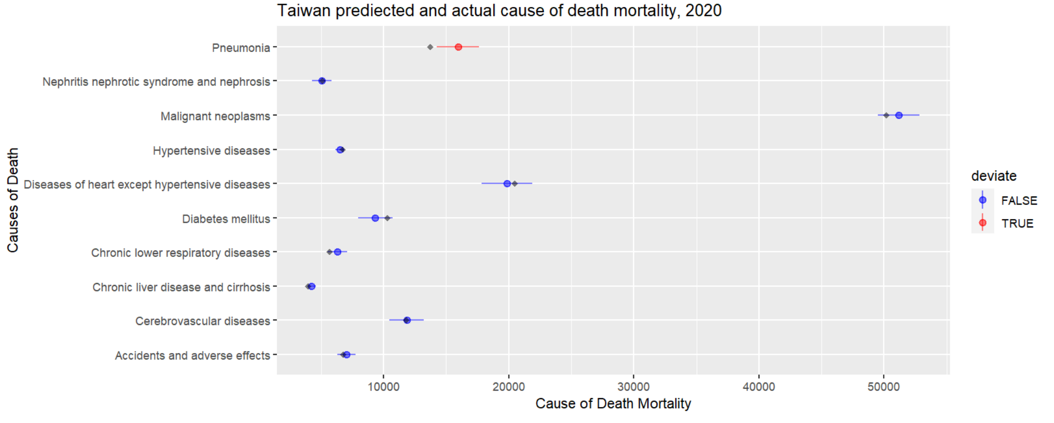
	real	forecast	up.95%	low.95%	ε	p-value
Neoplasms (C00-D48)	3784.00	3993.73	4151.85	3835.60	80.68	0.00***
Endocrine, nutritional and metabolic diseases (E00-E90)	387.00	292.00	360.92	223.08	35.17	0.00***
Respiratory system (J00-J99, U07)	716.00	571.95	672.06	471.85	51.07	0.00***
Digestive system (K00-K93)	751.00	632.00	714.22	549.78	41.95	0.00***
Skin and subcutaneous tissue (L00-L99)	27.00	15.55	25.07	6.03	4.86	0.01**
Nervous system and sense organs (G00-H95)	430.00	360.23	403.22	317.23	21.94	0.00***
Infectious and parasitic diseases (A00-B99)	161.00	152.18	188.63	115.72	18.60	0.32
Diseases of the blood and blood-forming organs (D50-D89)	27.00	26.27	35.80	16.73	4.86	0.44
Mental, behavioural disorders (F00-F99)	180.00	175.00	240.26	109.74	33.30	0.44
Circulatory system (I00-I99)	7669.00	7533.27	8206.27	6860.26	343.38	0.35
Musculo-skeletal system and connective tissue (M00-M99)	63.00	53.29	75.27	31.31	11.22	0.19
Genito-urinary system (N00-N99)	191.00	156.72	198.29	115.14	21.21	0.05
Complications of pregnancy, childbirth and puerperium (O00-O99)	1.00	-0.60	3.17	-4.38	1.93	0.20
Certain conditions originating in the perinatal period (P00-P96)	12.00	4.47	35.70	-26.77	15.94	0.32
Congenital malformations and chromosomal abnormalities (Q00-Q99)	21.00	16.70	39.18	-5.78	11.47	0.35
Symptoms, signs and ill-defined causes (R00-R99)	447.00	542.00	778.55	305.45	120.69	0.22
Injury and poisoning (V01-Y89)	944.00	769.00	1281.75	256.25	261.61	0.25

Note: One-sided p-value, adjusted for the direction. $^{*}p<0.05$; $^{**}p<0.025$; $^{***}p<0.005$

4.3.3. *Taiwan*

The cause of deaths data in Taiwan is also included to be used as an example of the "zero COVID policy" that was popular in Asia back in 2020. The top 10 causes of death in 2020 is shown in the graph 9 and table V.

FIGURE 9.—Taiwan cause of death mortality



During the zero COVID policy, all causes of death stayed the same except for a decrease in Pneumonia. The reasoning for deviation in Pneumonia shall be similar to that of Germany, where social distancing and mask rules successfully prevented some transmissions.

There were concerns that the "zero COVID policy" might result in more (or less) extra mortality, but the result for Taiwan disapproves this idea. Note that this holds only for Taiwan and in 2020. It can vary with the management capability of the government and different COVID variants.

TABLE V

TAIWAN PREDICTED AND ACTUAL CAUSE OF DEATH MORTALITY, 2020

	real	forecast	up.95%	low.95%	ε	p-value
Pneumonia	13736.00	15938.00	17649.28	14226.72	873.12	0.01**
Malignant neoplasms	50161.00	51173.08	52837.45	49508.71	849.18	0.12
Heart except hypertensive diseases	20457.00	19859.00	21861.56	17856.44	1021.73	0.28
Cerebrovascular diseases	11821.00	11843.97	13229.65	10458.30	706.99	0.49
Diabetes mellitus	10311.00	9339.21	10732.22	7946.21	710.73	0.09
Accidents and adverse effects	6767.00	7019.36	7733.47	6305.24	364.35	0.24
Hypertensive diseases	6706.00	6504.82	6855.85	6153.79	179.10	0.13
Chronic lower respiratory diseases	5657.00	6301.00	7094.97	5507.03	405.10	0.06
Nephritis nephrotic syndrome and nephrosis	5096.00	5049.00	5832.78	4265.22	399.89	0.45
Chronic liver disease and cirrhosis	3964.00	4240.00	4569.30	3910.70	168.01	0.05

Note: One-sided p-value, adjusted for the direction. *p<0.05; **p<0.025; ***p<0.005

4.3.4. *Other Countries*

Due to the space limit, the graphs and tables for Hungary (table XVI), Slovenia (table XVII), and Singapore (table XVIII and XIX for 2020 and 2021) are in the Appendix.

In general, the phenomenon that the mortality from respiratory diseases decreased happened also in Hungary ($p < 0.05$), Slovenia ($p < 0.025$), and Singapore ($p < 0.025$) in 2020.

Moreover, in Hungary, the mortality from "intentional self-harm" increased ($p < 0.025$). And in Slovenia, the mortality from "External causes" increased ($p < 0.025$).

For Singapore, in 2020, the deaths from the circulatory system increased (($p < 0.005$)). As the only country in which 2021 cause-specific mortality is available, there is no significant deviation for all of the causes of death, even though the was a small outbreak of delta variant in 2021.

4.4. *Cause of Death across countries*

In most countries, the "Anti-COVID19" policies including lockdowns, social distancing, and mandatory policies led to a significant change in a few related causes of death.

4.4.1. *Respiratory diseases*

In the former part of this section, it is shown that most countries encountered a decrease in diseases of respiratory diseases. Table VI collected the predicted values for all countries in this analysis. The column "Trend" gives a straightforward interpretation of the numbers.

In 6 investigated countries, 4 of them present a decrease in these statistics ($p < 0.025$) in 2020. The most interesting statistics are in Taiwan where the respiratory disease is separated into Pneumonia (transmissible) and Chronic lower respiratory diseases (generally not transmissible). The decrease happened only in the former category. It provides support to the interpretation that the decrease in deaths from respiratory was due to reduced transmission.

For Hungary, the only related statistics were recording non-transmissible respiratory diseases. Similar to Taiwan, there was no significant change. At least for this specific category, there was not enough evidence to show misclassification.

TABLE VI

RESPIRATORY DISEASES ACROSS COUNTRIES

	real	forecast	ε	p-value	Trend
Germany	61348.00	73159.52	3036.00	0.00***	Decrease
Estonia	716.00	571.95	51.07	0.00***	Increase
Slovenia	800.00	1077.00	130.16	0.02**	Decrease
Singapore					
In 2020	4610.00	5034.25	186.36	0.01**	Decrease
In 2021	8077.00	8275.28	301.62	0.26	Same
Taiwan					
Pneumonia	13736.00	15938.00	873.12	0.01**	Decrease
Chronic lower respiratory diseases	5657.00	6301.00	405.10	0.06	Same
Hungary					
bronchitis, pulmonary emphysema and asthma	5352.00	6262.00	464.41	0.03*	Decrease

Note: One-sided p-value, adjusted for the direction. *p<0.05; **p<0.025; ***p<0.005

4.4.2. *Neoplasms*

Neoplasm-related deaths are considered to be the highest cause of death in many countries. The cause of death statistics for neoplasm is therefore a good indicator to measure the indirect shock, especially on healthcare systems, that COVID19 and anti-COVID19 caused.

TABLE VII

NEOPLASMS MORTALITY ACROSS COUNTRIES

	real	forecast	ε	p-value	Trend
Germany	239552.00	241223.21	1759.35	0.17	Same
Estonia	3784.00	3993.73	80.68	0.00***	Decrease
Slovenia	6481.00	6613.29	137.67	0.17	Same
Singapore					
In 2020	6480.00	6370.11	110.60	0.16	Same
In 2021	4926.00	5008.28	239.38	0.37	Same
Taiwan	50161.00	51173.08	849.18	0.12	Same
Hungary	31623.00	32160.32	636.61	0.20	Same

Note: One-sided p-value, adjusted for the direction. $^{*}p<0.05$; $^{**}p<0.025$; $^{***}p<0.005$

Table VII shows the neoplasms mortality across countries. In the sample studied in this thesis, no country had a significant increase in mortality. It is expected since, at the start of the pandemic, most countries implemented strict anti-COVID 19 policies until summer so that there is no large outbreak during most of 2020.

From the "over- and under-estimated" point of view, if many of the cause of death mortality changes are expected, it is less likely that any under- or over-estimated took place in 2020. This result agrees with the second part of the result, that the actual mortality, in general, did not deviate too much from the summation of predicted mortality and death from COVID19.

5. CONCLUSION AND DISCUSSION

5.1. *Conclusion*

During the COVID-19 pandemic, four selected countries in Europe experienced waves of high infection, while Taiwan and Singapore did not, until the Delta and Omicron waves.

For the selected countries where the COVID-19 infection was high, there is enough evidence to confirm the existence of excess mortality. For Germany, Slovenia, and Hungary, the excess mortality existed only in the winter of 2020 and 2021, with about 1 or 2 months of delay with respect to the exponential growth in the confirmed cases. For Estonia, excess mortality is often presented, starting from winter 2020. And for all countries, the excess mortality faded in the Omicron wave from spring 2022, albeit with high confirmed cases.

In the "predicted mortality + COVID-19 death" versus the actual mortality part, the forecast figures for Slovenia and Hungary are significantly lower than the actual, which can be interpreted as a delay of less than 1 month. The EU countries, except for Estonia, have the same pattern that after a wave of infections and high excess death, the actual numbers are lower than the predicted numbers. It could be a result of the lockdown policy and "acceleration" of death.

For most of the investigated countries, the cause specific-mortalities are only available in 2020. For most countries, there was a decrease in death from respiratory diseases. More specifically, the death from transmissible respiratory diseases such as Pneumonia and Influenza decreased, whereas data in Taiwan indicated that there was no effect on chronic respiratory diseases. It implies that the anti-COVID policy had positive effects in reducing the transmission of the virus.

For most other causes of death, including major causes such as neoplasms, there is not enough evidence to confirm a systematic deviation from the forecast. In other words, there is not enough evidence to show that anti-COVID policies are causing mortality indirectly. This also holds for the countries that implemented the "Zero COVID policy."

From the perspective of under- or over-reporting, all results drive the conclusion that at the end of 2020, under-reporting is very likely to have happened in Slovenia and Hungary.

5.2. *Limits and Improvements*

5.2.1. *Data limits and improvements*

The cause of death data used in this thesis are yearly and available only in 2020. However, as stated in the result part, only after October or November 2020, the COVID really started to hit every country. And only started from that time were very strict lockdown measure was in place. Infers that if data are available in 2021, the impact of COVID-19 and lockdown will be more clear.

And if there are monthly causes of death data, which are kept secret for most countries, the prediction can be more accurate and the trend that changes with COVID infection can be shown better. It is especially important for any further analysis of COVID, as a wave of infection always last for only about 3-4 months, depending on the policy.

Due to the time written, the monthly mortality data for the Omicron variant are not complete. Although in most countries the Omicron variant did not bring excess mortality when the wave started, it could be due to the fact that the data is not complete. It is shown in the Delta wave that the mortality can accelerate in the second half of the wave.

Due to the same reasoning, more research is needed on the Omicron variant, as the Omicron variant mutates faster and can infect again to those infected with COVID (Karim and Karim, 2021). For instance, will the Omicron variant or the new variant in autumn and winter 2022 bring a permanent change in the mortality pattern.

More research can be done to investigate the long-term effect of COVID, especially on mortality. In theory, it can be done by investigating the existence of a permanent change in the cause of death-mortem model. Again, the latest data would be required.

5.2.2. *Inclusion of other variables*

This thesis focuses mainly on comparing each country, so it only utilizes confirmed cases of COVID-19 and death numbers in the analysis. It results not only from the difficulty and complexity of finding data but also from the different statistics that could potentially be hard to compare.

In investigating the COVID-19 impact on fewer countries, the medical resources data could be the direct indicator for measuring the impact of COVID-19.

5.2.3. *Range of countries*

A biased selection of countries for this theory could be a significant issue. Similar to the econometric idea of "truncated data." The idea behind the nation selection procedure is that the country's data are readily accessible and the period is sufficient for model stability.

Countries like the United Arab Emirates, Malaysia, and South Africa do not supply the public with official data. It is possible that they are concealing themselves on purpose. Finding these "missing" data could result in more valuable outcomes.

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APPENDIX

TABLE VIII

ACTUAL MORTALITY AND PREDICTED MORTALITY IN GERMANY

	actual	forecast	ε	p-value
Jan 2020	84927.43	87424.71	2896.51	0.19
Feb 2020	79968.86	84178.63	3435.24	0.11
Mar 2020	87771.14	89603.81	3528.46	0.30
Apr 2020	82926.86	77541.01	3556.65	0.06
May 2020	76177.00	75813.95	3562.96	0.46
Jun 2020	72144.00	71730.63	3564.70	0.45
Jul 2020	73912.57	75281.22	3565.12	0.35
Aug 2020	78692.29	74006.38	3565.23	0.09
Sep 2020	74213.29	71008.37	3565.26	0.18
Oct 2020	79975.86	76660.55	3565.26	0.18
Nov 2020	86678.29	76654.55	3565.26	0.00***
Dec 2020	108622.43	82927.45	3565.26	0.00***
Jan 2021	106457.43	87342.65	3579.46	0.00***
Feb 2021	81619.29	84248.73	3585.22	0.23
Mar 2021	81719.14	89923.68	3586.31	0.01**
Apr 2021	81798.14	78037.68	3586.65	0.15
May 2021	80837.00	76348.62	3586.72	0.11
Jun 2021	76333.86	72425.25	3586.74	0.14
Jul 2021	76667.43	76002.64	3586.75	0.43
Aug 2021	76587.00	74584.51	3586.75	0.29
Sep 2021	77802.29	71578.57	3586.75	0.04*
Oct 2021	85195.14	77272.98	3586.75	0.01**
Nov 2021	94191.43	77367.36	3586.75	0.00***
Dec 2021	101727.14	83555.78	3586.75	0.00***
Jan 2022	89263.29	87911.49	3630.28	0.35
Feb 2022	82150.71	84795.83	3647.83	0.23
Mar 2022	92442.71	90457.15	3651.16	0.29
Apr 2022	84945.29	78565.15	3652.18	0.04

Note: $^{*}p<0.05$; $^{**}p<0.025$; $^{***}p<0.005$

One-sided p-value, adjusted for the direction.

TABLE IX

ACTUAL MORTALITY AND PREDICTED MORTALITY IN ESTONIA

	actual	forecast	ε	p-value
Jan 2020	1364.14	1510.98	71.83	0.02*
Feb 2020	1282.86	1356.92	75.33	0.16
Mar 2020	1402.71	1433.65	75.38	0.34
Apr 2020	1333.43	1244.32	75.60	0.12
May 2020	1296.29	1262.37	75.76	0.33
Jun 2020	1184.43	1150.86	75.90	0.33
Jul 2020	1263.71	1217.16	76.03	0.27
Aug 2020	1262.43	1202.36	76.14	0.22
Sep 2020	1270.00	1148.31	76.24	0.06
Oct 2020	1283.00	1248.81	76.33	0.33
Nov 2020	1325.86	1202.96	76.41	0.05
Dec 2020	1557.00	1351.38	76.48	0.00***
Jan 2021	1695.57	1473.40	82.31	0.00***
Feb 2021	1497.86	1336.27	83.11	0.03*
Mar 2021	1851.29	1424.53	83.20	0.00***
Apr 2021	1597.29	1237.47	83.34	0.00***
May 2021	1467.86	1246.45	83.44	0.00***
Jun 2021	1383.71	1145.62	83.54	0.00***
Jul 2021	1395.57	1215.54	83.63	0.02**
Aug 2021	1351.00	1187.55	83.71	0.03*
Sep 2021	1435.29	1140.61	83.77	0.00***
Oct 2021	1643.29	1240.30	83.83	0.00***
Nov 2021	1742.57	1189.58	83.89	0.00***
Dec 2021	1698.00	1351.87	83.94	0.00***
Jan 2022	1621.14	1478.45	92.59	0.06
Feb 2022	1627.86	1310.03	93.65	0.00***
Mar 2022	1624.86	1379.79	93.72	0.00***
Apr 2022	1308.00	1213.62	93.86	0.16

Note: *p<0.05; **p<0.025; ***p<0.005

One-sided p-value, adjusted for the direction.

TABLE X

ACTUAL MORTALITY AND PREDICTED MORTALITY IN SLOVENIA

	actual	forecast	ε	p-value
Jan 2020	1959.00	2014.71	86.73	0.26
Feb 2020	1891.00	1835.48	95.40	0.28
Mar 2020	1859.14	1914.92	95.41	0.28
Apr 2020	1722.14	1677.13	95.50	0.32
May 2020	1621.00	1594.80	95.85	0.39
Jun 2020	1613.71	1505.38	95.89	0.13
Jul 2020	1597.86	1581.50	95.89	0.43
Aug 2020	1617.86	1586.11	95.89	0.37
Sep 2020	1667.71	1552.74	95.90	0.12
Oct 2020	2141.57	1699.32	95.90	0.00***
Nov 2020	3114.86	1625.77	95.90	0.00***
Dec 2020	3229.86	1813.88	95.90	0.00***
Jan 2021	2608.43	2060.72	96.42	0.00***
Feb 2021	1845.00	1877.35	96.53	0.37
Mar 2021	1933.14	1893.10	96.53	0.34
Apr 2021	1798.14	1669.08	96.53	0.09
May 2021	1759.00	1612.43	96.54	0.06
Jun 2021	1670.14	1508.68	96.54	0.05
Jul 2021	1532.43	1596.20	96.54	0.25
Aug 2021	1501.86	1591.16	96.54	0.18
Sep 2021	1771.71	1552.08	96.54	0.01**
Oct 2021	2004.29	1693.98	96.54	0.00***
Nov 2021	2433.57	1632.50	96.54	0.00***
Dec 2021	2266.14	1827.83	96.54	0.00***
Jan 2022	2130.43	2016.84	99.69	0.13
Feb 2022	2114.29	1863.74	100.34	0.01**
Mar 2022	2014.57	1920.85	100.34	0.18

Note: *p<0.05; **p<0.025; ***p<0.005

One-sided p-value, adjusted for the direction.

TABLE XI

ACTUAL MORTALITY AND PREDICTED MORTALITY IN HUNGARY

	actual	forecast	ε	p-value
Jan 2020	11786.29	12724.57	509.59	0.03*
Feb 2020	11154.29	11874.79	565.68	0.10
Mar 2020	11660.43	12080.41	566.15	0.23
Apr 2020	10494.00	10520.18	566.15	0.48
May 2020	9924.29	10171.88	566.15	0.33
Jun 2020	9674.29	9620.66	566.15	0.46
Jul 2020	9780.57	10077.89	566.15	0.30
Aug 2020	9978.00	10091.51	566.15	0.42
Sep 2020	10312.43	9878.78	566.15	0.22
Oct 2020	12593.00	10766.34	566.15	0.00***
Nov 2020	16722.14	10431.52	566.15	0.00***
Dec 2020	17031.14	11742.65	566.15	0.00***
Jan 2021	13726.14	13086.50	569.00	0.13
Feb 2021	11917.29	11999.51	569.66	0.44
Mar 2021	18079.71	12024.49	569.66	0.00***
Apr 2021	15412.43	10442.08	569.66	0.00***
May 2021	11111.14	10113.99	569.66	0.04*
Jun 2021	10506.14	9699.87	569.66	0.08
Jul 2021	10426.86	10061.85	569.66	0.26
Aug 2021	9880.57	10078.69	569.66	0.36
Sep 2021	10279.14	9868.97	569.66	0.24
Oct 2021	12010.57	10708.26	569.66	0.01**
Nov 2021	15867.00	10360.18	569.66	0.00***
Dec 2021	16328.00	11654.90	569.66	0.00***
Jan 2022	13251.00	13053.69	593.02	0.37
Feb 2022	12374.71	11996.43	598.31	0.26
Mar 2022	12268.00	12024.20	598.36	0.34

Note: *p<0.05; **p<0.025; ***p<0.005
One-sided p-value, adjusted for the direction.

TABLE XII

GERMANY PREDICTED MORTALITY WITH DEATH FROM COVID

	actual	forecast	ε	p-value
Jan 2020	84927.43	87424.71	2896.51	0.19
Feb 2020	79968.86	84179.63	3435.24	0.11
Mar 2020	87771.14	91903.81	3528.46	0.12
Apr 2020	82926.86	83589.01	3556.65	0.43
May 2020	76177.00	76579.95	3562.96	0.45
Jun 2020	72144.00	71877.63	3564.70	0.47
Jul 2020	73912.57	75412.22	3565.12	0.34
Aug 2020	78692.29	74135.38	3565.23	0.10
Sep 2020	74213.29	71337.37	3565.26	0.21
Oct 2020	79975.86	79727.55	3565.26	0.47
Nov 2020	86678.29	88252.55	3565.26	0.33
Dec 2020	108622.43	108716.45	3565.26	0.49
Jan 2021	106457.43	107411.65	3579.46	0.39
Feb 2021	81619.29	90983.73	3585.22	0.00***
Mar 2021	81719.14	95462.68	3586.31	0.00***
Apr 2021	81798.14	84788.68	3586.65	0.20
May 2021	80837.00	79142.62	3586.72	0.32
Jun 2021	76333.86	72719.25	3586.74	0.16
Jul 2021	76667.43	76166.64	3586.75	0.44
Aug 2021	76587.00	75457.51	3586.75	0.38
Sep 2021	77802.29	73344.57	3586.75	0.11
Oct 2021	85195.14	80740.98	3586.75	0.11
Nov 2021	94191.43	87540.36	3586.75	0.03
Dec 2021	101727.14	92434.78	3586.75	0.00***
Jan 2022	89263.29	91549.49	3630.28	0.26
Feb 2022	82150.71	90935.83	3647.83	0.01**
Mar 2022	92442.71	97692.15	3651.16	0.08
Apr 2022	84945.29	82269.15	3652.18	0.23

Note: $^{*}p<0.05$; $^{**}p<0.025$; $^{***}p<0.005$

One-sided p-value, adjusted for the direction.

TABLE XIII

ESTONIA PREDICTED MORTALITY WITH DEATH FROM COVID

	actual	forecast	ε	p-value
Jan 2020	1364.14	1510.98	71.83	0.02
Feb 2020	1282.86	1356.92	75.33	0.16
Mar 2020	1402.71	1436.65	75.38	0.33
Apr 2020	1333.43	1291.32	75.60	0.29
May 2020	1296.29	1275.37	75.76	0.39
Jun 2020	1184.43	1150.86	75.90	0.33
Jul 2020	1263.71	1217.16	76.03	0.27
Aug 2020	1262.43	1203.36	76.14	0.22
Sep 2020	1270.00	1148.31	76.24	0.06
Oct 2020	1283.00	1257.81	76.33	0.37
Nov 2020	1325.86	1241.96	76.41	0.14
Dec 2020	1557.00	1468.38	76.48	0.12
Jan 2021	1695.57	1663.40	82.31	0.35
Feb 2021	1497.86	1506.27	83.11	0.46
Mar 2021	1851.29	1737.53	83.20	0.09
Apr 2021	1597.29	1493.47	83.34	0.11
May 2021	1467.86	1340.45	83.44	0.06
Jun 2021	1383.71	1162.62	83.54	0.00***
Jul 2021	1395.57	1218.54	83.63	0.02**
Aug 2021	1351.00	1207.55	83.71	0.04
Sep 2021	1435.29	1205.61	83.77	0.00***
Oct 2021	1643.29	1414.30	83.83	0.00***
Nov 2021	1742.57	1458.58	83.89	0.00***
Dec 2021	1698.00	1483.87	83.94	0.01**
Jan 2022	1621.14	1579.45	92.59	0.33
Feb 2022	1627.86	1513.03	93.65	0.11
Mar 2022	1624.86	1598.79	93.72	0.39
Apr 2022	1308.00	1298.62	93.86	0.46

Note: *p$<$0.05; **p$<$0.025; ***p$<$0.005

One-sided p-value, adjusted for the direction.

TABLE XIV

SLOVENIA PREDICTED MORTALITY WITH DEATH FROM COVID

	actual	forecast	ε	p-value
Jan 2020	1959.00	2014.71	86.73	0.26
Feb 2020	1891.00	1835.48	95.40	0.28
Mar 2020	1859.14	1927.92	95.41	0.24
Apr 2020	1722.14	1760.13	95.50	0.35
May 2020	1621.00	1611.80	95.85	0.46
Jun 2020	1613.71	1505.38	95.89	0.13
Jul 2020	1597.86	1587.50	95.89	0.46
Aug 2020	1617.86	1599.11	95.89	0.42
Sep 2020	1667.71	1573.74	95.90	0.16
Oct 2020	2141.57	1909.32	95.90	0.01**
Nov 2020	3114.86	2778.77	95.90	0.00***
Dec 2020	3229.86	3251.88	95.90	0.41
Jan 2021	2608.43	2923.72	96.42	0.00***
Feb 2021	1845.00	2211.35	96.53	0.00***
Mar 2021	1933.14	2111.10	96.53	0.03
Apr 2021	1798.14	1887.08	96.53	0.18
May 2021	1759.00	1737.43	96.54	0.41
Jun 2021	1670.14	1559.68	96.54	0.13
Jul 2021	1532.43	1606.20	96.54	0.22
Aug 2021	1501.86	1612.16	96.54	0.13
Sep 2021	1771.71	1679.08	96.54	0.17
Oct 2021	2004.29	1921.98	96.54	0.20
Nov 2021	2433.57	2175.50	96.54	0.00***
Dec 2021	2266.14	2256.83	96.54	0.46
Jan 2022	2130.43	2336.84	99.69	0.02**
Feb 2022	2114.29	2538.74	100.34	0.00***
Mar 2022	2014.57	2246.85	100.34	0.01**

Note: *p<0.05; **p<0.025; ***p<0.005

One-sided p-value, adjusted for the direction.

TABLE XV

HUNGARY PREDICTED MORTALITY WITH DEATH FROM COVID

	actual	forecast	ε	p-value
Jan 2020	11786.29	12724.57	509.59	0.03
Feb 2020	11154.29	11874.79	565.68	0.10
Mar 2020	11660.43	12096.41	566.15	0.22
Apr 2020	10494.00	10816.18	566.15	0.28
May 2020	9924.29	10383.88	566.15	0.21
Jun 2020	9674.29	9681.66	566.15	0.49
Jul 2020	9780.57	10088.89	566.15	0.29
Aug 2020	9978.00	10109.51	566.15	0.41
Sep 2020	10312.43	10029.78	566.15	0.31
Oct 2020	12593.00	11751.34	566.15	0.07
Nov 2020	16722.14	13504.52	566.15	0.00***
Dec 2020	17031.14	16456.65	566.15	0.16
Jan 2021	13726.14	16073.50	569.00	0.00***
Feb 2021	11917.29	14449.51	569.66	0.00***
Mar 2021	18079.71	17787.49	569.66	0.30
Apr 2021	15412.43	17245.08	569.66	0.00***
May 2021	11111.14	12307.99	569.66	0.02**
Jun 2021	10506.14	9957.87	569.66	0.17
Jul 2021	10426.86	10095.85	569.66	0.28
Aug 2021	9880.57	10110.69	569.66	0.34
Sep 2021	10279.14	10000.97	569.66	0.31
Oct 2021	12010.57	11247.26	569.66	0.09
Nov 2021	15867.00	14152.18	569.66	0.00***
Dec 2021	16328.00	16319.90	569.66	0.49
Jan 2022	13251.00	15272.69	593.02	0.00***
Feb 2022	12374.71	14540.43	598.31	0.00***
Mar 2022	12268.00	13545.20	598.36	0.02**

Note: *p$<$0.05; **p$<$0.025; ***p$<$0.005

One-sided p-value, adjusted for the direction.

FIGURE 10.—Hungary cause of death mortality

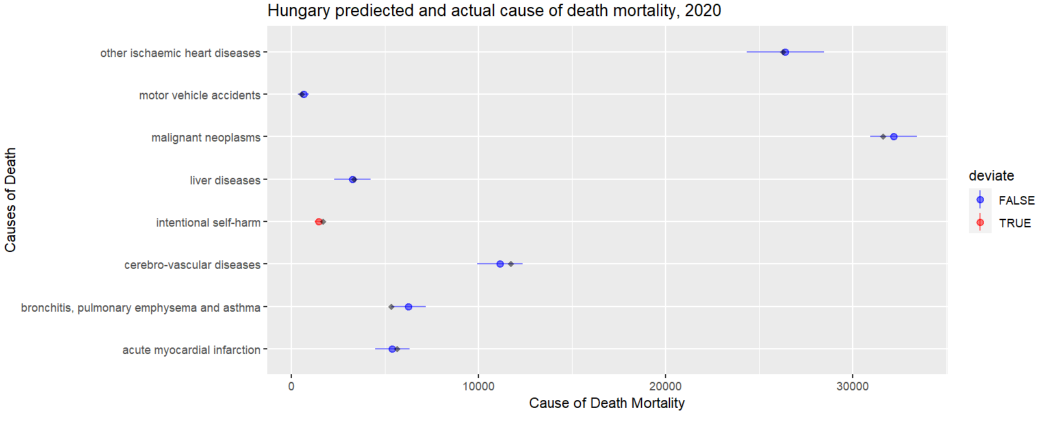

TABLE XVI

HUNGARY PREDICTED AND ACTUAL CAUSE OF DEATH MORTALITY, 2020

	real	forecast	up.95%	low.95%	ε	p-value
intentional self-harm	1706.00	1460.93	1669.31	1252.55	106.32	0.01**
bronchitis, pulmonary emphysema and asthma	5352.00	6262.00	7172.23	5351.77	464.41	0.03*
malignant neoplasms	31623.00	32160.32	33408.05	30912.59	636.61	0.20
other ischaemic heart diseases	26280.00	26392.79	28455.14	24330.44	1052.24	0.46
cerebro-vascular diseases	11722.00	11152.48	12369.81	9935.15	621.10	0.18
acute myocardial infarction	5655.00	5397.17	6310.32	4484.02	465.90	0.29
liver diseases	3361.00	3266.97	4229.29	2304.65	490.99	0.42
motor vehicle accidents	554.00	654.38	943.16	365.60	147.34	0.25

Note: One-sided p-value, adjusted for the direction. *p$<$0.05; **p$<$0.025; ***p$<$0.005

FIGURE 11.—Slovenia cause of death mortality

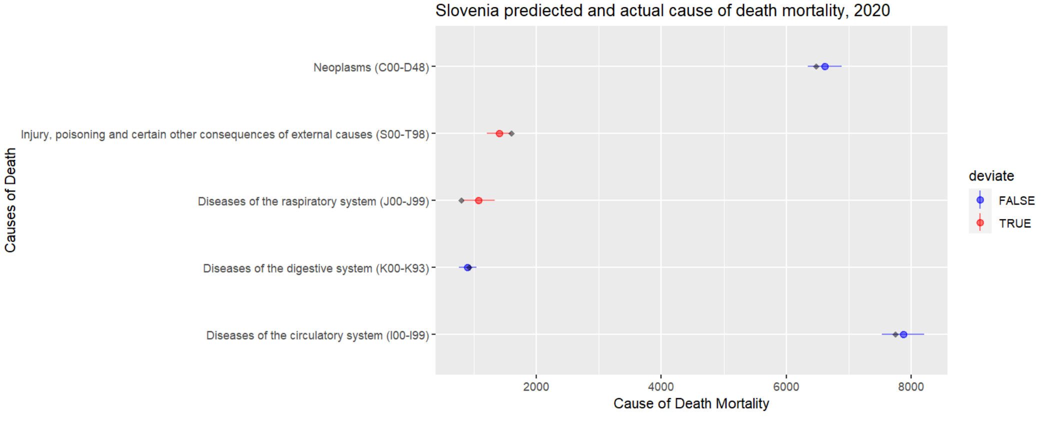

TABLE XVII

SLOVENIA PREDICTED AND ACTUAL CAUSE OF DEATH MORTALITY, 2020

	real	forecast	up.95%	low.95%	ε	p-value
External causes (S00-T98)	1610.00	1403.00	1595.58	1210.42	98.26	0.02**
Respiratory system (J00-J99)	800.00	1077.00	1332.12	821.88	130.16	0.02**
Circulatory system (I00-I99)	7747.00	7867.76	8207.79	7527.72	173.49	0.24
Digestive system (K00-K93)	934.00	901.00	1042.38	759.62	72.13	0.32
Neoplasms (C00-D48)	6481.00	6613.29	6883.12	6343.46	137.67	0.17

Note: One-sided p-value, adjusted for the direction. *p<0.05; **p<0.025; ***p<0.005

FIGURE 12.—Singapore cause of death mortality

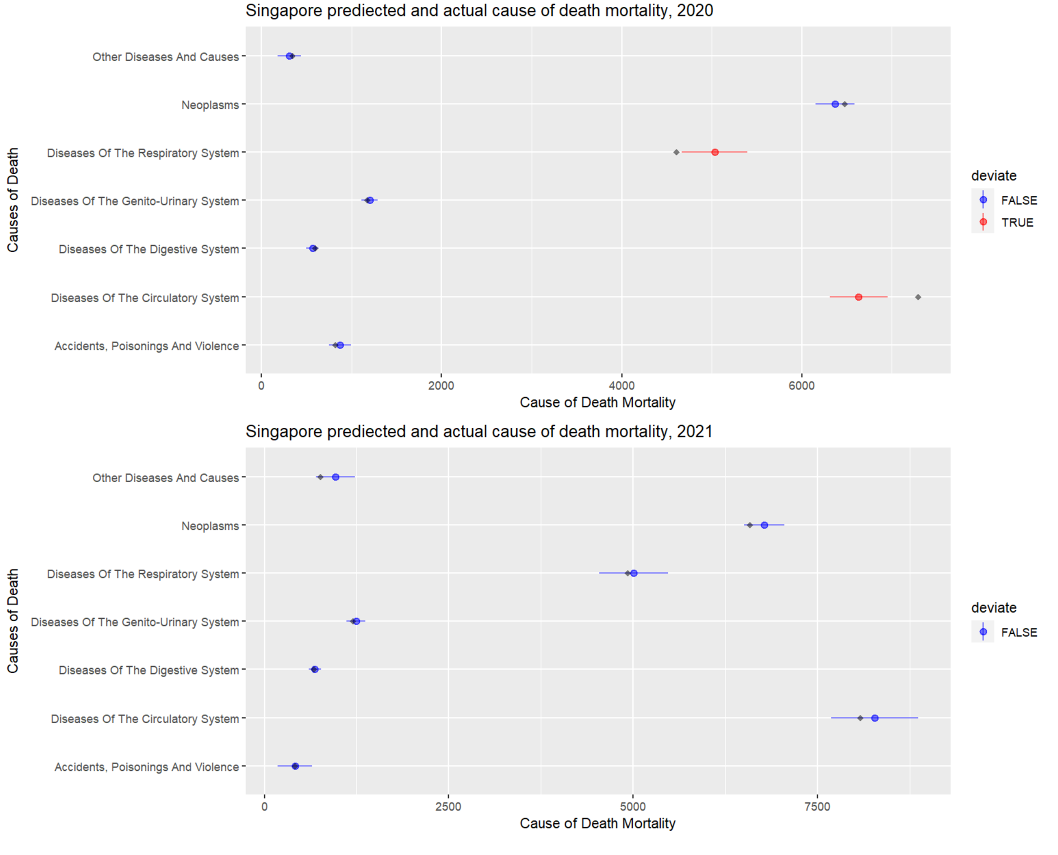

TABLE XVIII

SINGAPORE PREDICTED AND ACTUAL CAUSE OF DEATH MORTALITY, 2020

	real	forecast	up.95%	low.95%	ε	p-value
Circulatory System	7296.00	6630.70	6951.31	6310.10	163.58	0.00***
Respiratory System	4610.00	5034.25	5399.52	4668.98	186.36	0.01**
Total Deaths By Causes	22054.00	21670.44	22259.24	21081.64	300.42	0.10
Infective And Parasitic Diseases	216.00	229.62	309.90	149.34	40.96	0.37
Neoplasms	6480.00	6370.11	6586.88	6153.34	110.60	0.16
Endocrine, Nutritional And Metabolic Diseases	286.00	293.81	422.19	165.42	65.51	0.45
Blood And Blood-Forming Organs	12.00	17.06	34.52	-0.41	8.91	0.29
Nervous System And Sense Organs	156.00	178.62	222.81	134.44	22.54	0.16
Digestive System	594.00	566.00	632.51	499.49	33.93	0.20
Genito-Urinary System	1177.00	1200.96	1292.86	1109.06	46.89	0.30
Congenital Anomalies	45.00	44.56	75.72	13.40	15.90	0.49
Certain Causes Of Perinatal Mortality	23.00	23.46	79.72	-32.81	28.71	0.49
Accidents, Poisonings And Violence	818.00	869.52	991.35	747.68	62.16	0.20
Other Diseases And Causes	341.00	308.81	439.32	178.30	66.59	0.31

Note: One-sided p-value, adjusted for the direction. $^{*}p<0.05$; $^{**}p<0.025$; $^{***}p<0.005$

TABLE XIX

SINGAPORE PREDICTED AND ACTUAL CAUSE OF DEATH MORTALITY, 2021

	real	forecast	up.95%	low.95%	ε	p-value
Total Deaths By Causes	24220.00	25663.68	26863.14	24464.21	611.98	0.01**
Infective And Parasitic Diseases	977.00	977.00	1296.73	657.27	163.13	0.50
Neoplasms	6584.00	6776.83	7046.69	6506.96	137.69	0.08
Endocrine, Nutritional And Metabolic Diseases	301.00	332.21	493.89	170.52	82.49	0.35
Blood And Blood-Forming Organs	14.00	14.00	33.50	-5.50	9.95	0.50
Nervous System And Sense Organs	208.00	208.00	272.06	143.94	32.68	0.50
Circulatory System	8077.00	8275.28	8866.45	7684.11	301.62	0.26
Respiratory System	4926.00	5008.28	5477.46	4539.10	239.38	0.37
Digestive System	673.00	686.77	774.54	598.99	44.78	0.38
Genito-Urinary System	1205.00	1243.12	1373.34	1112.90	66.44	0.28
Congenital Anomalies	47.00	40.37	74.80	5.94	17.56	0.35
Certain Causes Of Perinatal Mortality	36.00	25.67	116.58	-65.24	46.38	0.41
Accidents, Poisonings And Violence	414.00	414.00	647.86	180.14	119.32	0.50
Other Diseases And Causes	758.00	966.44	1228.49	704.39	133.70	0.06

Note: One-sided p-value, adjusted for the direction. $^{*}p<0.05$; $^{**}p<0.025$; $^{***}p<0.005$