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EXCESS MORTALITY DURING THE COVID-19 PANDEMIC IN PORTUGAL

A NATIONAL AND REGIONAL ANALYSIS

AUTHORED BY:
FRANCISCO SALES
GONÇALO SILVA
INÊS COELHO
RUBEN BENTO

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e-mail: novaeconomicsclub@novasbe.pt
website: www.novaeconomicsclub.pt

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Authors: *Francisco Sales, Gonçalo Silva, Inês Coelho, Ruben Bento*
Partner: *Nova SBE Health Economics & Management Knowledge Center*
Advisor: *Professor Judite Gonçalves*
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Francisco Sales

Nova Economics Club

Nova School of Business and Economics

franciscotrovaosales@novasbe.pt

Gonçalo Silva

Nova Economics Club

Nova School of Business and Economics

39353@novasbe.pt

Inês Coelho

Nova Economics Club

Nova School of Business and Economics

42881@novasbe.pt

Ruben Bento

Nova Economics Club

Nova School of Business and Economics

32396@novasbe.pt

Abstract: The COVID-19 pandemic generated a significant increase in deaths all over the world, and Portugal was no exception. This paper studies the impact of COVID-19 in Portugal regarding excess mortality, by forecasting the number of daily deaths that would be registered if the pandemic were not to occur. The magnitude of excess mortality differs from COVID-19 deaths due to various reasons, including the decrease in medical care provided, both related to fear of going to the hospital and because the National Health Service was under great pressure. To forecast daily deaths in normal circumstances, this paper uses a regression model that takes into account trends, seasonality, and temperature anomalies. A national analysis showed that, since March 2020 until the end of the year, cumulative excess mortality was around 11,700 deaths. Regional analyses showed that the impact of COVID-19 was not homogeneous across the Portuguese territory. In absolute terms, Norte was the most affected region (5,150 deaths), followed by Lisboa e Vale do Tejo (3,810). The results of this paper also suggest that around 41% of excess mortality is not due to COVID-19 deaths but might be explained by factors such as worsening of medical conditions associated with the fall in medical contacts.

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1 Introduction

The COVID-19 pandemic has caused immense damage across the globe, posing a great challenge to today's society. Despite all countries being hit, not all of them were able to successfully address the problem. For example, while Asian countries have mostly dealt effectively with the pandemic and demonstrated resilience to new outbreaks through the adoption of stringent public health measures, Europe and the US have been struggling to "flatten the curve" in consecutive waves, with a massive burden being imposed on national healthcare systems. One measure of "success" of a country's response is excess mortality.

Excess mortality is commonly defined as "the mortality attributable to the crisis, above and beyond deaths that would have occurred in normal conditions" by Checchi and Roberts (2005). This indicator plays an important role in assessing the impact of a crisis, and, so, it can be useful to enlighten policy decisions.

This study is concerned with comprehending excess mortality during the COVID-19 pandemic in Portugal, including its key drivers and geographical patterns. Acknowledging that the current literature still lacks a clear dissection of indirect excess mortality caused by COVID-19, it aims at exploring and quantifying the impact of other events, such as heat and cold waves, on the excess mortality Portugal is experiencing, both on national and regional levels. It should be added that the use of the expressions such as *death(s) by COVID-19* and *COVID-19 deaths* throughout this paper refers to deaths considered by Portuguese health authorities to be directly caused by the referred disease. Terms such as *non-COVID deaths* refer to deaths which were not considered to be the result of the infection. In Portugal, a death by COVID-19 is registered whenever a death certificate presents it as being the ultimate cause of death.

The past year has been one of the deadliest registered in recent decades. According to the Portuguese National Statistics Institute (*Instituto Nacional de Estatística*, INE), since the beginning of March 2020, deaths have been 13% superior to those registered in homologous periods (more specifically, from 2015 to 2019). Numerous studies were conducted to find out the percentage of excess deaths in 2020 that corresponded to deaths by COVID-19. The conclusion was that, until the 1st of November, around 46% of the excess deaths were directly due to COVID-19, according to INE (2020). These numbers must be carefully observed to try to solve the problem of this majority of non-COVID fatalities. Among the factors that could be behind these numbers are the fact that patients could not be seeking health care or could being turned away from emergency departments, which delays diagnostic and treatment, the suspension of planned non-urgent medical appointments, exams, and surgeries, and even the heat wave that took place in July. It is fair to say that the real impacts of these factors will only be correctly determined in the long run, since some of the consequences of the delay of medical care may take a long time to stand out.

The model used in this work considers the effects of temperature anomalies, the long-term trend of mortality in Portugal, seasonality of fatalities, and the effect of weekends to try to isolate the impact of the pandemic. Firstly, mortality was studied at a national level. Afterwards, explorations on the different regions of Portugal were conducted, in order to have a glance at the disparities between those areas.

The remainder of this paper is organized as follows. Section 2 looks at studies that were already produced around this theme and highlights the main results of each. Section 3 explains how the research was approached, including data collection and a justification for the methods chosen. Finally, in Section 4, a bridge between the mathematical results of the study and how these translate to reality is rendered.

2 Literature Review

This section presents only studies that consider excess mortality in Portugal. Globally, they cover the various methodological approaches in the broader literature. Cardoso, Vasconcelos, Rodrigues, & Cruz-Correia (2020) address critical problems on the mortality data provided by each country. Using the deviation from the expected value in homologous periods (DEV), and the residual after seasonal time series decomposition (RSTS), with data from 2010 until 2020, the authors found that every country studied had excess mortality. Portugal was the country that presented less excess mortality (10.6% (DEV)) compared to England, Wales, France, Italy, and the Netherlands, and it was also the country that provided the most coherent data, with a shorter delay, even though lacking the detailed gender-specific or regional data on causes of death. In fact, the results for Portugal can be justified by the early action that took place, which can be considered a success in the first phase of the pandemic.

Kontis, et al. (2020) designed a probabilistic model in which an historical average number from daily death registrations in the past 10 years was used to predict death rates from mid-February 2020 until May 2020, as if this was a non-pandemic period. Following that, the results were compared with the reported deaths. The model accounted for variables that could influence mortality, such as seasonality, temperature, and public holidays. Portugal was pointed out as a relatively low-effect country, experiencing lower excess deaths as compared to countries that include Italy, Spain, and England. The work concluded that it is still difficult to justify the excessive mortality among the locations studied, but delayed disease prevention and medical procedures for acute and chronic conditions, loss of jobs and income and changes in other infectious diseases could be some of the factors behind the results.

Vieira, Peixoto, Aguiar, & Abrantes (2020) undertake a first analysis of excess mortality induced by COVID-19 in Portugal, adopting as time horizon the first month after the first death by COVID-19. In methodological terms, first, a comparison between observed deaths and historical averages of death records for the last 10 years was made. Afterwards, a more sophisticated ARIMA model was used. The main results of the paper point out to a mortality rate of 2.3% and excess 1,255 all-cause deaths (first month of the pandemic), that is, a 14% increase compared to the average, of which 49% were deaths by COVID-19 and the remaining 51% were registered as other causes. These figures suggest either inability of the Portuguese healthcare system to deal with non-COVID patients, people’s fear of going to the hospital and resulting deaths from illnesses which could be averted with appropriate treatment, non-detection of COVID-19 infections or a mix of the three factors. In addition, excess mortality was mostly attributed to people aged over 75.

Nogueira, Nobre, Nicola, Furtado, & Carneiro (2020) take a different approach and reach slightly different results. Using minimum observed mortality in the baseline period and assuming excess mortality to be zero until March 11, then smoothing the mortality series, the study found excess mortality between 2,400 and 4,000 deaths until April 22, which was much higher in magnitude than the number of deaths by COVID-19. Excess mortality was also concluded to be more frequent in older age groups. The most unique input to the discussion brought by this paper refers to an analysis by district, which found out that, in relative terms, estimated excess mortality seems overall homogeneous across districts, despite tending to be higher in districts with older populations and lower population density.

3 Data and Methodology

3.1 Data

This paper uses daily data from the 1st of January of 2014 until the 31st of December of 2020. The values of the central variable, "Deaths", which represents the number of deaths in a certain day, were obtained from the SICO/eVM website, administrated by the Portuguese Directorate-General of Health. The data are automatically updated every 10 minutes using information from SICO (Portuguese Mortality Information System). The data on "Deaths" were extracted both at the national and regional levels; the latter considers the place of residence of the deceased in accordance with the five health regions (Norte, Centro, Lisboa e Vale do Tejo, Alentejo and Algarve)[1]. Data on the number of COVID-19 deaths were extracted from the COVID-19 Data Repository from the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University. These data are in line with the daily reports of the Portuguese Health Authorities.

Data on temperatures were obtained from the website of the National Information System on hydric resources. From the 790 available weather stations, a list of 25 that had updated information (until the 31st of December of 2020) for average daily temperature in degrees Celsius was achieved. One station per region out of those 25 was then selected. To make that selection, the weather station in each of the five regions for which there were fewer missing values in the studied period was used. To obtain an estimate of the average daily temperature at the National level, an average of the average daily temperatures in each of the 5 selected stations was computed, weighted by the

[1] The study does not comprise both Madeira and Azores due to the small number of deaths registered in these regions, which would create a bad fit using this model.

population of each region. Population totals were obtained from INE/PORDATA for the year 2020.

3.2 Methodology

The pandemic was assumed to have started on the 2^{nd} of March of 2020, as this was the day in which the first case in Portugal was reported. As aforementioned, the data used comprises the period from 2014 until the report of the first case of COVID-19 in Portugal (2^{nd} of March of 2020) to fit the model below. Then, to estimate excess mortality, the model was used to forecast the deaths that the country would have in normal circumstances, i.e., if the pandemic were not to occur, throughout the remainder of 2020, and, afterwards, those forecasts were compared with actual deaths. The model is:

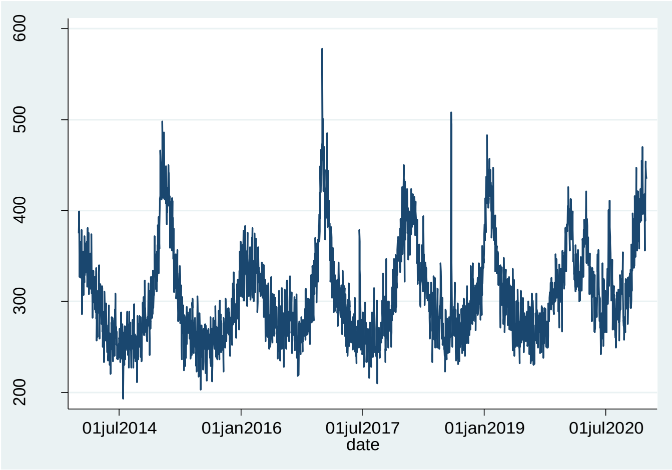
$$\begin{aligned} lo\,g(Deaths_t) = \alpha + \beta_1 trend + \beta_2 day + \beta_3 weekend + \beta_4 temp.anomalypos_t \\ + \beta_5 temp.anomalyneg_t + \beta_6 Deaths_{t-365} + \varepsilon_t \end{aligned}$$

This model was estimated by OLS in STATA, using the dependent variable in logarithmic form, due to the distribution of the variable daily deaths. Moreover, by doing this transformation, it is possible to improve the fit of the model when compared with a model in which the dependent variable is used in levels. During this paper, **excess mortality** is defined as the difference between the actual number of deaths and the predictions given by the model.

The rationale of each variable is the following:

$trend$ – a linear trend that captures any long run linear tendency of mortality in Portugal.

day – a set of dummies for each day of the year (1 through 365) that captures the seasonality of mortality in Portugal. This is particularly important, because, as it can be seen on Graph 1, the mortality in Portugal evolves in a U-shape over the year and, by including this set of variables, this behaviour can be captured.



Graph 1 - Daily deaths

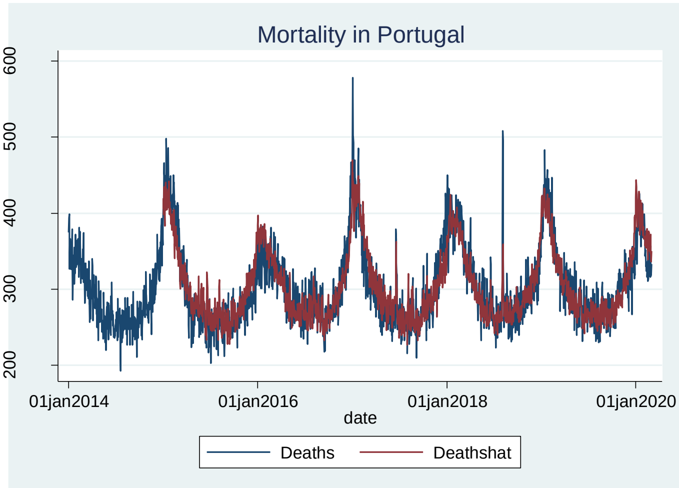
$weekend$ – binary variable that captures the fact that, during weekends, deaths registered tend to be lower than during business days.

$temp.anomalypos_t$ & $temp.anomalyneg_t$ – these two variables capture the impact of temperature anomalies on mortality, as it is expected that, when unusual significant temperature increases or temperature drops occur, mortality increases (Almeida, et al. (2020) and Almendra (2019)). Two variables for temperature anomaly were used, as unusually high or low temperatures can have different impacts on mortality. The variable $temp.anomalypos_t$ ranges from zero to 16.9, where zero denotes no or negative anomalies. The variable $temp.anomalyneg_t$ takes the absolute value of negative temperature anomalies; it ranges from zero to 13.9, where zero denotes no or positive anomalies. Both variables are obtained by taking the difference between daily temperature and the average of the last five years. For instance, if this difference is negative, there is a negative temperature anomaly. In this case, this result will be used in absolute value in the variable of $temp.anomalyneg_t$ and a zero will be attributed for the variable $temp.anomalypos_t$ for the same day[2].

[2] The possibility of using heat waves and cold spells as controls for temperature was also explored in the model. Both heat waves (when in an interval of at least 6 consecutive days, daily maximum temperature is 5ºC higher than the average value of maximum daily temperatures in the reference period) and cold spells (happens when in an interval of at least 6 consecutive days, daily minimum temperature is 5ºC lower to the average value of minimum daily temperatures in the reference period) were considered in accordance with IPMA definition.

$Deaths_{t-365}$ – an autoregressive component that uses the homologous deaths to estimate current deaths, as it is expected that mortality in one day is closely correlated with mortality in the same day one year after. This variable provides memory to the model in terms of magnitude, while the dummies used to capture seasonality will provide tendencies that are usual to occur.

This model was first applied to national mortality data and all explanatory variables were found to be statistically significant at the conventional 5% significance level. Graph 2 depicts both the actual value of deaths and the fitted values[3]. The national model has a MAE (Mean Absolute Error) of 15.4 deaths, or 5%, which gives the authors confidence that, in normal circumstances, it would be appropriated to estimate deaths using it. Given this, the excess mortality obtained through this model, which will be discussed in the following section, can be trusted.



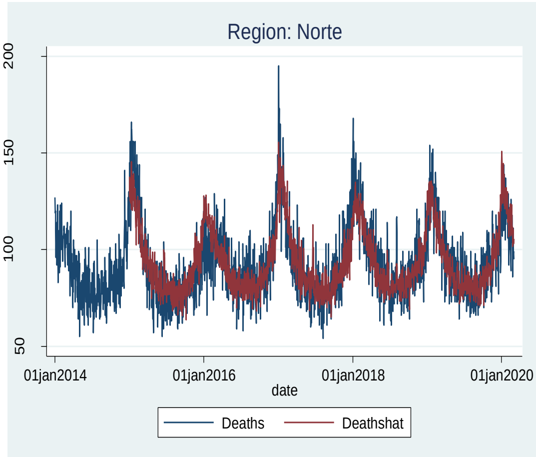
Graph 2 - Fitted values of daily deaths

This same model was then applied to the 5 regions in mainland Portugal, according to the NUTS 2 division (Norte, Centro, Lisboa e Vale do Tejo, Alentejo and Algarve), to study excess mortality in each region in more detail. As it is visible in Graphs 3 through 7, the models for Norte and Lisboa e Vale do Tejo are more adequate in terms of fit. This can be explained by the fact that the other regions have fewer daily deaths, which increases

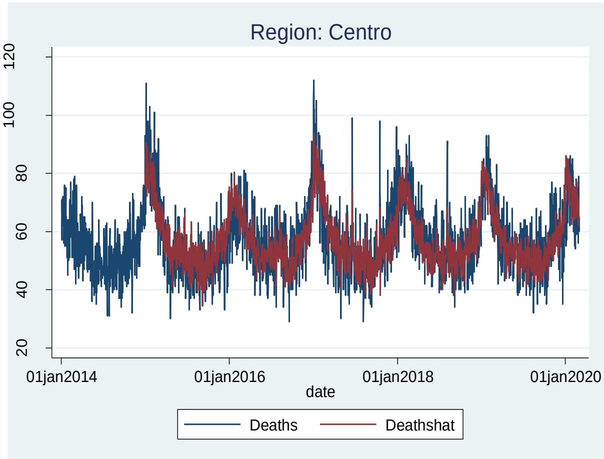
When used simultaneously with temperature anomaly, the variables for heat waves and cold spells had negligible effect in the model prediction capacity. Moreover, by only using the dummies for heat waves and cold spells instead of temperature anomaly, the relative MAE (Mean Absolute Error) of the model would increase from 5.08% to 5.29%. Thus, the final model did not include the dummies for heat waves and cold spells.

[3] Please note that there is no predicted value for 2014 due to the lag of 365 days of the dependent variable.

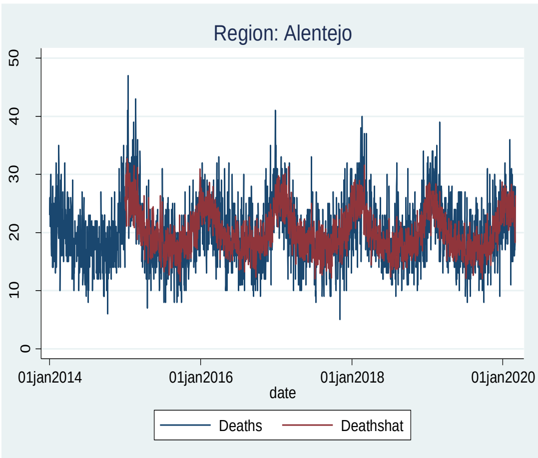
relative volatility (law of small numbers), hence making it harder for the model to produce a precise forecast. Moreover, in these regions, there are more missing values for temperature anomalies.



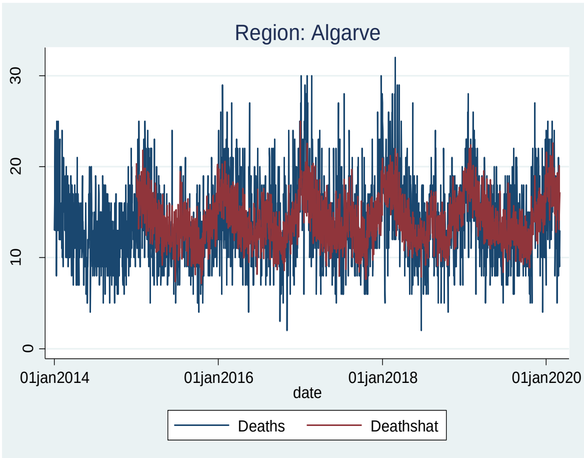
Graph 6 - Fitted values of daily deaths in Norte



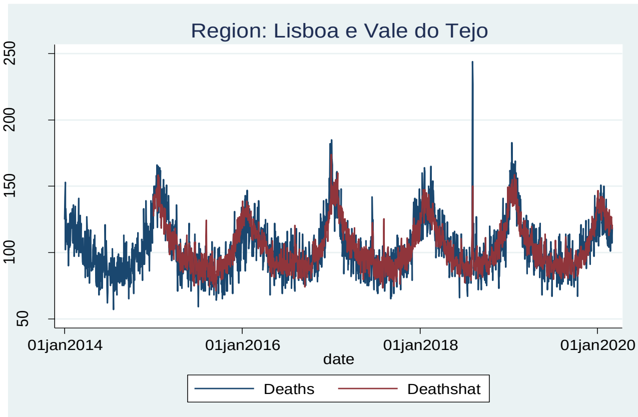
Graph 7 - Fitted values of daily deaths in Centro



Graph 5 - Fitted values of daily deaths in Alentejo



Graph 4 - Fitted values of daily deaths in Algarve



Graph 3 - Fitted values of daily deaths in LVT

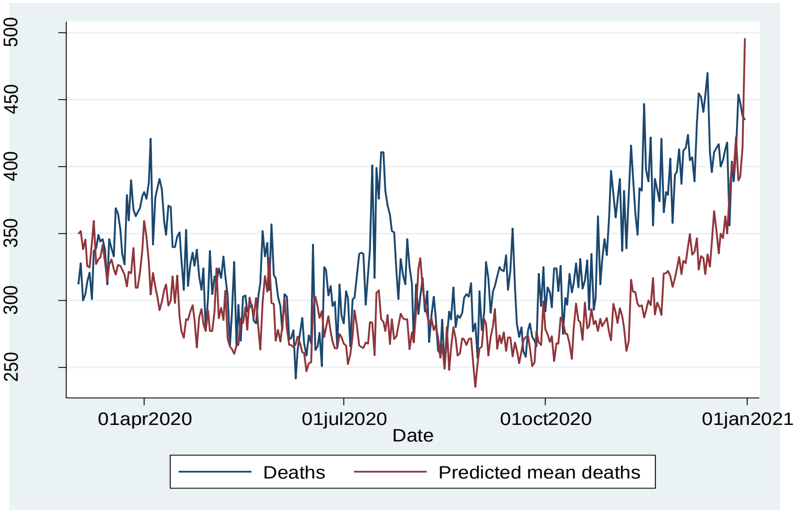
	Alentejo	Algarve	Centro	LVT	Norte	National
Relative MAE	13.79%	17.60%	9.00%	7.11%	7.62%	5.08%

Table 1 - Relative MAE of each model

4 Results

4.1 National analysis

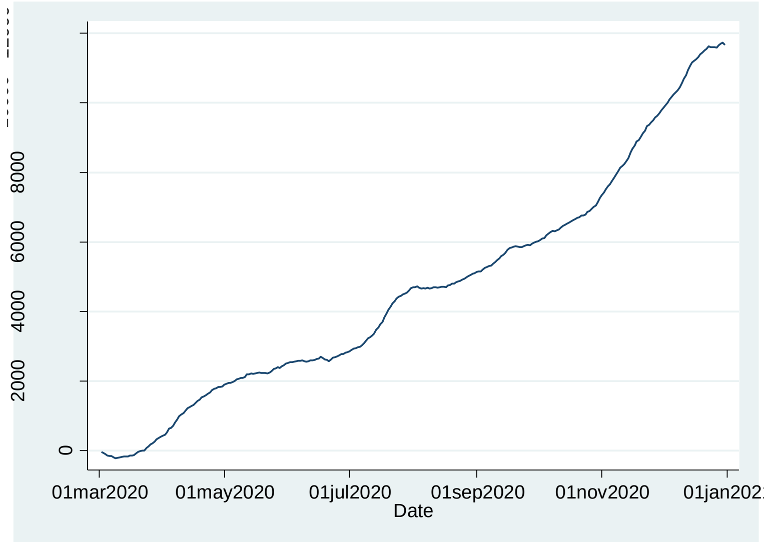
In this work, the model which is believed to portray what could be close to "normal conditions" (graph 8) was used. The difference between the forecasts based on the model and the actual number of deaths for the period from the 2nd of March 2020 to the 31st of December[4] was what was considered to be Excess Mortality. The figures for predicted Excess Mortality are rounded to the nearest hundred when the number is greater than a thousand, and to the tenth when the number is greater than a hundred (as in Kontis et. al (2020)). This was done to avoid putting very detailed numbers on a subject with much uncertainty, which could generate a false sense of precision.



Graph 8 - Forecast of daily deaths

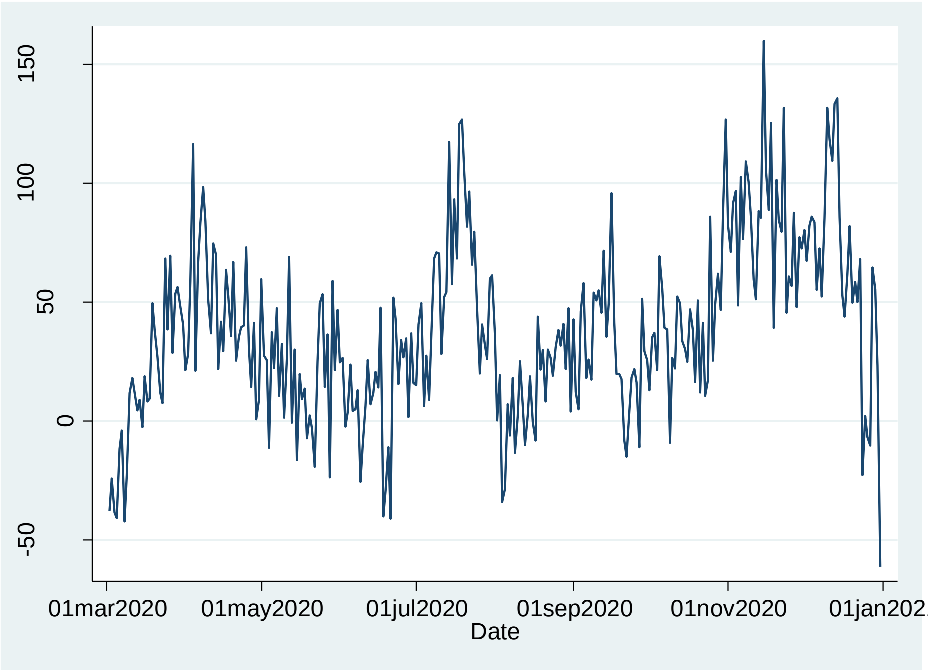
[4] The choice of a starting day is mostly arbitrary. Some studies choose the day of the first death, others the day in which the country reaches 100 cases. However, this choice does not significantly change the results.

According to the results and the used definition for excess mortality, an Excess Mortality of around 11,700 deaths (Graph 9) for the analysed period in mainland Portugal is observed. Total deaths in Portugal during that period were 101,635 deaths. To put this number in perspective, if the same period in 2019 is considered, that number was 88,456 deaths. Estimated excess mortality found in this work is, thus, very relevant, and, in a generic way, one could say that, in the period of analysis, something close to 11.5% of observed deaths are attributable to the pandemic context – both to COVID-deaths and because of other associated factors which will be further explored.



Graph 9 - Cumulative excess mortality

The second result worth to be highlighted is that excess mortality did not increase at a constant pace throughout the pandemic period in 2020. The model predicts excess mortality in 88% of the days, with only 38 out of the 305 days seeing actual deaths below the number of deaths the model predicts Graph 10). This is a clear indicator that there was some degree of excess mortality along the whole period of analysis. There are only three weeks in the entire period in which the model does not present a positive value for excess mortality (2nd-9th of March, 15th-21st of June and 3rd-9th of August). The week of 2nd-9th March was the week in which the first case was detected in Portugal; the first death occurred only on the 17th of March and the Emergency State was only declared on the 18th of the same month. Therefore, it is reasonable that the model does not detect excess mortality for that first week. The other two weeks in which it does not capture excess mortality are in June and August, both Summer/vacation months, when the pandemic situation was stable (actually, the week of 3rd-9th of August was the week with fewer reported COVID-19 cases, excluding the first two weeks of the pandemic in March). During the Summer of 2020, COVID-19 hampered movements and deeply affected tourism, and, thus, economic and social activities in Portugal[5]. With less travellers (both tourists and emigrants), touristic regions were subject to less pressure than in other years, which might create a downward effect on mortality, due, for example, to lower levels of traffic and fewer accidents. Not having comprehensive data on cause of death (both at national and regional levels) limits the capacity of quantifying these effects.

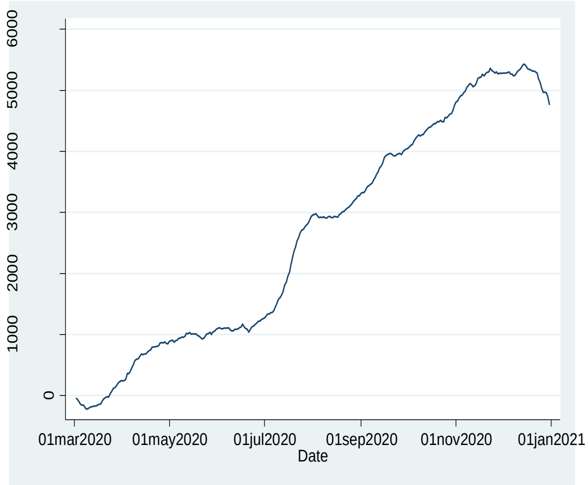


Graph 10 - Daily excess mortality

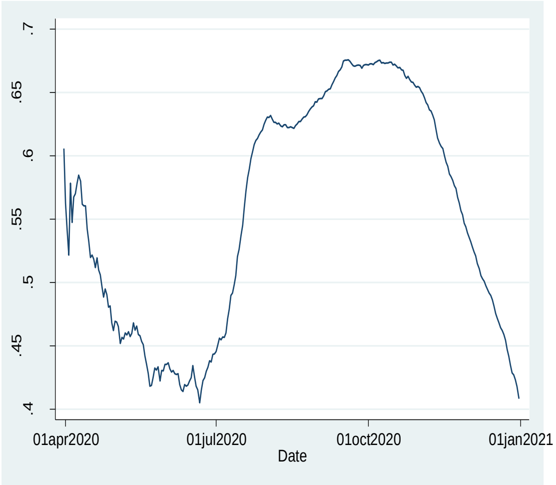
The estimates of excess mortality were more salient in certain periods, as observable in Graph 10. The first is during the month of April (which coincides with the first wave of the pandemic and the first "full" lockdown in Portugal), the second during the month of July (coinciding with the outbreak in the Lisbon area that led to restrictions in several Municipalities) and, finally, the third relates to a clear increase in November and December (coinciding with the second wave). It is also very clear that excess mortality increased at a faster pace from October onwards, and almost half of the excess mortality is predicted to have happened in the last 3 months of the year (around 5,700 deaths of the total of 11,700), as conveyed by Graph 9.

[5] A rapid estimation by *Instituto Nacional de Estatística* predicted a fall of about 47% and 68% in overnight stays during July and August, respectively.

When the estimates of Excess Mortality are broken down into COVID-19 and non-COVID-19 Deaths, it can be seen that, out of the predicted 11,700 excess deaths, 6,906 are COVID-19 deaths, which leaves around 4800 of the deaths (41% of the total excess mortality) in the analysis period as non-COVID-19 deaths, as seen in Graphs 11 and 12.



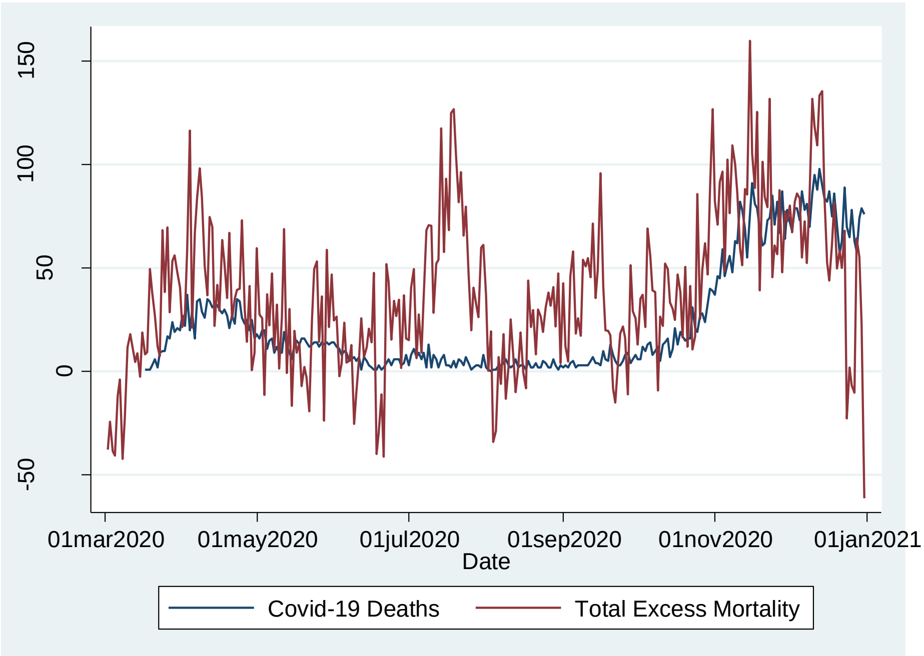
Graph 12 - Non-COVID deaths from excess mortality



Graph 11 - Share of non-COVID deaths

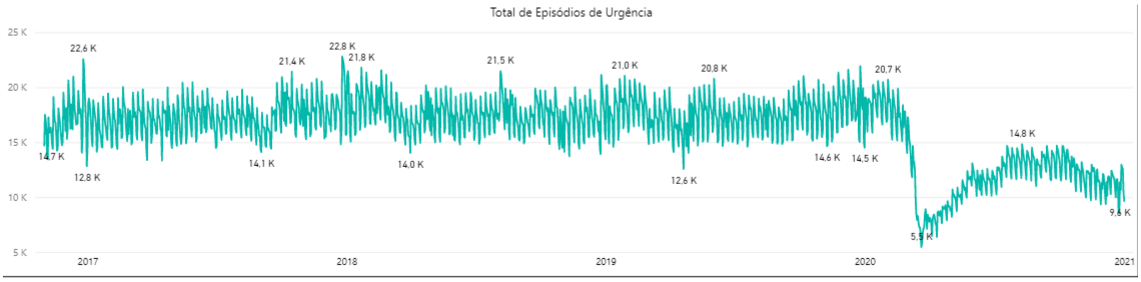
In this regard, there are three differences that are important to highlight, patent on Graph 13. The first one relates to the first months of the pandemic, when, along with the first rise in COVID-19 deaths, a clear increase in excess mortality was predicted. Following that period, a stabilization of COVID-19 Deaths was registered, and the ratio of non-COVID-19 deaths to Total Excess Mortality stabilized at around 40-50%. Then, in July, a period of divergence arises: COVID-19 Deaths remained mostly stable, but the predictions for excess mortality were quite high in some periods (mainly during July and also in September). The non-COVID-19 deaths to Total Excess Mortality ratio increased from around 50% in the beginning of July to 66% by the end of the month and peaked in mid-September at around 70%. Finally, from November onwards, when there was a rampaging of COVID-19 Deaths, there was a new convergence and the total excess mortality followed closer, bringing down the non-COVID-19 deaths to Total Excess Mortality ratio to 41%. Note that slight changes and variations in this ratio might be a result of model adjustments (the ratio being cumulative, meaning this kind of anomalies should be less significative when the analysis period is taken as a whole). All this presents strong evidence that, during these months, COVID-19 Deaths were not the sole explanation for Excess Mortality. The ratio of non-COVID-19 deaths to Total Excess

Mortality is very substantial (higher than 40%), throughout the entire analysis period. This basal value can be related to the postponement of treatment of other health conditions, prioritisation of COVID-19 patients, the deepening of mental and physical health problems due to high levels of social isolation[6], among several other potential explanations. During periods of relatively low infections and mortality by COVID-19, most of these factors were still very present: visits to the emergency department never fully recovered (graph 14), restrictive measures were never fully lifted and the tone was always of concern – people's lives as society never recouped fully. The fact that health institutions, social tissues and the human psyche might take more time to adapt and heal can lead one to observe periods when the pandemic appears to be controlled, but when there is still substantial excess mortality due to non-COVID-19 deaths, leading to an increase in the ratio of non-COVID-19 deaths to Total Excess Mortality.



Graph 13 - Daily covid-19 deaths and excess mortality

[6] Social isolation has long been linked to negative health effects, as reported in Berkman & Kawachi (2001), Holt-Lunstad et al (2015), Hawkley & Cacioppo (2010) and this effect seems prevalent during the COVID-19 pandemic, Horigian & Feaster (2020), Groarke et al (2020), Hwang et al (2020).

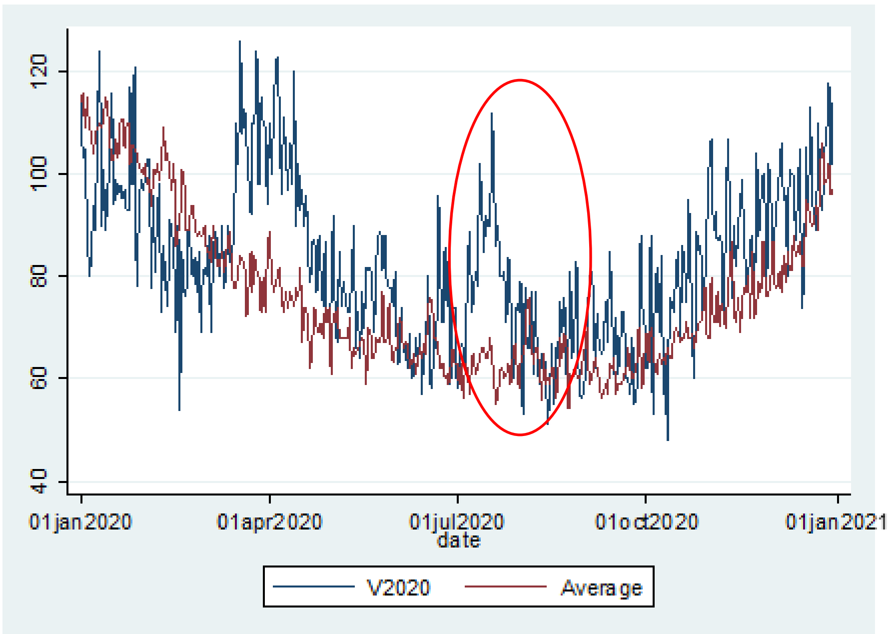


Graph 14 - Visits to emergency departments

One aspect of the evolution of excess mortality that grabs attention is the spike during the month of July, which was not followed by COVID-19 deaths, as verified in Graph 13. During this month, COVID-19 deaths were 159, while excess mortality during the same period was around 1,830. Moreover, not even the daily cases of COVID-19 were rising during this month, in which there was an average of around 300 cases per day. Therefore, one cannot explain this increase in excess mortality by an overload of the national health service due to new COVID-19 cases.

One possible explanation is that during Summer months, in Portugal, it is common to have relatively high daily mortality, mostly related to high temperatures. The model should capture this effect either through the variable of temperature anomaly or the variable "day", which captures seasonality. However, the effect of temperature on mortality may not be linear as the model assumes; it may be larger when extreme variations of temperature occur (either heat or cold waves) and it can be the case that the model is not capturing this entirely. Actually, during the month of July, Portugal was affected by a heat wave.

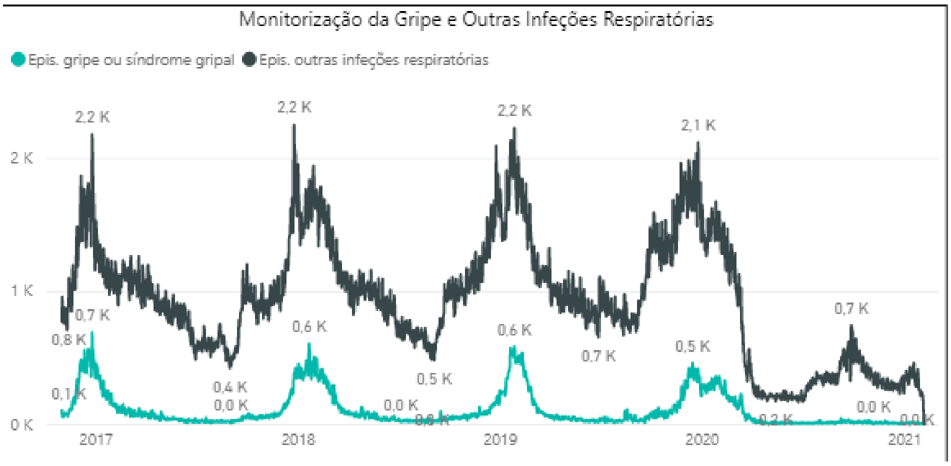
An alternative explanation is that a heat wave creates various health risks mostly for the elderly and isolated people, such as dehydration, heat exhaustion, heat stroke and others, according to Marto (2005). While during "normal" years people may go to the emergency department to receive care, during a pandemic there is a general fear to be contaminated there. On Graph 15, the blue line represents daily deaths at home during 2020 and the red line refers to a five-year average of daily deaths at home. It is clear that deaths at home during July 2020 are well above the historical average, which hints that people refrained from going to hospitals. The same phenomenon occurred during the first lockdown, when the national health service was not yet under pressure.



Graph 15 - Daily deaths at home

Yet another possible explanation is related with the delay of non-urgent care and exams that took place since the start of the pandemic. According to *Movimento Saúde em Dia*, until October, there was an 18% reduction (6.6 million) in first medical appointments and a 10% decrease in urgent surgeries. Therefore, part of the excess mortality during July could be the result of those delays. This should be a less likely explanation, as it would have a sustained effect on excess mortality (as opposed to causing a spike).

When one looks at the share of excess mortality by non-COVID-19 deaths, an interesting pattern after November can be found. During this period, Portugal was hit by a second wave, causing a surge in COVID-19 daily cases and deaths. This event created a great pressure on the national health service, which could also result in a significant increase of non-COVID-19 deaths. However, this was not the case, as Graph 11 suggests. During this period, there was a shrinkage in the share of non-COVID-19 deaths, which can be explained by two possible reasons: firstly, the boom in COVID-19 infections potentially started taking the lives of those that had other conditions and that were left with no proper follow-up in the previous months (e.g. chronic conditions), borrowing from non-COVID-19 mortality; secondly, this is the period when the flu season normally starts, according to *Instituto Nacional de Saúde Doutor Ricardo Jorge*. In 2019, the flu epidemic caused around 3,000 deaths. With containment measures to prevent COVID-19 infections, a substantial part of flu cases and other respiratory infections was avoided, which becomes clear when looking at Graph 16, and, consequently, flu-related mortality. According to the same source, in 2020, "the flu had almost zero incidence rate".



Graph 16 - Monitorization of the flu and other respiratory infections

Looking at the big picture, since the start of the pandemic in March of 2020, there were 6,906 COVID-19 deaths in Portugal, while excess mortality was around 11,700. This means that, out of every 100 excess deaths, 42 were not directly related to COVID-19. In the authors' view, this is mainly explained by two factors: first, the national health service was under great pressure. This resulted in the delay of many medical appointments and surgeries and consequently, in an increase in mortality not related to COVID-19 – for instance, there was a decrease of more than 2.7 million in the number of hospital contacts (medical appointments, surgeries and others) and a decrease in programmed and urgent surgeries of 21% and 10%, respectively. Second, as previously mentioned, people refrained from going to the hospital, both in urgent cases (27% less episodes treated in emergency rooms) and for medical appointments (18% less first medical appointments).

4.2 Regional analysis

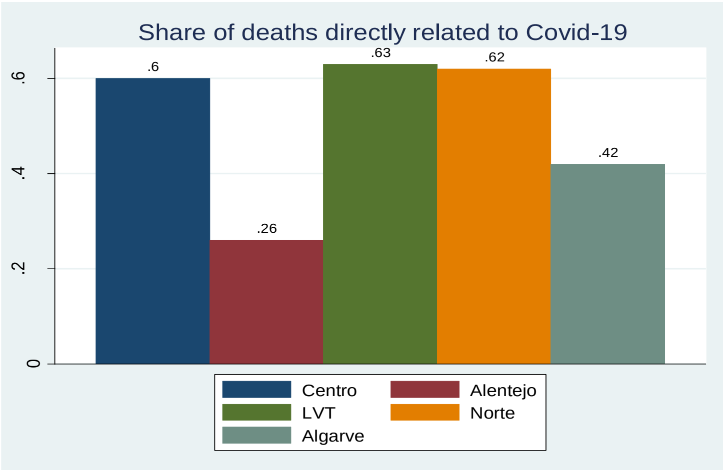
In this section, the same model will be used to analyse excess mortality in each region: Centro, Lisboa e Vale do Tejo (LVT), Algarve, Alentejo and Norte. As Table 2 depicts, both the spread of COVID-19 and the excess mortality in Portugal are not homogeneously distributed among regions and their differences are the result of many factors that will now be analysed in detail (discussing only the results or justifications that differ from those presented previously, for the national results).

	Population	Covid-19 Cases	Covid-19 Deaths	Excess Mortality	Cases to Population	Deaths to Population	Excess Mortality to Population	Share of COVID-19 deaths
Alentejo	509,849	11,123	218	840	2.18%	0.043%	0.165%	26%
Algarve	451,006	7,698	71	170	1.71%	0.016%	0.038%	42%
Centro	1,744,525	47,721	996	1660	2.74%	0.057%	0.095%	60%
LVT	3,659,871	133,739	2,392	3810	3.65%	0.065%	0.104%	63%
Norte	3,682,370	209,964	3,194	5150	5.70%	0.087%	0.140%	62%
National	10,325,452	413,678	6,906	11700	4.01%	0.067%	0.113%	59%

Table 2 - Summary of results by region

Prior to any analysis, it is important to mention that the model fit for Alentejo and particularly Algarve is lower when compared to the other regions or to the National model. The specification for Alentejo presents a relative MAE of roughly 13.8% and the specification for Algarve of 17.6% (the national model has a relative MAE of 5%), as showed in Table 1. This may be because both regions present low absolute numbers of deaths (with higher variability) and because there are more missing observations for temperature (mainly for Algarve). This reduces the confidence in the predictions that one can make for these regions, mainly when the magnitude of the results is small.

As it is clear in Table 2, Norte was the most affected region by COVID-19 (with the highest COVID-19 cases to population and COVID-19 deaths to population ratios), which can be partly explained by the fact that it is one of the most populous areas in Portugal (with the second highest population density, only lower than in LVT). It was also the first area in Portugal to suffer from severe outbreaks. Algarve was the least affected region, with proportionally less infections and deaths by COVID-19. This region is a touristic destination with lower activity and movement during most months of the year, normally contrasting with a frenzy Summer, that was much constrained under pandemic circumstances. Furthermore, Algarve is located in the South of Portugal and its single national border is with Alentejo[7], the second least affected region by COVID-19 deaths and infections in proportional terms. Centro was the third most affected region in the country; it shares its boundaries with both LVT and Norte, which were the most affected regions. Additionally, there is a large daily movement of workers from areas in Centro to Lisbon, which can explain why, during some periods of the pandemic, Centro was the second worst region in Portugal.



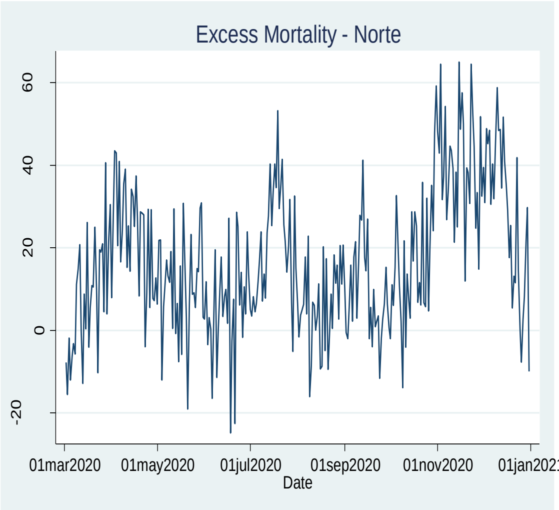
Graph 17 - Share of Covid-19 deaths by region

The estimates of excess mortality per region presented on Table 2 reach its maximum in absolute terms in Norte, with 5,150 deaths, accounting for about 44% of the estimation of National excess mortality. LVT and Centro follow, respectively, with estimated excess mortality of 3,810 and 1,660 deaths. Algarve presents both the lowest absolute and relative excess mortality, with an estimation of absolute excess mortality of 170. Alentejo is a particularly interesting case, with an absolute excess mortality of 840; it is the region with the highest excess mortality weighted by its population, despite being the second least affected region in terms of infections and deaths by COVID-19 (weighted by population). Therefore, the estimates seem to point that the indirect effects of the pandemic were particularly large in Alentejo. In Alentejo, only 26% of the excess mortality

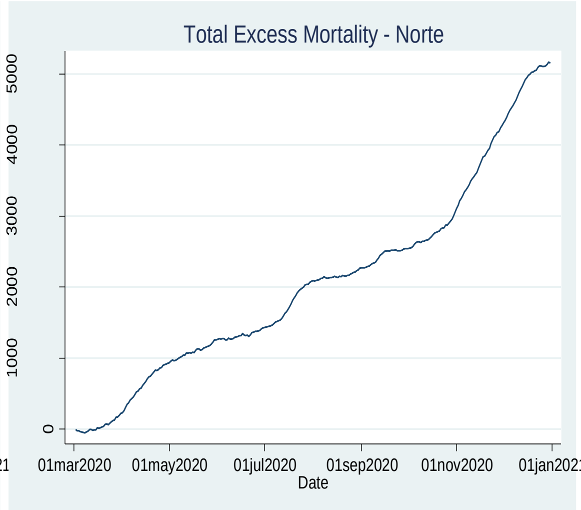
[7] Algarve also borders Spain. However, during the most acute pandemic moments borders between the two countries were closed.

is estimated to be explained by COVID-19 deaths. For the three regions with higher mortality due to COVID-19, the share is close to 60%, as one may notice on Graph 17.

As in the National Model, the rhythm of increase in Excess Mortality in different regions was not constant, and some tendencies can be detected. The importance of each region during the three main spikes of excess mortality will be contextualized in the analysis period: the first was at the beginning of the pandemic during the first lockdown, the second in the month of July and the third was during the final months of the year starting in October. Norte is the region where these 3 spikes are most clear (Graph 18 & 19).



Graph 19 - Daily excess mortality in Norte



Graph 18 - Cumulative excess mortality in Norte

Norte contributed greatly to the excess mortality observed in Portugal during the first spike, especially during the first months of the pandemic, when the north of Portugal was the most affected area by the virus. All other regions also present some excess mortality, as one can analyse on Graphs 20 through 27, for the first 3-months of the pandemic (March, April and May). However, the first spike is not as clear in any of them. Norte was responsible for an estimated excess mortality of 1,260 deaths in this period, while all the other regions combined contributed to an excess mortality of 1,210 deaths in the same period.

Even though, on average, Norte is a less-aged region, in April, Norte registered around 60% of all cases confirmed in Portugal. Additionally, more than half the deaths directly related with COVID-19 happened in Norte, while the region contains only a third of the Portuguese population. The reason why Norte performed so bad during the beginning of the pandemic was, according to the director of DGS[8], Dr. Graça Freitas, the fact that this region had many imported cases from Northern Italy (the most affected European area at that time), as a result of the Fashion Week in Milan (fashion is a sector that employs many workers in Norte). This, in turn, generated many transmission chains, making Norte the worse region in Portugal. However, this explanation only fits the first weeks of March. According to Nuno Sousa, Professor at the School of Medicine – University of Minho, the explanation of why Norte performed so bad during the first phase of the pandemic that ended up putting this region in a bad scenario for the rest of the year was the fact that a great part of the population in Norte works in the industrial sector, whose tasks cannot be done at home. Coupled with the fact that this region has a higher population density, this might explain why Norte was so affected by the virus. Moreover, the proximity to Spain helped fuel the first outbreak of COVID-19 in the region. Professor Nuno Sousa also stated that one of the reasons why the rate of mortality from COVID-19 in Norte was, and still is, so high is due to the family structure in this region, in which it is very common to have three generations in the same house, increasing the exposure of the elderly[9].

The second key moment takes place in the month of July and is marked by a salient spike in excess mortality in most regions. Excess mortality was most significant in Norte, LVT and Alentejo, as evidenced by Graphs 18, 20 and 24, while particularly low (but positive) for Algarve.

For the region of LVT, an excess mortality of around 610 deaths for the month of July is estimated (only lower than the 700 excess deaths estimated for November). This value is close to the total sum for excess mortality in March, April, May, and June for this region, with 640 deaths. From the 610 deaths, 130 are COVID-19 deaths (during July, there were only 158 new deaths from COVID-19 in Portugal; 28 outside of LVT, turning the region into the biggest national focus of COVID-19 during that month). Manuel Carmo Gomes, professor of epidemiology at Universidade de Lisboa, highlighted as main motives for LVT to be the new epicentre of the virus in June/July the facts that "the cases were mainly focused on the suburbs of Lisbon, where there is a high population density, and where

[8] DGS – Direção Geral da Saúde
[9] Declarations retrived from Jornal de Notícias, Figueira (2020)

people cannot work from home and where they need to use public transportation to go to work" and that "after reopening, public health services in Lisbon were not reinforced in a way that would allow a fast response to register new cases and to trace potential contagion chains."[10]. This was further deepened by a reduced supply of public transportation services, that partly suspended their activity during the lockdown months and did not replace them immediately.

While LVT was the most affected region in that month, COVID-19 only accounted for about 20% of the estimated excess mortality, meaning most deaths happened because of other causes. An important factor to consider is that, from the 23rd of June and through the month of July, several municipalities in LVT were under a regional state of contingency that placed several restrictions on movement, opening and closing hours of public spaces and public gatherings. In this phase, although hospitals in LVT never surpassed their maximum occupation, the occupation rates were relatively high and the tone was of great caution, to avoid overloading health institutions. Furthermore, it must be considered, as it was done in the national model, that the country was being hit by a heat wave, as highlighted by Graph 28. The factors considered in the National Analysis section are believed to be of good use here, not only owing to the fact that there was a heat wave affecting the region, but also since the pandemic situation was a matter of apprehension in the region during that phase. This combination of factors might have turned out deadly – a population avoiding urgency treatment, facing a delay of diagnosis and treatment of several conditions (since the beginning of the pandemic), during a time of particular social isolation[11] and facing a heat wave, leading to a substantial increase in excess mortality in this specific period in LVT.

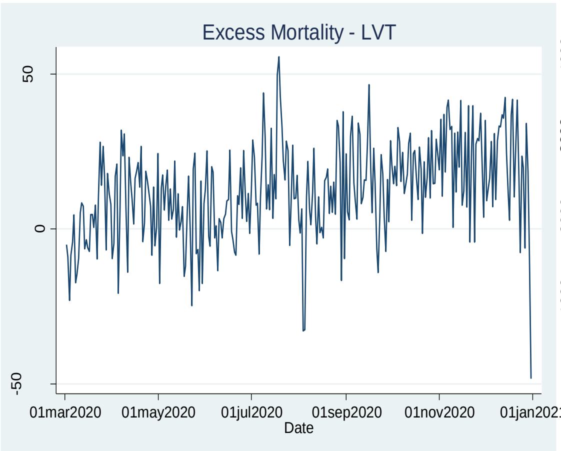
In the case of Alentejo, the month of July is also particularly relevant to explain excess mortality in this region and the very low share of COVID-19 deaths. 220 deaths in excess are estimated for the month of July in Alentejo (compared to 191 in the 4 previous months). Furthermore, July was the month with the largest excess mortality estimation in Alentejo, representing 26% of the total estimated excess mortality. This is particularly relevant, because Alentejo is the only analysed region where the month with the highest

[10] Declarations retrieved from El País Internacional – Sánchez (2020)
[11] Social isolation is pointed as one of the factors that might lead to higher heatwave-related mortality risk of the elderly population – see Kim, Yong-ook, et al. (2020)

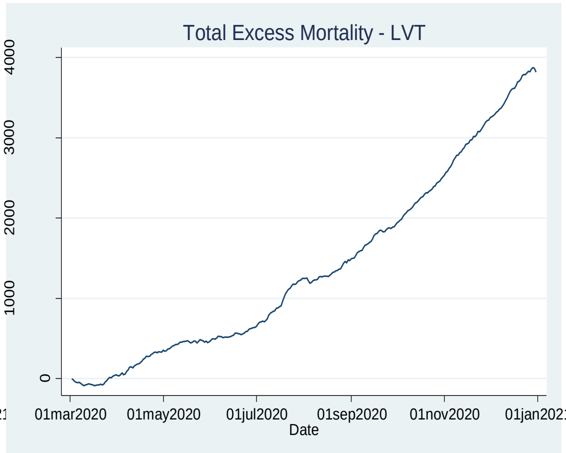
estimated excess mortality is not October, November or December. This peak in estimated excess mortality is in line with what was verified in this analysis until now. In the case of Alentejo, its aged population and the already large pre-pandemic social isolation of the elder (which, in other phases, might have prevented some infections and a worse outcome for the region) might be substantial factors to explain why the July heat wave gave place to a large estimation of excess mortality.

Excess mortality was also substantial in both Norte and Centro, but not as significant to explain the total excess mortality of these two regions. In Algarve, there was not a substantial increase in predicted excess mortality in July, which could be the result of the lower predictive capacity for this region, but also of the reduced effects of the heat wave in Algarve[12].

Regarding the last spike after October, this was a period in which all regions saw a substantial increase in COVID-19 cases and deaths, with the second wave of COVID-19 hitting the country. Excess mortality spiked in all regions, except in Algarve, in the last three months of the year. The estimation is that in Norte, Centro and LVT around 50% of the total excess mortality in the analysis period took place in these 3 months. From October onwards, COVID-19 deaths ramped and assumed a higher share of estimated excess mortality in all regions, while other mortality causes related to that time of the year (flu and related respiratory infections) were mainly controlled (exerting downward pressure in other causes of excess mortality).



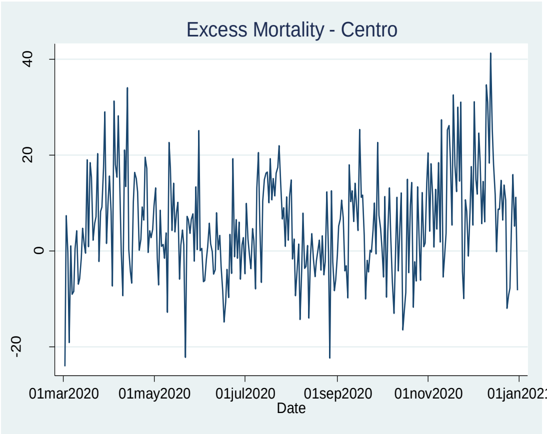
Graph 210 - Daily excess mortality in LVT



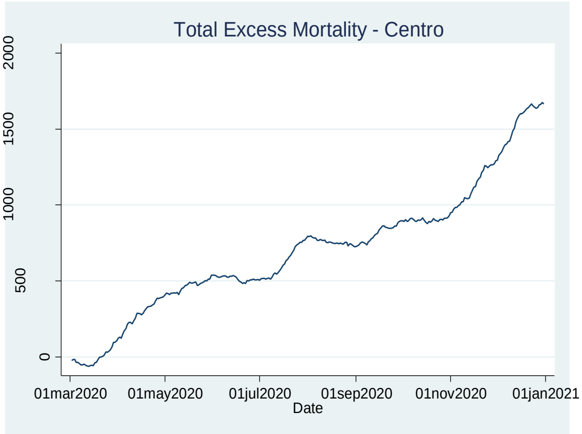
Graph 201 - Cumulative excess mortality in LVT

[12] Algarve was the region with the lowest increase in maximum temperatures during July – Graph 28

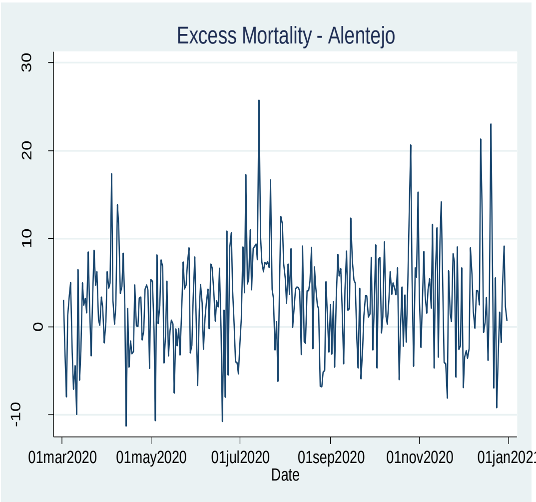
Even in the case of Alentejo, the region with the lowest share of COVID-19 deaths, the last 3 months present a strong increasing tendency in this share. Until the 1st of October, there were 23 deaths by COVID-19 in Alentejo, whereas the estimated excess mortality was of 540 deaths. The rest of the year was responsible for 195 COVID-19 deaths and the estimated excess mortality was of 300 deaths.



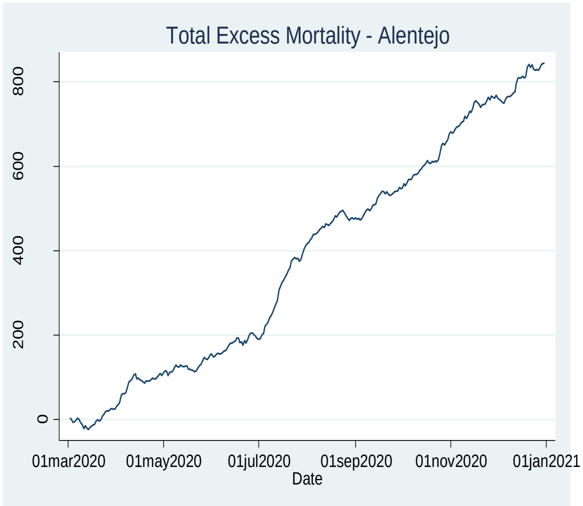
Graph 22 - Daily excess mortality in Centro



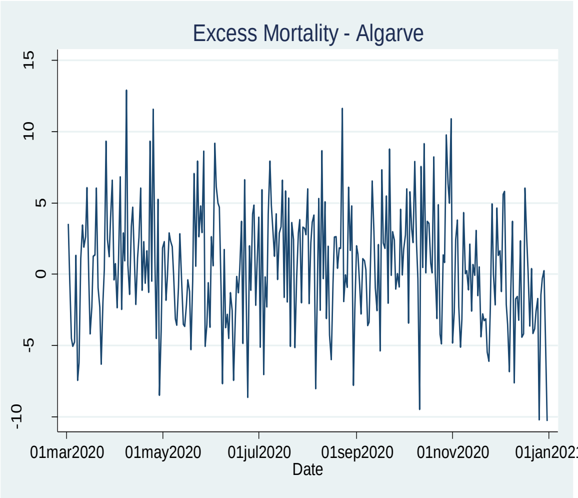
Graph 23 - Cumulative excess mortality in Centro



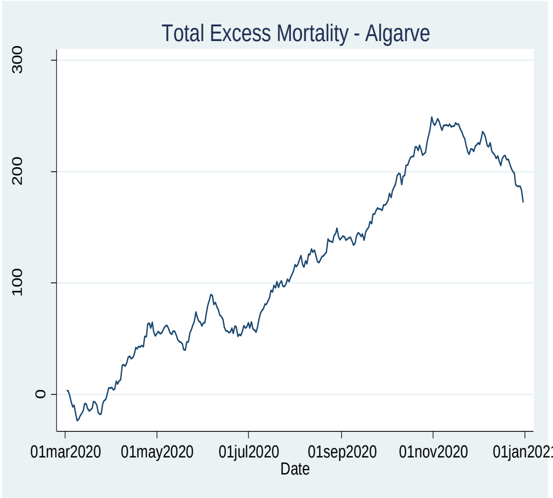
Graph 224 -Daily excess mortality in Alentejo



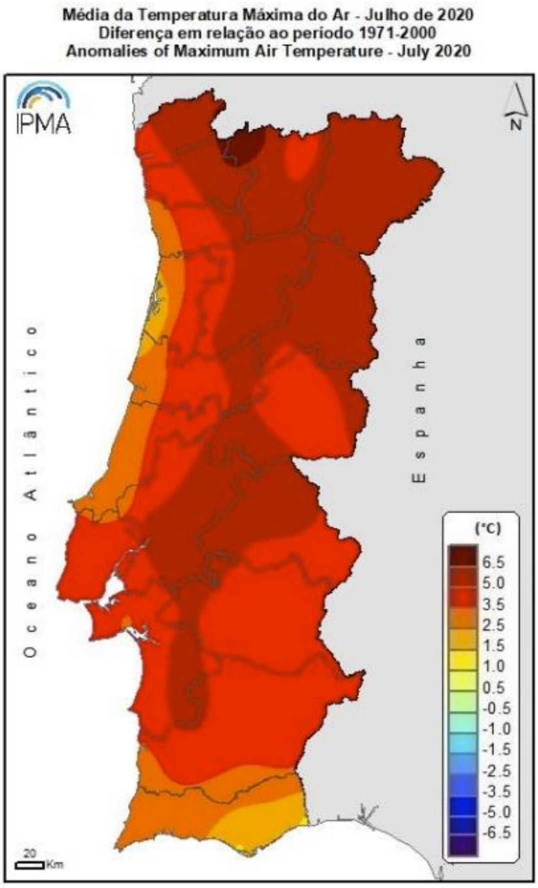
Graph 25- Cumulative excess mortality in Alentejo



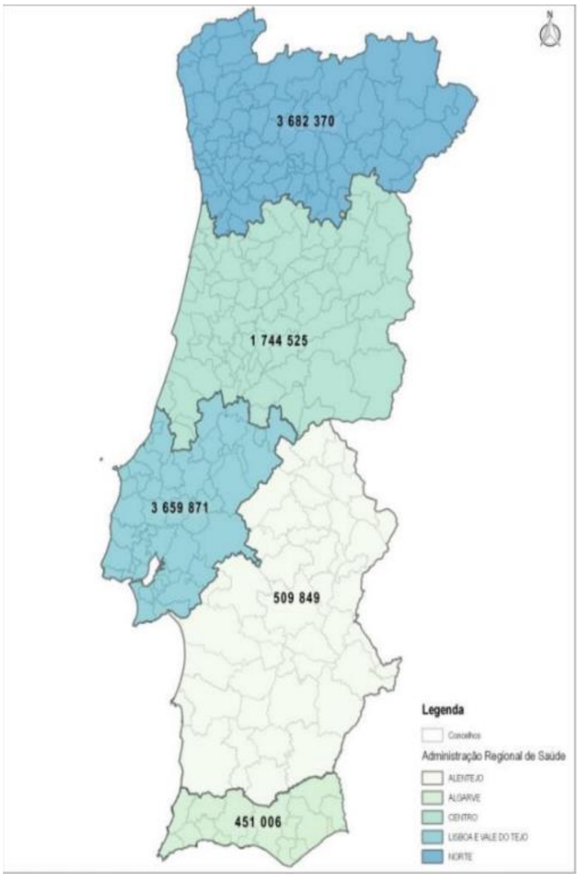
Graph 2625 - Daily excess mortality in Algarve



Graph 247 - Cumulative excess mortality in Algarve



Graph 28 - Heat wave in Portugal, Source: IPMA



Graph 239 – SNS ACSS

5 Conclusions

At a national level, the model predictions followed the results found in previous literature. The research highlighted that 268 of the 305 days of the 2020 pandemic (since the 2nd of March until the 31st December 2021) experienced excess mortality. These results, when analysed closely throughout the year, can be divided into a group of peak periods and one trough. There were three periods with lower excess mortality, the first on the very beginning of the pandemic and the other two during Summer. During the months of June and August, the low excess mortality could be related to the stability of the pandemic, mixed with the fact that people travelled less than usual during these periods (e.g. fewer traffic accidents).

The peaks of excess mortality took place during very different periods as well. The first was during the month of April (when the first wave of the pandemic took place), the second during the month of July, and the last one started in November, increasing up until December. Along the year, non-COVID-19 deaths kept having a high impact on excess fatalities. The phenomenon can be justified by many reasons, such as the postponement of treatment of other health conditions, the prioritisation of COVID-19 related health services and the worsening of mental and physical health. During the July peak, Portugal experienced a heatwave, that likely contributed to excess mortality. The high-temperature anomaly creates health risks, mostly for the elderly and people in isolated areas. When combined with postponed medical care, which never fully recovered throughout the year, a rise in deaths (and, more specifically, deaths at home) is expected.

At the regional level, this study concluded that the impact of the pandemic has been heterogeneous across mainland Portugal, due to the emergence of region-specific characteristics. Norte, with 5,150 excess deaths has been the most affected region, especially during the first wave, which could be linked with factors such as imported cases from Northern Italy, strong reliance on the industrial sector, whose activities cannot be moved to remote working, and greater exposure of the elderly to their families. It has been followed by LVT, which is quickly catching up, with 3,810 excess deaths, presumably due to specific features like high population density in suburban areas and lack of proper supply of public transportation. Centro, with 1,660 excess deaths, follows, which may be explained by adjacency to Norte and LVT. Finally, Alentejo, with 840 excess deaths and Algarve, with 170 were the least affected regions in absolute terms. However, Alentejo presented the highest value for excess mortality when weighted by its population, (although small numbers of deaths hinder the precision of the models).

It should also be acknowledged that the dynamics of the pandemic intensified during the month of January of 2021. The identified trends concerning the postponement of medical appointments, diagnostic exams and surgeries will likely remain, creating an upward pressure on excess mortality in the months or even years to come, which calls for a permanent need to monitor excess mortality. Additionally, phenomena such as heat waves and cold spells should be handled with particular care during the pandemic by giving special attention to the elder, vulnerable and more isolated, in order to avoid the considerable cross effects of temperature anomalies and COVID-19 in excess mortality.

In this work, the authors are only capable of quantifying the impact on excess mortality of non-COVID-19 deaths as a residual of the results. For future research on excess mortality during the pandemic and its causes, using detailed data on the causes of death seems very relevant. This work focuses on Regional analysis because data at the municipality level is not available. In the case of Portugal, research at that level can bring a further layer of detail to the results, by taking advantage of the discontinuity created by having neighbour counties with different restrictions during the same period. Further research should try to explain how restricting movements and social behaviour affects excess mortality by using socioeconomic variables as proxies, such as fuel consumption or internet traffic. It would also be interesting to dwell on how the pandemic has been overwhelming medical supply chains and Portuguese hospitals, specifically, how intensive- and intermediate-care units and wards could improve planning capabilities to face another major event, being it a pandemic, a war, or a natural disaster. COVID-19 has exposed the fragilities of the national healthcare system and a proper understanding of what led it to the edge of the abyss is key not only to strengthen it, but also to avoid the repetition of past mistakes in the future.

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