Appendix

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ICD10 codes for comorbidities

Comorbidity	ICD-10
Dementia	F00
	F01
	F02
	F051
Coronary heart disease	I099
	I110
	I130
	I132
	I255
	I420
	I425
	I426
	I427
	I428
	I429
	I43
	I50
	P290
Hypertension	I10
	I11
	I12
	I13
	I15
COPD	I278
	I279
	J40
	J41
	J42
	J43
	J44
	J45
	J46
	J47
	J60
	J61
	J62
	J63
	J64
	J65
	J66
	J67
	J684
	J701

	J703
Diabetes	E100
	E101
	E102
	E103
	E104
	E105
	E106
	E107
	E108
	E109
	E110
	E111
	E112
	E113
	E114
	E115
	E116
	E117
	E118
	E119
	E120
	E121
	E122
	E123
	E124
	E125
	E126
	E127
	E128
	E129
	E130
	E131
	E132
	E133
	E134
	E135
	E136
	E137
	E138
	E139
	E140
	E141
	E142
	E143
	E144

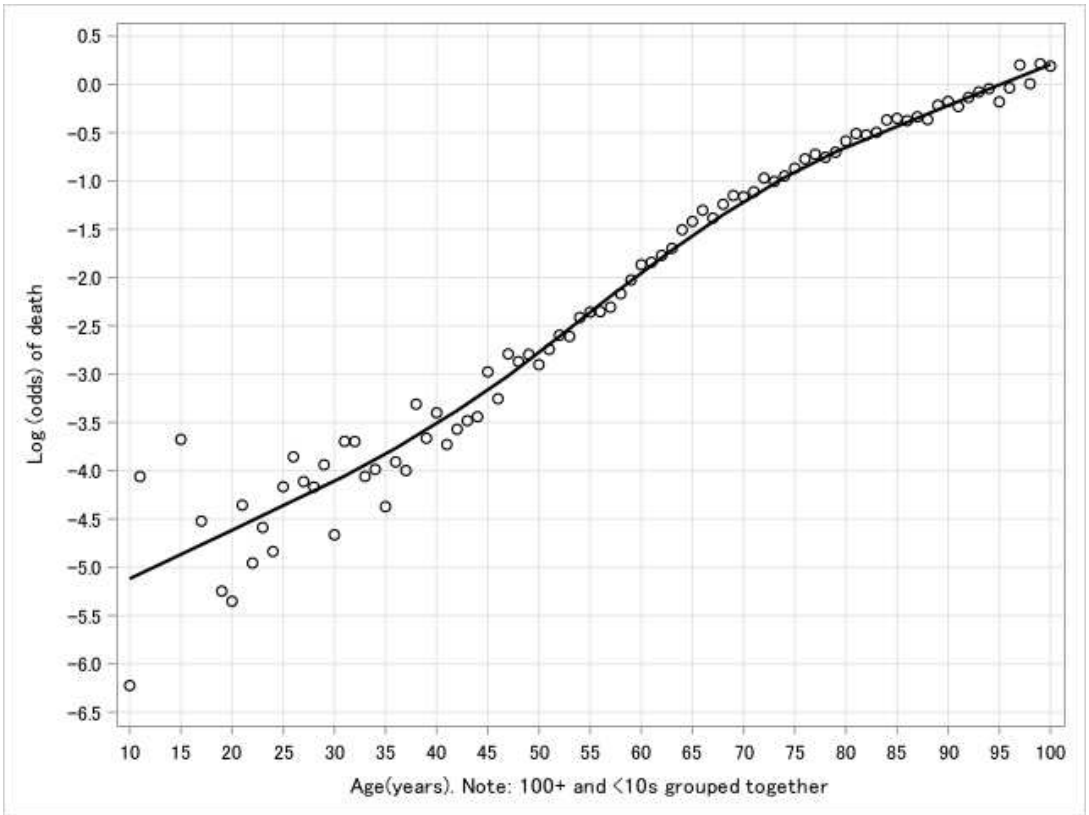
	E145
	E146
	E147
	E148
	E149
Renal	I120
	I131
	N18
	N19
	N250
	Z490
	Z491
	Z492
	Z940
	Z992
Cancer	C0
	C1
	C20
	C21
	C22
	C23
	C24
	C25
	C26
	C30
	C31
	C32
	C33
	C34
	C37
	C38
	C39
	C40
	C41
	C43
	C45
	C46
	C47
	C48
	C49
	C5
	C6
	C70
	C71
	C72
	C73

	C74 C75 C76 C77 C78 C79 C80
	C81 C82 C83 C84 C85 C88 C900 C902 C96 C97
Obesity	E66

How we modelled the hospital-level variables

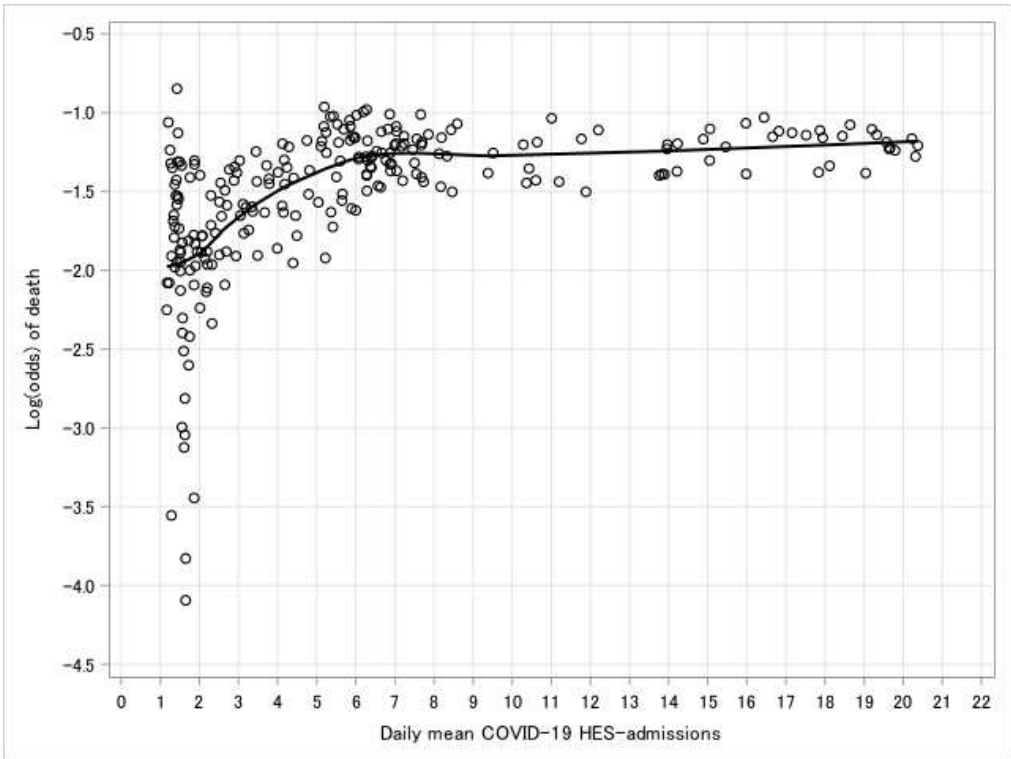
We plotted continuous variables against the outcome to check for linearity and applied linear splines with 1 knot as described below. For the final model, if the odds ratios were not different from 1 to two decimal places and $p>0.05$, the spline was replaced with a simpler linear term.

Figure A1. Locally weighted smoothing (LOESS) plot of age against the log(odds) of death for 122 English hospitals from August 2020 to March 2021



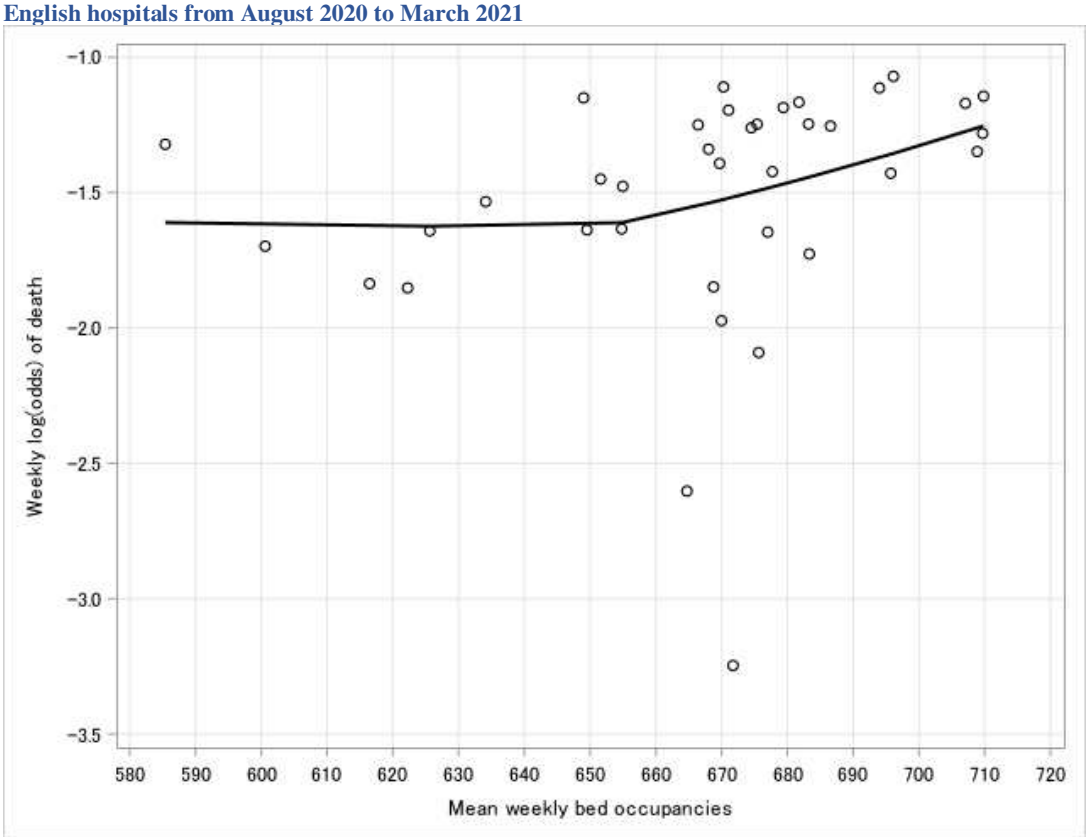
A linear term only and an addition of a quadratic term was trialled. The quadratic age term improved the model fit.

Figure A2. LOESS plot of daily mean COVID-19 hospital admissions against the daily mean log(odds) of death for 122 English hospitals from August 2020 to March 2021



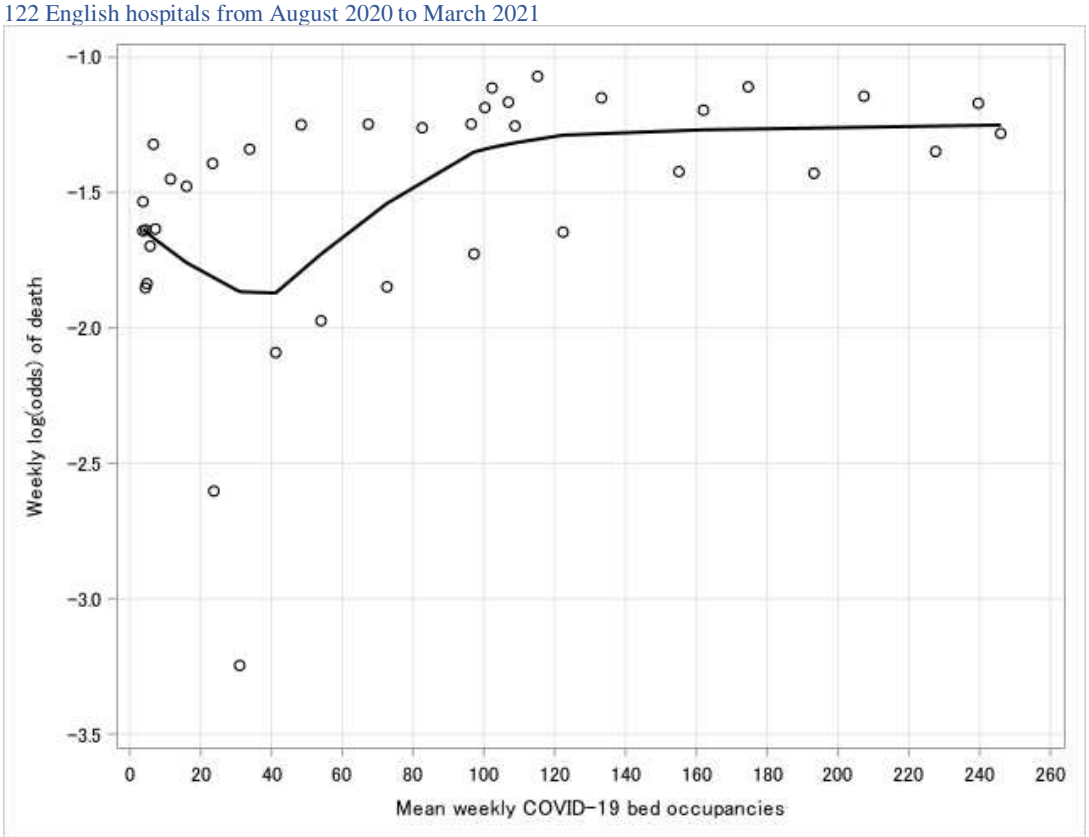
We tried this as linear and as a spline with a knot at 6. With the knot, the odds ratio was very small and $p<0.05$. The fit was approximated best as linear.

Figure A3. LOESS plot of weekly mean bed occupancies against the weekly log(odds) of death for 122 English hospitals from August 2020 to March 2021



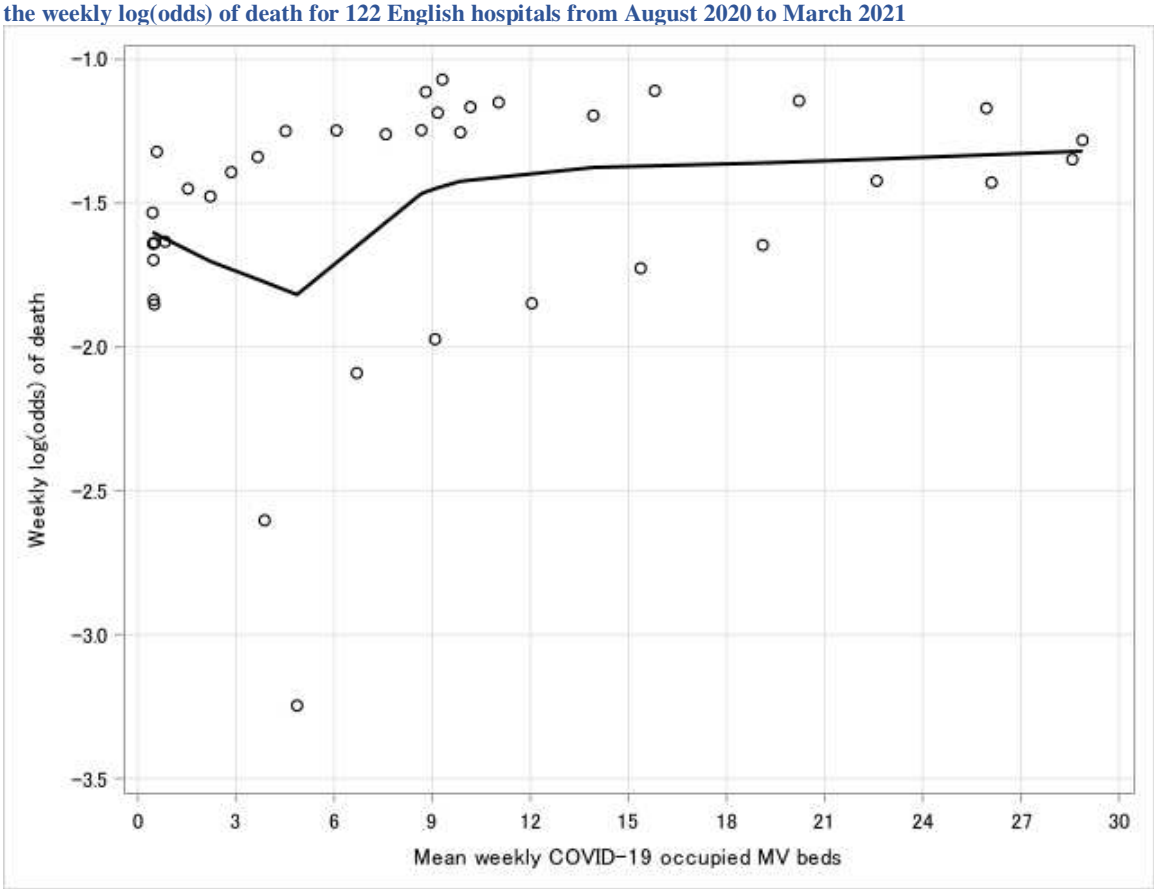
Tried a knot at 655 and as linear. Better fit with the knot at 655 but odds ratio was very small and $p<0.05$ so the final model was run with a linear term.

Figure A4. LOESS plot of weekly mean COVID-19 bed occupancies against the weekly log(odds) of death for 122 English hospitals from August 2020 to March 2021



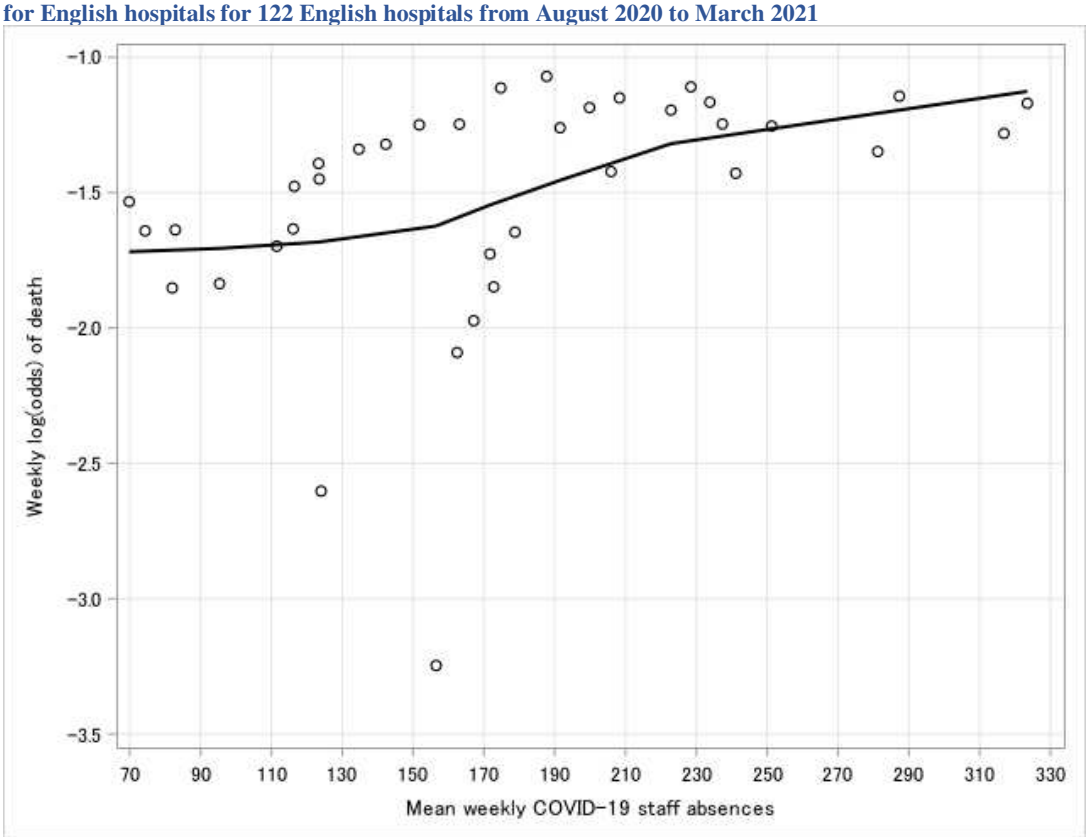
Tried a linear term, a knot at 40 and a knot at 100. The fit was best as linear term.

Figure A5. LOESS plot of weekly mean COVID-19 occupied mechanically ventilated (MV) beds against the weekly log(odds) of death for 122 English hospitals from August 2020 to March 2021



Tried a linear term, a knot at 5 and a knot at 8. The fit was best as linear

Figure A6. LOESS plot of weekly mean COVID-19 staff absences against the weekly log(odds) of death for English hospitals for 122 English hospitals from August 2020 to March 2021



Tried a linear term and a knot at 160. The fit was best as linear.

Figure A7: COVID-19 crude in-hospital mortality rates with 95% confidence intervals (CI) among 122 English hospitals by month of admission

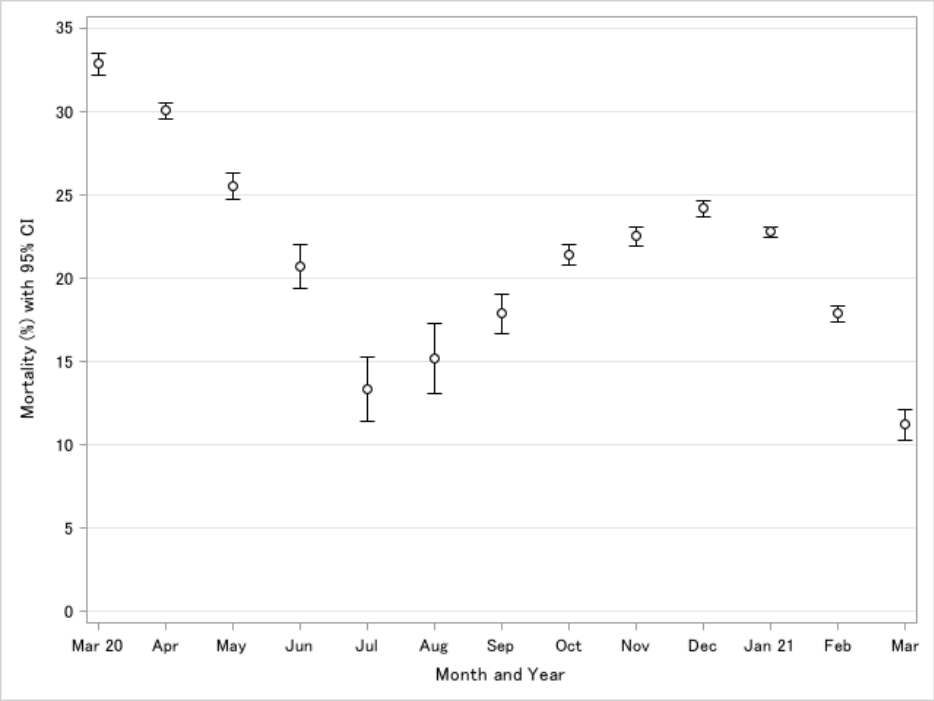


Figure A8: Calibration plot for the first wave two-level model (March to July 2020)

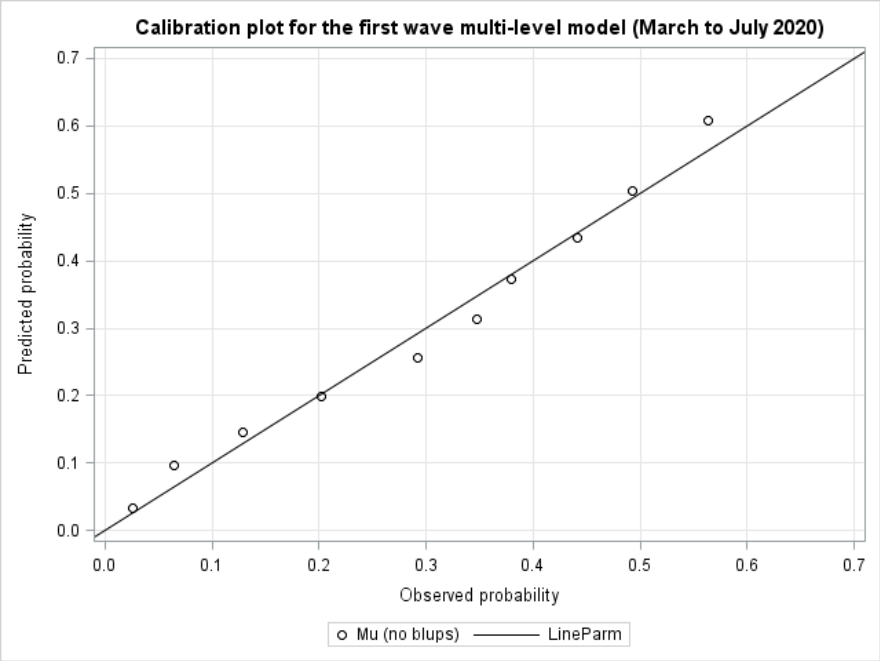


Figure A9: Calibration plot for the second wave two-level model (August 20 to March 21)

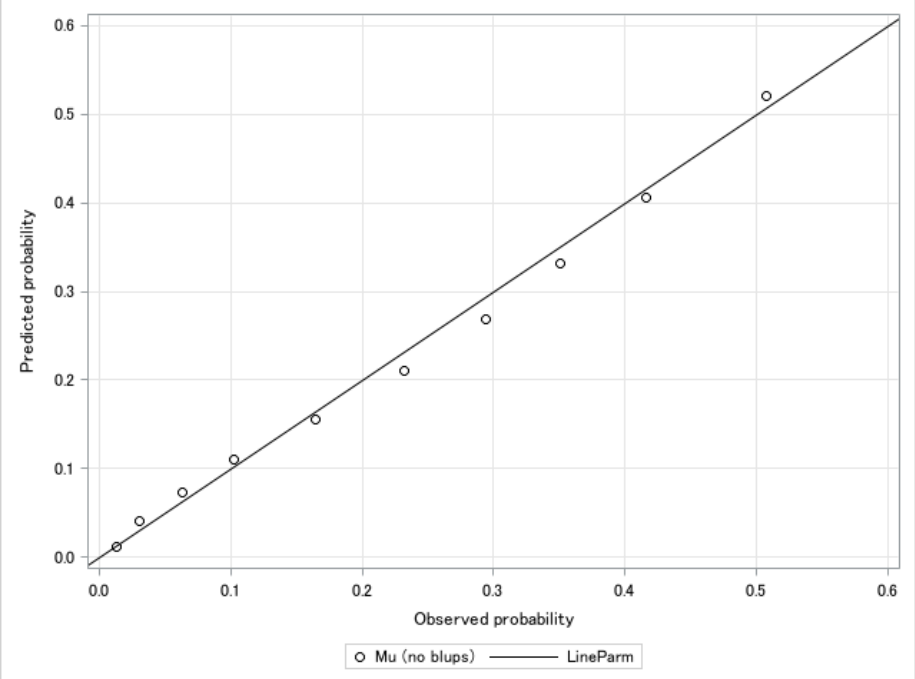


Figure A10: Funnel plot for crude COVID-19 mortality rate for 122 trusts in the first wave (March 2020 to July 2020)

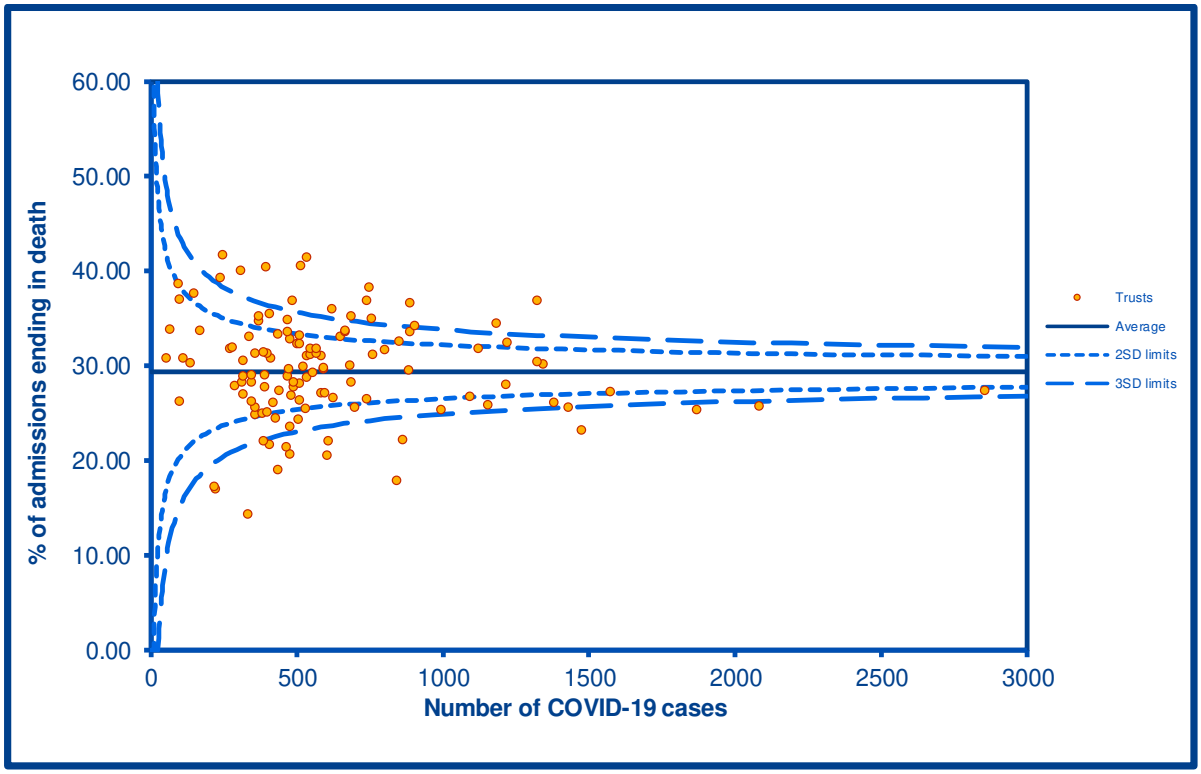


Figure A11: Funnel plot for crude COVID-19 mortality rate for 122 trusts in the second wave (August 2020 to March 2021)

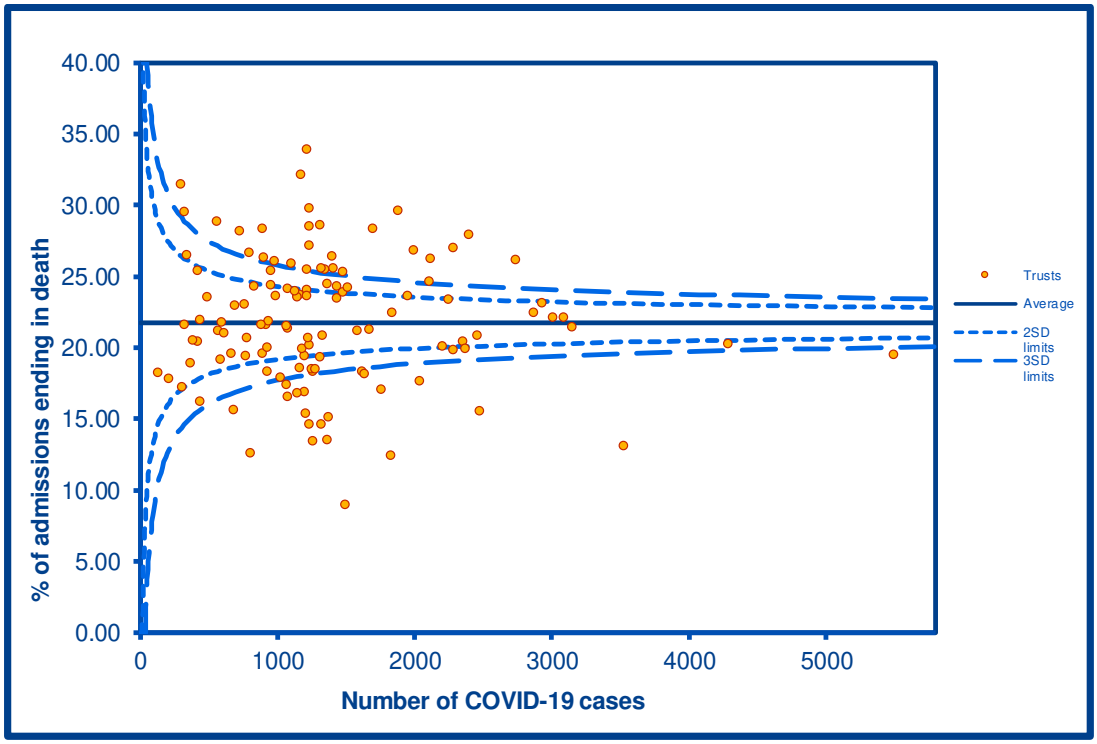


Figure A12: Funnel plot for adjusted COVID-19 standardised mortality ratio for 122 trusts in the first wave (March 2020 to July 2020)

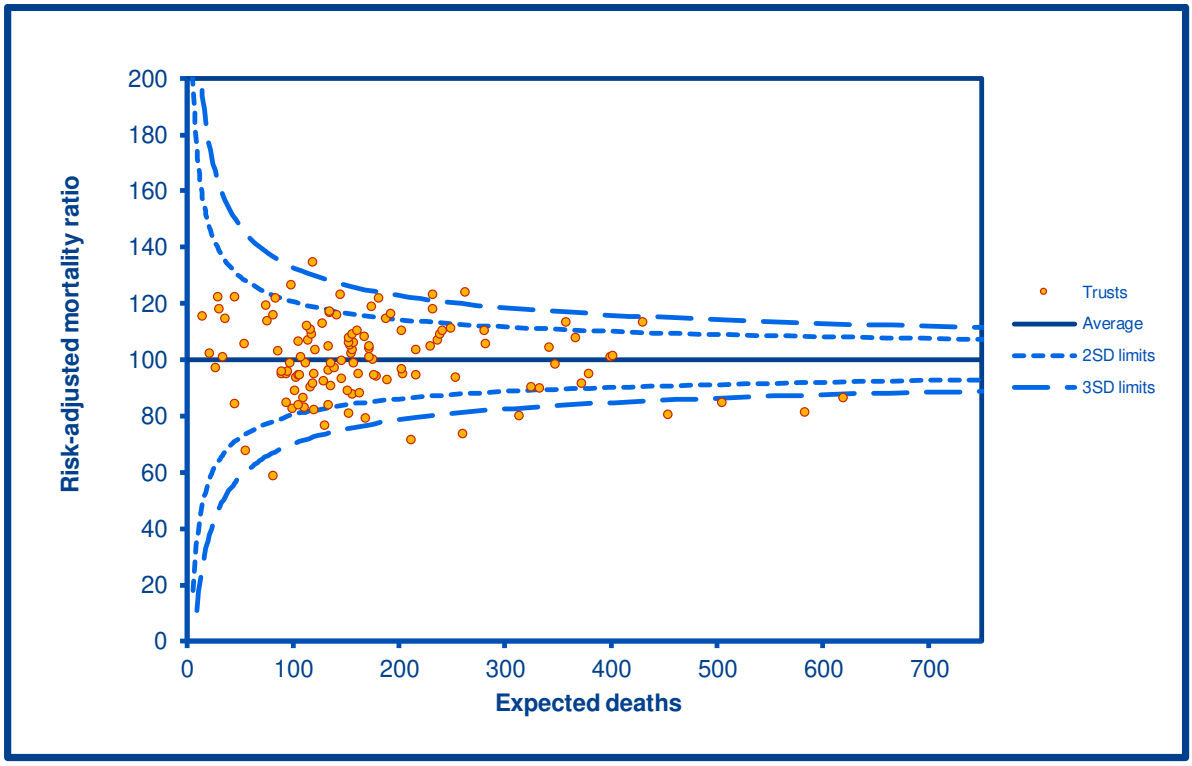


Table A1: Overall p-value for significance for all covariates in the first and second wave two-level models

Feature	Overall p-values	
	First wave (March to July 2020)	**Second wave (August 2020 to March 2021)**
Age		
Age	-	<0.0001*
Age squared	-	<0.0001*
<45 years (spline)	<0.0001*	-
45+ years (spline)	<0.0001*	-
Gender	<0.0001*	<0.0001*
Ethnic group	<0.0001*	<0.0001*
Deprivation quintile	<0.0005*	<0.0001*
Method of admission	0.0035*	0.0045*
Admission source	<0.0001*	<0.0001*
Emergency admissions in previous 12 months	<0.0001*	<0.0001*
Admission month	<0.0001*	<0.0001*
Diabetes	<0.0001*	<0.0001*
Hypertension	<0.0001*	<0.0001*
Coronary heart disease	<0.0001*	<0.0001*
COPD	0.0129*	<0.0001*
Obesity	<0.0001*	<0.0001*
Cancer	<0.0001*	<0.0001*
Renal disease	<0.0001*	<0.0001*
Dementia	<0.0001*	<0.0001*
COVID19 daily admissions	-	0.0047*
<4 admissions	0.2500	-
4+ admissions	0.4425	-
Bed occupancy	0.1849	0.1077
COVID19 bed occupancy	0.1507	<0.0001*
COVID19 MV bed occupancy	-	<0.0001*
<4 beds	0.5867	-
4+ beds	0.4861	-
COVID19 related staff absences	0.9398	0.6952

*statistically significant

Table A2: Average crude rates by age group for lowest- and highest-mortality hospital quartiles in the first and second wave

Lowest quartile				**Highest quartile**				
First wave				**First wave**				
Age	**Crude rate (%, 95% CI)**	**OR cf <50**	**OR cf prev age**	**Age**	**Crude rate (%, 95% CI)**	**OR cf <50**	**OR cf prev age**	**OR cf lowest quartile**
<50	3.5 (3.0 to 4.0)	1	1	<50	6.5 (5.4 to 7.5)	1	1	1.92
50-59	11.3 (10.3 to 12.4)	3.5	3.5	50-59	17.8 (16.1 to 19.4)	3.1	3.1	1.70
60-69	21.4 (20.1 to 22.7)	7.5	2.1	60-69	30.7 (28.8 to 32.6)	6.4	2.0	1.63
70-79	32.8 (31.5 to 34.2)	13.5	1.8	70-79	41.9 (40.2 to 43.7)	10.4	1.6	1.48
80-89	40.7 (39.3 to 42.0)	18.9	1.4	80-89	50.3 (48.7 to 51.9)	14.6	1.4	1.47
90+	44.9 (42.7 to 47.2)	22.5	1.2	90+	55.8 (53.2 to 58.4)	18.2	1.2	1.55
Second wave				**Second wave**				
Age	**Crude rate (%, 95% CI)**	**OR cf <50**	**OR cf prev age**	**Age**	**Crude rate (%, 95% CI)**	**OR cf <50**	**OR cf prev age**	**OR cf lowest quartile**
<50	1.6 (1.3 to 1.9)	1	1	<50	4.2 (3.7 to 4.6)	1	1	2.70
50-59	5.4 (4.8 to 5.9)	3.5	3.5	50-59	10.7 (9.9 to 11.5)	2.7	2.5	2.10
60-69	12.5 (11.7 to 13.4)	8.8	2.5	60-69	22.3 (21.4 to 23.3)	6.5	2.1	2.01
70-79	23.0 (22.0 to 24.0)	18.4	2.1	70-79	34.2 (33.2 to 35.2)	11.9	1.5	1.74
80-89	33.2 (32.1 to 34.4)	30.6	1.7	80-89	44.9 (43.8 to 45.9)	18.6	1.3	1.64
90+	40.5 (38.5 to 42.5)	41.9	1.4	90+	52.3 (50.5 to 54.1)	25.0	1.2	1.61

Cf, compared with; OR = odds ratio

Sensitivity analysis results

There were 393,711 admissions with COVID-19 in any diagnosis position, with 272,293 in the first wave and 121,418 admissions in the second wave. Where it occurred in a secondary position for the second wave, 35·7% of the time, the first one was occupied by a wide range of conditions, most commonly ICD-10 N390 (urinary tract infection, site not specified, 1·3%), A419 (unspecified sepsis, 1·0%), R296 (tendency to fall, not elsewhere classified, 0·9%), N179 (unspecified acute renal failure, 0·8%) and S720 (fracture of neck of femur, 0·8%).

Hospital SMRs for the adjusted sensitivity model for COVID-19 in any diagnosis code during admission ranged from 66 to 127, with 19·7% high and 18·9% low mortality outliers at 2SD and 6·6% high and 9·8% low mortality outliers at 3SD on the funnel plots for the second wave. For the second wave main analysis given earlier, hospital SMRs for the adjusted model ranged from 52 to 135, with 22·1% high and 13·9% low mortality outliers at 2SD and 9·0% high and 12·3% low mortality outliers at 3SD on the funnel plots. Correlation with the SMRs derived from COVID-19 as the primary diagnosis was high at 0·87 ($p<0·0001$) for the second wave.

When we restricted admissions to only confirmed cases (U071), there were 158,231 admissions in the second wave. The adjusted hospital SMR sensitivity model ranged from 52 to 133, with 21·3% high and 13·9% low mortality outliers using 95% control limits and 9.8% high and 11·5% low mortality outliers using 99·8% limits for the second wave. Correlation with the SMRs derived from the main analysis was very high at 0·99 ($p<0·0001$) for the second wave.