Regional excess mortality during the 2020 COVID-19 pandemic: a study of five European countries

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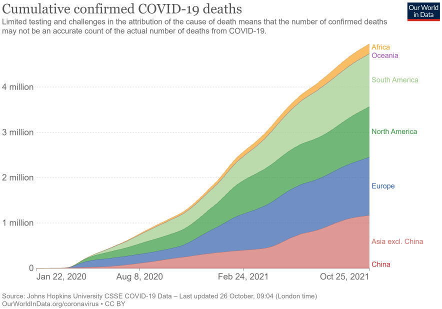
Outline

Introduction

COVID-19 burden

- In 2020: 1,88 million COVID-19 deaths globally
- COVID-19 deaths:
  - accuracy, completeness, different definitions
  - Not indirect effects
- Excess all cause-mortality: observed versus expected had the pandemic not occurred



Global deaths attributable to the COVID-19 pandemic in 2020 is at least 3 million, with 37% in Europe.

Previous studies in Europe

Country level: Differential effect by country and wave

- Kontis et al 2020, England and Wales, Spain and Italy: 70 to 102 deaths per 100,000.
- Islam et al 2021 October to December 2020, large excess mortality in Switzerland.

Regional level: Differential effect by region and wave

- Blangiardo et al 2020, highest excess in North-west during the first wave in Italy.
- Davies et al 2021, highest in London and in the West Midlands during the first wave in England.
- ELSTAT report 2021, 10% excess mortality in northern Greece compared with 3% in the islands.

Limitations of previous studies

- Most common approach: average number of deaths over previous years, but neglects:
  - Changes in population size and age structure
  - long– and short–term trends in mortality
  - time–varying factors like temperature
- Model based studies examining regional excess are wave specific and not for the entire 2020 (Blangiardo et al 2020 and Scortichini et al 2020)
- Kontis et al 2020 and Islam et al are for the entire 2020, but at the country level.

Help our understanding of the transmission patterns and the effectiveness of policies and measures to contain the pandemic.

Aim

Use a model-based approach to predict weekly deaths for 2020 by specific age- and sex groups, under the counterfactual scenario that COVID-19 had not occurred.

Features:

1. Perform cross validation to calculate accuracy of predictions
2. The modelling approach adopted allow us to present any aggregation desired.
3. We developed a shiny web app to communicate the results.

Methods

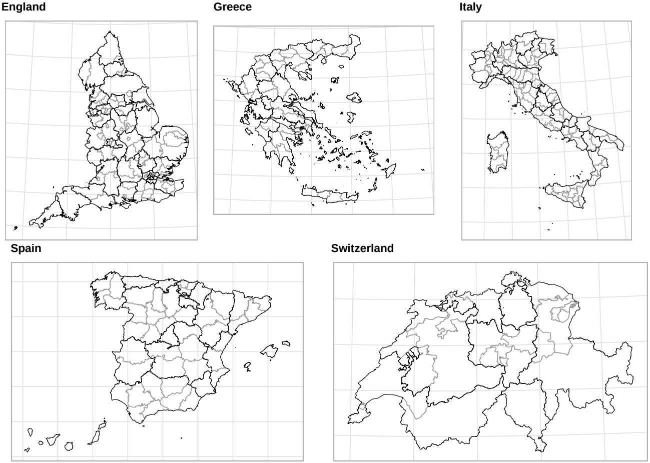
Data

Deaths and population across the different countries (2015-2020).

Country	Deaths	Population	Time point
England	Small Area Health Statistics Unit (SAHSU)	ONS	30-06
Greece	Hellenic Statistical Authority (ELSTAT)	ELSTAT	01-01
Italy	Italian National Institute of Statistics (ISTAT)	ISTAT	01-01
Spain	National Statistics Institute (INE)	INE	01-01
Switzerland	Federal Statistical Office (BFS)	BFS	31-12

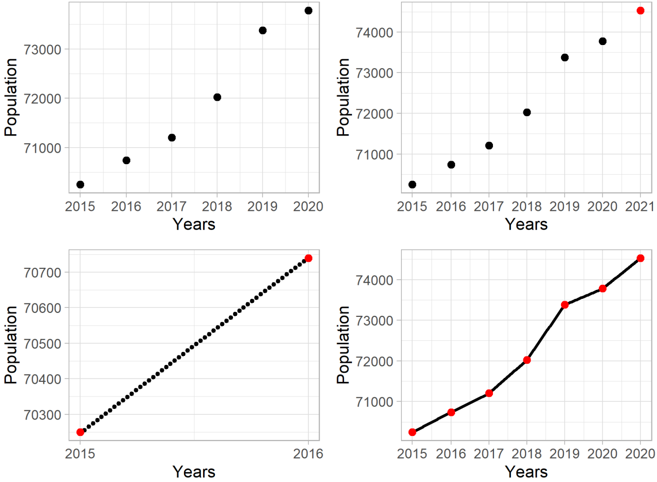
Data

Deaths and population were available by age group (40 $<$, 40-59, 60-69, 70-79, 80+), sex and NUTS3 regions. Temporal resolution of deaths: weekly, of population: yearly



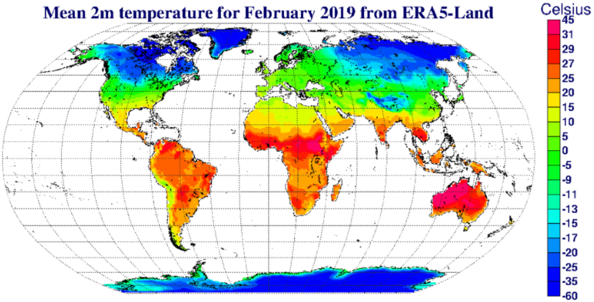
Population interpolation

1. Predict 1st January 2021, had the pandemic not occurred
2. Use 2 relevant years for weekly interpolation



Covariates

- Daily temperature at 9×9 km: ERA5 reanalysis data set of the Copernicus climate data
- National holidays (1-If week includes a national holiday)



Statistical model

Let y_{jtsk} be the number of deaths, P_{jtsk} be the population at risk and r_{jtsk} the risk in the j-th week of the t-th year, for the s-th spatial unit and k-th age-sex group:

$$
\begin{aligned}
y_{jtsk} &\sim \text{Poisson}\big(r_{jtsk} P_{jtsk}\big) \\
\log\left(r_{jtsk}\right) &= \beta_0 + \beta_1 Z_j + x_{jts} + b_s + w_j + \epsilon_t \\
x_{jts} \mid x_{(j-1)ts}, x_{(j-2)ts}, \tau_x &\sim \text{Normal}(2x_{(j-1)ts} + x_{(j-2)ts}, \tau_x^{-1}) \\
b_s &= \frac{1}{\tau_b}\left(\sqrt{1-\phi}\, v_s^\star + \sqrt{\phi}\, u_s^\star\right) \\
w_j \mid w_{j-1}, \tau_w &\sim \text{Normal}(w_{j-1}, \tau_w^{-1}) \\
\epsilon_t &\sim \text{Normal}(0, \tau_\epsilon^{-1})
\end{aligned}
$$

Cross validation

Leave out one year cross validation:

1. Select a year i among 2015-2019 to leave from the model fit
2. Fit the model proposed on the previous slide
3. Predict the missing year i:
   $p(y_{jski} \mid \mathcal{D}) = \int p(y_{jski} \mid \boldsymbol{\theta}) p(\boldsymbol{\theta} \mid \mathcal{D}) d\boldsymbol{\theta}$
4. Calculate correlation between observed and predicted and coverage probability
5. Repeat for the rest of the years

Repeat for the different countries, sex and age groups.

Model fit - Metrics

- Use 2015-2019 to train the model
- Predict 2020:

$$p(y_{jsk2020} \mid \mathcal{D}) = \int p(y_{jsk2020} \mid \boldsymbol{\theta}) p(\boldsymbol{\theta} \mid \mathcal{D}) d\boldsymbol{\theta}$$

- Calculate relative (percent) increase in mortality: O-E/E, together with 95%CrI
- Posterior probability that the relative excess mortality is larger than 0.

Results

Exploratory analysis

- 5-year mean to calculate excess
- Excess varies by age and country

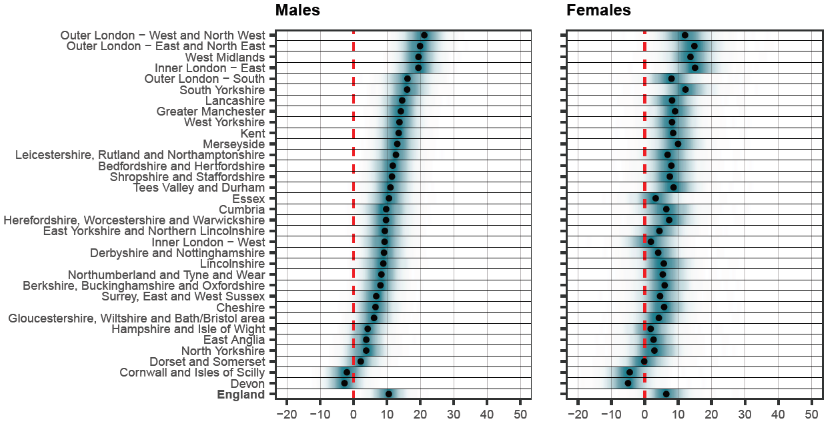
	England			Greece			Italy			Spain			Switzerland		
	Excess	Observed	Population	Excess	Observed	Population	Excess	Observed	Population	Excess	Observed	Population	Excess	Observed	Population
<40	-1,705	10,817	28,314,021	-226	1,768	4,911,980	-983	7,118	23,536,674	-128	6,305	20,276,614	53	1,377	4,020,006
40-59	4,158	45,084	14,728,847	301	9,051	3,114,996	2,331	42,074	18,351,674	836	34577	14,869,360	-122	4,531	2,499,892
60-69	4,809	61,049	5,869,801	1,258	13,653	1,291,668	6,151	65,665	7,364,402	5,985	48,483	5,350,794	186	6,893	956,197
70-79	19,568	127,065	4,907,711	1,163	24,922	1,003,965	20,107	148,569	5,968,591	15,439	90,112	3,984,582	2,177	15,025	742,950
≥ 80	41,537	321,490	2,882,587	8,793	83,120	395,839	83,927	493,024	4,419,878	46,944	306,059	2,851,238	8,021	49,396	462,252
Total	68,368	565,505	56,702,967	11,289	132,514	10,718,447	111,532	756,450	59,641,219	69,077	485,536	47,332,587	10,314	77,222	8,681,297

Cross validation

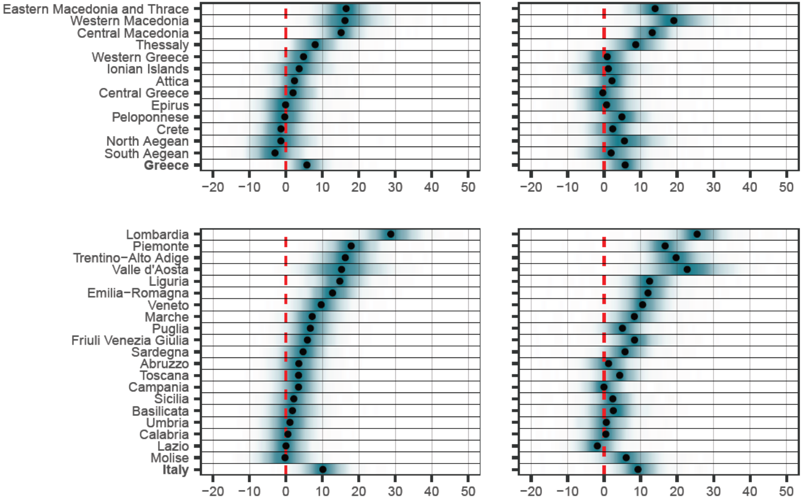
	Males									
	England		Greece		Italy		Spain		Switzerland	
Age group	Correlation	Coverage	Correlation	Coverage	Correlation	Coverage	Correlation	Coverage	Correlation	Coverage
< 40	0.23 (0.21, 0.24)	0.94	0.56 (0.57, 0.62)	0.92	0.51 (0.50, 0.52)	0.94	0.69 (0.68, 0.70)	0.93	0.41 (0.38, 0.44)	0.93
40-59	0.45 (0.44, 0.46)	0.95	0.87 (0.86, 0.87)	0.94	0.83 (0.83, 0.84)	0.95	0.90 (0.90, 0.91)	0.94	0.69 (0.67, 0.71)	0.94
60-69	0.55 (0.54, 0.55)	0.95	0.90 (0.89, 0.90)	0.95	0.87 (0.85, 0.88)	0.95	0.92 (0.92, 0.93)	0.94	0.74 (0.72, 0.76)	0.94
70-79	0.70 (0.69, 0.71)	0.95	0.93 (0.92, 0.93)	0.95	0.93 (0.91, 0.93)	0.95	0.95 (0.94, 0.95)	0.93	0.84 (0.83, 0.85)	0.95
$\geq$80	0.83 (0.82, 0.84)	0.94	0.96 (0.95, 0.96)	0.95	0.95 (0.94, 0.95)	0.93	0.97 (0.97, 0.97)	0.91	0.92 (0.91, 0.93)	0.95
	Females									
$40 <$	0.15 (0.14, 0.16)	0.93	0.43 (0.40, 0.46)	0.88	0.38 (0.37, 0.40)	0.92	0.58 (0.56, 0.59)	0.92	0.28 (0.26, 0.31)	0.89
40-59	0.35 (0.34, 0.36)	0.95	0.81 (0.79, 0.81)	0.93	0.78 (0.77, 0.79)	0.95	0.86 (0.85, 0.86)	0.94	0.57 (0.55, 0.59)	0.93
60-69	0.46 (0.45, 0.47)	0.95	0.86 (0.85, 0.86)	0.94	0.83 (0.82, 0.83)	0.95	0.88 (0.87, 0.88)	0.95	0.64 (0.63, 0.66)	0.94
70-79	0.65 (0.63, 0.65)	0.95	0.92 (0.91, 0.92)	0.95	0.91 (0.90, 0.92)	0.95	0.92 (0.91, 0.93)	0.94	0.81 (0.80, 0.82)	0.94
$\geq$80	0.87 (0.82, 0.84)	0.94	0.97 (0.96, 0.97)	0.94	0.96 (0.95, 0.96)	0.92	0.97 (0.97, 0.98)	0.90	0.94 (0.93, 0.95)	0.94

Dropped < 40 from the analysis

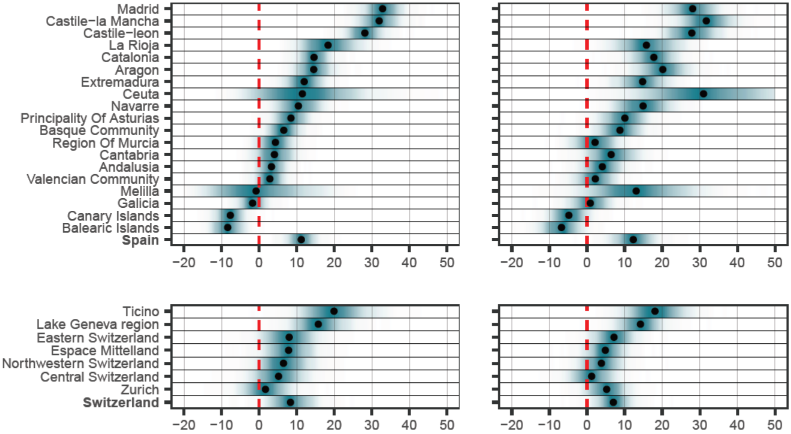
Relative excess NUTS2 regions: England



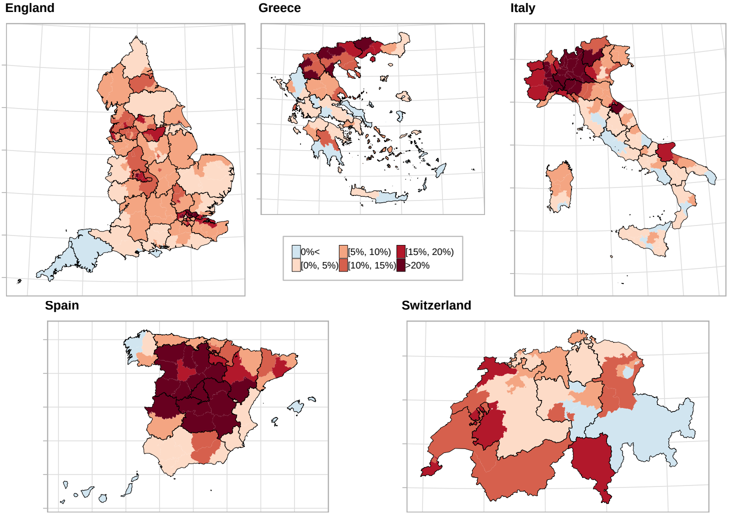
Relative excess NUTS2 regions: Greece and Italy



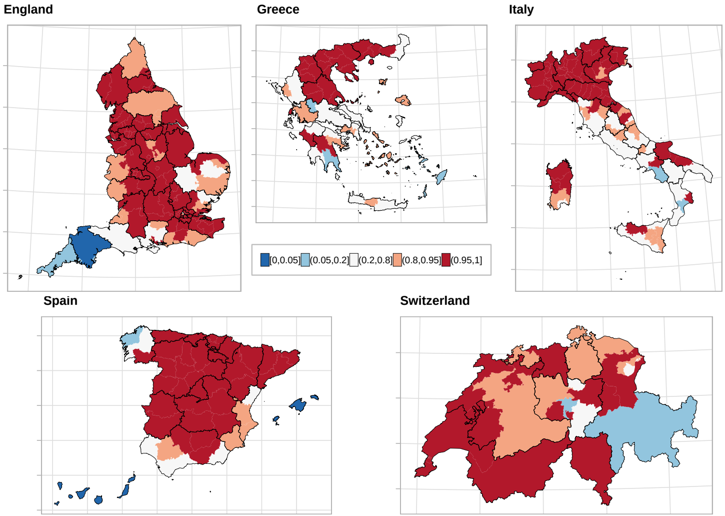
Relative excess NUTS2 regions: Spain and Switzerland



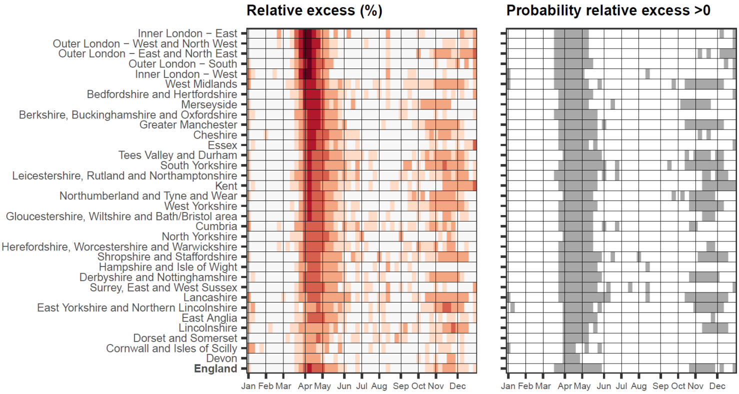
Relative excess NUTS3 regions



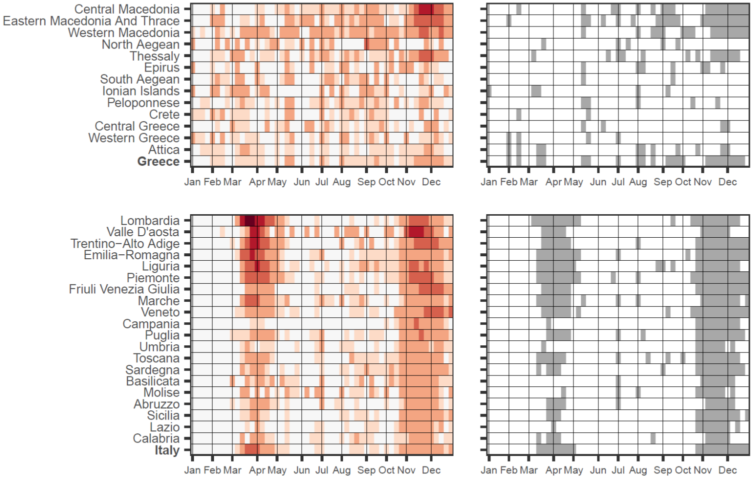
Posterior probability excess > 0



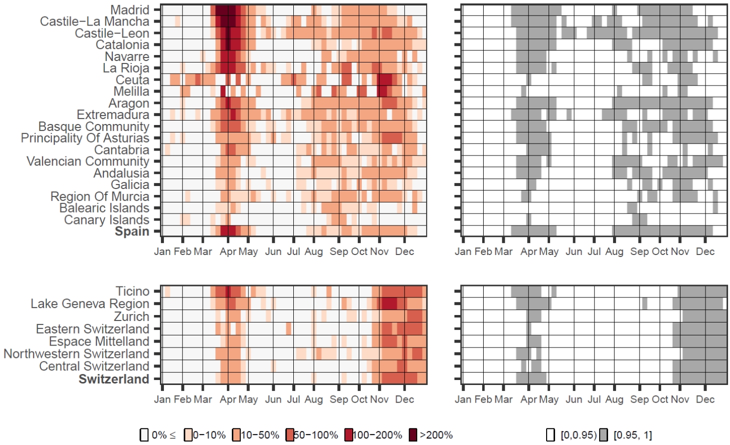
Spatiotemporal excess: England



Spatiotemporal excess: Greece and Italy

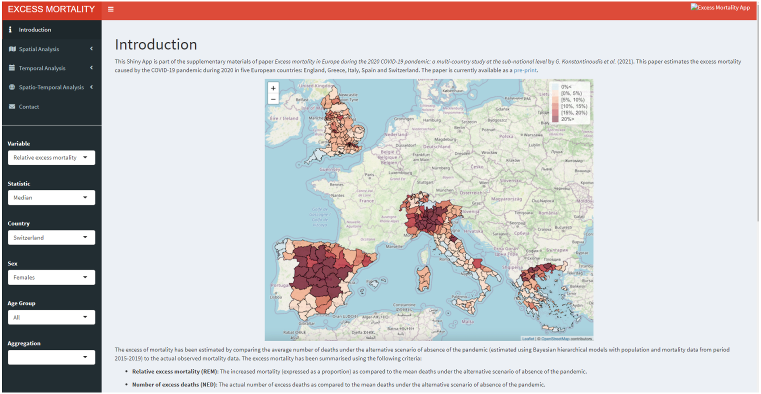


Spatiotemporal excess: Spain and Switzerland



Shiny web app

http://atlasmortalidad.uclm.es/excess/



Discussion

Summary of the results

- Excess mortality in 2020 varied across countries and within countries
- Spain experienced the largest excess mortality among the five countries studied
- First wave: localised excess in England, Italy, Spain and Switzerland but not Greece
- Second wave: excess lower and more homogeneous in England, Italy and Spain, but higher in Switzerland and Greece

Strengths and limitations

Strengths

- Multi-regional study for the entire 2020 at the subnational level
- Model-based approach accounting for population changes, temperature etc.
- Validation of our results
- User-friendly web application

Limitations

- Short term and not long term impact of COVID-19
- Availability of detailed data on causes of death

In the context with previous studies

- ONS reports in England at the sub-national level ($\sim$20% in London in 2020)
- ELSTAT reports in Greece at the sub-national level (Macedonia and Thrace experience the largest excess: 14.9% in males and 12.9% in females)
- North-to-south geographical gradient in Italy
- EuroMOMO: highest excess in Madrid, 17.6% for age group 65 to 74 years during August 2020 to January 2021 to 21.6% for those aged 74 years or older during the period March to May 2020

Interpretation

Potential reasons for geographical discrepancies

- Mortality depends on the probability of being infected and mortality among those infected: demographics, socio-economic characteristics, age structure, environmental factors etc
- Timeframe of non-pharmaceutical interventions and the resilience and capacity of health care systems
- The mobility of populations across borders and between regions and the timeliness of lockdowns

Interpretation/Discussion

First wave

- Pandemic was exogenous with big transit hubs playing an important role
- Community transmission was established locally in the absence of mobility restrictions
- Stochastic super-spreader events
- The lockdown reduced mobility, allowing areas to maintain lower levels of community transmission

Second wave

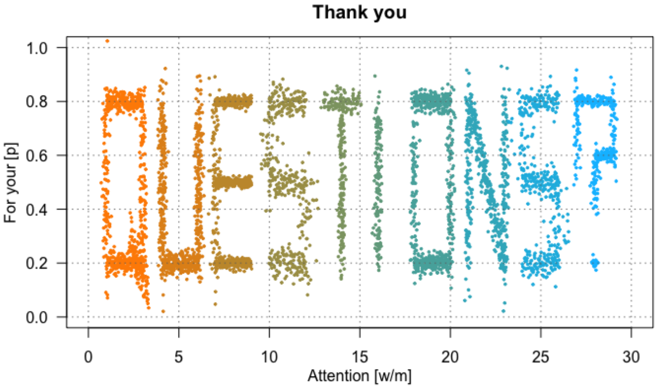
- Relaxation of non-pharmaceutical interventions and the public's loosening of preventive behaviours
- Multiple routes of entry and transmission, thus homogeneous
- Lockdowns during the second wave were slower to be implemented and less rigorous

Conclusion

- Excess mortality varied largely across countries, within countries and over time
- Timely lockdown led to reduced community transmissions, however, adverse short and long-term health, psychosocial and economic effects

Take home message

In the first stages of the pandemic, rapid action is essential to limit transmission around the big transit hubs and prevent spread to other regions and countries.



github:

https://github.com/gkonstantinoudis/ExcessDeathsCOVID

https://github.com/gkonstantinoudis/TutorialExcess

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