Supplementary Materials Modelling and short-term forecasting of seasonal mortality

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Abstract

Excess mortality, i.e., the difference between expected and observed mortality, is used to quantify the death toll of mortality shocks, such as epidemics and pandemics of infectious diseases. However, predictions of expected mortality are sensitive to model assumptions. We analyse which specification of a Poisson regression for seasonal mortality yields more accurate predictions. We compare the Poisson Serfling model with 1) parametric effect for the trend and seasonality, 2) non-parametric effect for the trend and parametric effect for the seasonality, and 3) non-parametric effect for the trend and seasonality, also known as modulation model. Forecasting is achieved with P-splines smoothing. Model 2) resulted in more accurate historical forecasts on the series of monthly deaths from national statistical offices in many European countries. An application to the COVID-19 pandemic years illustrates how excess death can be used to evaluate the vulnerability of populations and aid public health planning.

1. Fitted models

1.1. Total death rates



Supp. Figure 1: Modelling and forecasting of monthly **deaths rates** (logarithmic scale) for **Austria**, **Bulgaria**, **Croatia**, **Czechia**, **Denmark**, **Estonia**, **Finland** with the Poisson Serfling model (PS) and modulation models (PS-STSS and PS-STFS). Trend function (dashed coloured line), fitted values (solid coloured line).



Supp. Figure 2: Modelling and forecasting of monthly **deaths rates** (logarithmic scale) for **France**, **Germany**, **Greece**, **Hungary**, **Iceland**, **Ireland**, **Italy**, **Lithuania**, **Luxembourg** with the Poisson Serfling model (PS) and modulation models (PS-STSS and PS-STFS). Trend function (dashed coloured line), fitted values (solid coloured line).



Supp. Figure 3: Modelling and forecasting of monthly **deaths rates** (logarithmic scale) for **Nether-lands**, **Norway**, **Poland**, **Portugal**, **Romania**, **Slovenia**, **Spain**, **Switzerland** with the Poisson Serfling model (PS) and modulation models (PS-STSS and PS-STFS). Trend function (dashed coloured line), fitted values (solid coloured line).



1.2. Death rates disaggregated by age and sex

Supp. Figure 4: Modelling and forecasting of monthly **deaths rates** (logarithmic scale) for **Denmark** with the Poisson Serfling model (PS) and modulation models (PS-STSS and PS-STFS). Trend function (dashed coloured line), fitted values (solid coloured line).



Supp. Figure 5: Modelling and forecasting of monthly **deaths rates** (logarithmic scale) for **Italy** with the Poisson Serfling model (PS) and modulation models (PS-STSS and PS-STFS). Trend function (dashed coloured line), fitted values (solid coloured line).



Supp. Figure 6: Modelling and forecasting of monthly **deaths rates** (logarithmic scale) for **Spain** with the Poisson Serfling model (PS) and modulation models (PS-STSS and PS-STFS). Trend function (dashed coloured line), fitted values (solid coloured line).



Supp. Figure 7: Modelling and forecasting of monthly **deaths rates** (logarithmic scale) for **Sweden** with the Poisson Serfling model (PS) and modulation models (PS-STSS and PS-STFS). Trend function (dashed coloured line), fitted values (solid coloured line).

2. Amplitude of the seasonal component

2.1. Total death rates



Supp. Figure 8: Changes in the seasonal component over time for Austria, Bulgaria, Croatia, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, with the models PS-STSS: detrended series (grey), modulated component (dashed black) and amplitude (dashed red).



Supp. Figure 9: Changes in the seasonal component over time for Ireland, Italy, Lithuania, Luxembourg, Netherlands, Norway, Poland, Portugal, Romania, Slovenia, Spain, Switzerland, with the models PS-STSS: detrended series (grey), modulated component (dashed black) and amplitude (dashed red).

3. Accuracy of the forecasts

3.1. Death rates disaggregated by age and sex

According to the mean MAPE (and mean RMSE), the PS-STFS would have been more accurate in predicting mortality one year ahead than the PS and the PS-STSS models in Denmark and Sweden. For Spain, using a 10-year fitting period instead of a 5-year fitting period provides a better forecasting accuracy. The preferred models with a 10-year fitting period are the modulation models PS-STSS and PS-STFS.

				5 years s	eries					10 years	series		
			RMSE			MAPE	E		RMSE			MAPE	
Sex	Age	PS	STSS	STFS	PS	STSS	STFS	PS	STSS	STFS	PS	STSS	STFS
Denmark													
men	0-64	28.6	28.5	28.4	5.3	5.2	5.1	34.0	30.0	30.0	6.6	5.6	5.6
men	65 - 74	28.8	28.8	28.8	4.3	4.3	4.3	32.2	31.9	31.8	4.8	4.8	4.8
men	75-84	44.0	42.2	42.1	5.0	4.8	4.8	70.6	48.9	48.2	8.5	5.1	5.0
men	85	41.8	41.9	41.6	5.7	5.7	5.7	44.7	46.4	46.1	5.7	5.9	5.9
women	0-64	21.3	21.4	21.4	6.2	6.2	6.2	17.6	20.5	20.5	5.6	6.6	6.6
women	65 - 74	21.4	21.5	21.4	4.6	4.6	4.6	19.4	19.8	19.8	3.9	4.0	4.0
women	75 - 84	38.8	37.7	37.5	5.0	4.8	4.8	56.8	40.4	39.8	7.7	5.1	5.1
women	85	67.9	67.2	66.7	5.5	5.4	5.4	65.8	67.1	65.5	4.8	5.3	5.1
Italy													
men	0-64	190.5	194.0	193.3	3.8	4.0	4.0	205.5	207.5	207.6	4.2	4.2	4.2
men	65 - 74	238.1	238.6	237.7	3.9	3.8	3.8	264.2	260.3	266.0	4.0	3.8	3.8
men	75-84	557.3	570.9	565.2	4.7	4.8	4.8	658.7	648.9	649.1	5.4	5.1	5.1
men	85	723.0	745.3	729.0	6.1	6.2	6.1	945.4	908.5	908.5	7.3	6.7	6.6
women	0-64	118.2	121.7	121.3	3.9	4.1	4.1	114.2	114.7	114.7	3.7	3.6	3.6
women	65 - 74	154.2	160.3	159.0	4.2	4.3	4.3	174.8	174.7	174.8	4.9	4.8	4.8
women	75-84	558.7	593.7	579.6	5.5	6.0	5.8	603.2	597.5	598.2	5.9	5.8	5.8
women	85	1495.4	1596.5	1492.0	7.0	7.5	7.0	1804.4	1773.3	1773.2	8.1	7.2	7.2
Spain													
men	0-64	201.2	200.3	199.3	4.4	4.5	4.4	297.8	252.6	252.3	6.1	5.7	5.8
men	65 - 74	279.2	268.3	268.5	6.0	5.6	5.6	382.3	385.2	385.4	6.9	7.1	7.1
men	75-84	588.5	598.9	598.7	7.4	7.4	7.4	883.5	926.0	925.8	9.8	10.9	10.9
men	85	815.7	824.9	825.6	8.8	8.7	8.8	1192.4	1317.1	1315.1	11.9	13.5	13.5
women	0-64	100.7	102.0	101.7	4.6	4.7	4.7	130.9	127.3	127.3	5.4	5.7	5.7
women	65 - 74	136.5	132.4	131.6	6.1	6.0	6.0	183.9	186.0	184.7	6.9	7.4	7.3
women	75-84	478.2	490.0	489.7	8.0	7.9	7.9	654.3	698.6	698.0	10.1	11.2	11.2
women	85	1456.2	1655.0	1556.2	9.6	10.9	10.2	1940.6	2604.9	2306.7	12.0	17.1	14.9
Sweden													
men	0-64	31.7	31.6	31.6	5.0	5.0	5.0	33.0	32.9	32.9	5.2	5.4	5.4
men	65 - 74	43.8	43.0	42.9	5.0	5.0	5.0	64.6	48.8	48.8	7.6	5.5	5.5
men	75-84	62.8	62.1	61.8	4.4	4.4	4.4	92.6	70.9	70.3	6.2	4.7	4.6
men	85	78.8	78.7	78.2	4.9	5.0	5.0	85.8	87.4	87.4	5.3	5.3	5.3
women	0-64	20.3	20.2	20.3	4.8	4.8	4.8	23.9	23.3	23.6	6.0	5.8	5.9
women	65 - 74	35.1	34.5	34.5	5.7	5.5	5.5	45.9	41.1	41.0	7.7	6.6	6.6
women	75-84	60.0	59.2	59.0	5.0	4.9	4.9	66.8	57.2	57.2	5.4	4.6	4.6
women	85	145.4	143.9	139.6	5.5	5.3	5.1	165.3	153.4	153.3	6.1	5.4	5.4
		13	2	17	12	2	18	12	8	12	14	4	14

Table 1: Mean RMSE and MAPE on death counts in Denmark, Italy, Spain, and Sweden for multiple fitting periods based on a rolling-window scheme.

				5 years	series			10 years series						
		RMSE			MAPE			RMSE			MAPE			
Sex	Age	PS	STSS	STFS	PS	STSS	STFS	$_{\rm PS}$	STSS	STFS	PS	STSS	STFS	
Denmark														
men	0-64	0.1	0.1	0.1	5.1	5.0	5.0	0.2	0.2	0.2	6.3	5.7	5.7	
men	65 - 74	1.2	1.2	1.2	4.6	4.5	4.5	1.7	1.2	1.2	6.7	4.7	4.7	
men	75 - 84	3.5	3.4	3.4	4.9	4.8	4.8	3.3	3.6	3.5	4.5	4.9	4.8	
men	85	12.9	12.9	12.8	5.8	5.8	5.8	13.1	13.6	13.4	5.8	6.1	6.0	
women	0-64	0.1	0.1	0.1	6.1	6.2	6.2	0.1	0.1	0.1	5.5	6.6	6.6	
women	65 - 74	0.8	0.8	0.8	4.7	4.7	4.7	1.0	0.7	0.7	6.4	3.9	3.9	
women	75 - 84	2.5	2.5	2.5	4.9	4.9	4.9	2.2	2.2	2.2	4.6	4.4	4.4	
women	85	10.4	10.3	10.2	5.5	5.5	5.5	10.4	9.8	9.7	4.9	5.2	5.0	
Italy					•									
men	0-64	0.1	0.1	0.1	3.9	4.0	4.0	0.1	0.1	0.1	4.2	4.2	4.2	
men	65 - 74	0.9	0.9	0.9	3.9	3.9	3.8	1.0	1.0	1.0	3.9	3.8	3.8	
men	75 - 84	3.3	3.3	3.3	4.7	4.6	4.6	3.5	3.7	3.7	4.7	4.9	4.9	
men	85	13.1	13.5	13.3	5.7	5.9	5.8	14.9	15.0	15.0	5.9	6.0	5.9	
women	0-64	0.1	0.1	0.1	3.9	4.1	4.1	0.1	0.1	0.1	3.5	3.6	3.6	
women	65 - 74	0.5	0.5	0.5	4.2	4.3	4.3	0.6	0.6	0.6	5.0	4.9	4.9	
women	75 - 84	2.4	2.6	2.4	5.5	5.9	5.6	2.5	2.5	2.5	5.5	5.6	5.5	
women	85	12.8	13.7	13.1	6.7	7.3	6.9	14.2	14.1	14.2	6.7	6.9	6.9	
Spain		•												
men	0-64	0.1	0.1	0.1	4.4	4.5	4.4	0.2	0.2	0.2	5.4	5.6	5.6	
men	65-74	1.5	1.5	1.5	5.7	5.5	5.5	2.1	2.1	2.1	6.9	7.1	7.1	
men	75 - 84	5.6	5.7	5.7	7.7	7.6	7.6	8.0	9.9	9.9	10.5	14.4	14.3	
men	85	19.1	19.3	19.3	8.4	8.5	8.5	26.1	28.7	28.7	10.8	12.5	12.5	
women	0-64	0.1	0.1	0.1	4.6	4.6	4.6	0.1	0.1	0.1	5.1	5.2	5.2	
women	65 - 74	0.7	0.6	0.6	5.8	5.8	5.8	0.9	0.9	0.9	7.2	7.3	7.2	
women	75 - 84	3.4	3.5	3.5	8.1	8.3	8.3	4.5	4.9	4.9	10.7	11.9	11.8	
women	85	17.3	19.8	18.6	9.3	10.9	10.2	21.6	23.6	23.5	11.1	12.5	12.4	
Sweden		I			I									
men	0-64	0.1	0.1	0.1	4.8	4.8	4.8	0.1	0.1	0.1	5.0	5.2	5.2	
men	65 - 74	0.9	0.9	0.9	4.7	4.7	4.6	1.0	1.0	1.0	4.8	4.9	4.9	
men	75-84	2.5	2.6	2.5	4.2	4.2	4.2	2.6	2.6	2.6	4.6	4.6	4.6	
men	85	10.5	10.6	10.6	4.9	5.1	5.1	11.1	11.1	11.1	5.2	5.3	5.3	
women	0-64	0.1	0.1	0.1	4.8	4.8	4.8	0.1	0.1	0.1	6.0	5.8	5.9	
women	65-74	0.7	0.7	0.7	5.3	5.2	5.2	0.9	0.8	0.8	5.8	5.8	5.8	
women	75-84	2.1	2.1	2.1	5.1	5.0	5.0	1.9	1.8	1.8	5.3	4.9	4.9	
women	85	10.5	10.4	10.1	5.5	5.4	5.2	11.6	11.5	11.3	5.9	5.8	5.7	
		15	3	14	13	2	17	16	6	10	21	3	8	

Table 2: Mean RMSE and MAPE (x 1000) on death rates in Denmark, Italy, Spain, and Sweden for multiple fitting periods based on a rolling-window scheme.

References