

Supplementary information

Community factors and excess mortality in first wave of the COVID-19 pandemic

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Supplementary Table 1. Characteristics of the 6,791 Middle Super Output Areas in England.

	Mean	Median	Range	Inter-quartile range
Population	8,288	7,985	2,224 – 26,513	6,831 – 9,320
Population (M)	4,098	3,926	1,089 – 14,535	3,348 – 4,629
Population (F)	4,191	4,052	1,135 – 11,978	3,468 – 4,722
Population over 40 (M)	1,994	1,926	410 – 4,459	1,660 – 2,277
Population over 40 (F)	2,155	2,090	286 – 4,794	1,788 – 2,155
Area (km ²)	19.2	3.04	0.294 – 1128	1.69 – 10.5
Baseline deaths (M), per 100,000 males over 40, 2015 – 2019	447	438	53.7 – 1,200	356 – 529
Baseline deaths (F), per 100,000 females over 40, 2015 – 2019	427	406	0 – 1,502	313 – 519

M – male; F – female; km- kilometre.

Supplementary Table 2. Characteristics of the study and comparison populations.

	Comparison period (1 March – 31 May, 2015 – 2019)	Study period (1 March – 31 May 2020)		
	Mean deaths per year (%)	Total deaths (%)	Deaths with COVID-19 as underlying cause of death (%)	Deaths with COVID-19 mentioned on death certificate (%)
Total	121,441	174,327	42,000	44,913
Sex				
Male	59,397 (48.9)	88,092(50.5)	23,349 (55.6)	24,917 (55.5)
Female	62,044 (51.1)	86,235 (49.5)	18,651 (44.4)	19,996 (44.5)
Age				
40-59	10,329 (8.51)	12,963(7.44)	2,523 (6.01)	2,755 (6.13)
60-69	14,300 (11.8)	18,286 (10.5)	4,110 (9.79)	4,422 (9.85)
70-79	26,976 (22.2)	38,988 (22.4)	9,470 (22.5)	10,188 (22.7)
80+	69,835 (57.5)	104,090 (59.7)	25,897 (61.7)	27,548 (61.3)
Place of death				
Hospital	56,780 (46.8)	70,188 (40.3)	26,890 (64.0)	28,578 (63.6)
Care home	27,128 (22.3)	52,268 (30.0)	12,611 (30.0)	13,301 (29.6)
Home	28,316 (23.3)	42,004(24.1)	1,791 (4.26)	2,046 (4.56)
Hospice	6,908 (5.69)	6,402 (3.67)	382 (0.91)	620 (1.38)
Other/elsewhere	2,309 (1.89)	3,465 (1.80)	326 (0.77)	368 (0.81)
Population on income support (%)				
≥ 0.80 to < 6.00	22,893 (18.9)	33,211 (19.1)	7,736 (18.4)	8,286 (18.4)
≥ 6.00 to < 8.79	25,060 (20.6)	34,859 (20.0)	7,629 (18.2)	8,185 (18.2)
≥ 8.79 to < 12.7	25,287 (20.8)	35,615 (20.4)	8,146 (19.4)	8,739 (19.5)
≥ 12.7 to < 18.8	24,449 (20.1)	35,238 (20.2)	9,090 (21.6)	9,673 (21.5)
≥ 18.8 to < 48.9	23,750 (19.6)	35,404 (20.3)	9,399 (22.4)	10,030 (22.3)
Population density (population per km²)				
≥ 5.65 to < 456	26,586 (21.9)	35,566 (20.4)	6,668 (15.9)	7,140 (15.9)
≥ 456 to < 1,877	27,230 (22.4)	38,145 (21.9)	8,558 (20.4)	9,157 (20.4)
≥ 1,877 to < 3,445	25,443 (21.0)	36,171 (20.7)	8,654 (20.6)	9,273 (20.6)
≥ 3,445 to < 5,340	24,263 (20.0)	35,550 (20.4)	9,071 (21.6)	9,728 (21.7)
≥ 5,340 to < 29,000	17,917 (14.8)	28,895 (16.6)	9,049 (21.5)	9,615 (21.4)
Population non-White (%)				
≥ 0.43 to < 2.10	28,389 (23.4)	36,172 (21.3)	6,924 (16.5)	7,402 (16.5)

≥ 2.10 to < 3.72	27,426 (22.6)	37,588 (21.6)	7,996 (19.0)	8,610 (19.2)
≥ 3.72 to < 8.28	25,531 (21.0)	35,505 (20.4)	8,082 (19.2)	8,647 (19.3)
≥ 8.28 to < 22.2	22,418 (18.5)	33,559 (19.3)	8,769 (20.9)	9,380 (20.9)
≥ 22.2 to < 94.4	17,677 (14.6)	30,503 (17.5)	10,229 (24.4)	10,874 (24.2)
Overcrowded homes (%)				
≥ 0.334 to < 1.65	26,440 (21.8)	36,047 (20.7)	7,353 (17.5)	7,904 (17.6)
≥ 1.65 to < 2.42	26,783 (22.1)	36,753 (21.1)	7,776 (18.5)	8,355 (18.6)
≥ 2.42 to < 3.67	26,578 (21.9)	36,955 (21.2)	8,394 (20.0)	8,975 (20.0)
≥ 3.67 to < 6.26	23,998 (19.8)	34,687 (19.9)	8,661 (20.6)	9,265 (20.6)
≥ 6.26 to < 36.5	17,641 (14.5)	29,885 (17.1)	9,816 (23.4)	10,414 (23.2)
NO₂ annual average (µg/m³)				
≥ 3.60 to < 9.52	28,654 (23.6)	37,311 (21.4)	6,414 (15.3)	6,900 (15.4)
≥ 9.52 to < 12.3	26,850 (22.1)	36,923 (21.2)	7,931 (18.9)	8,493 (18.9)
≥ 12.3 to < 14.9	24,460 (20.1)	34,569 (19.8)	8,145 (19.4)	8,747 (19.5)
≥ 14.9 to < 18.7	23,904 (19.7)	35,502 (20.4)	9,456 (22.5)	10,101 (22.5)
≥ 18.7 to < 47.5	17,571 (14.5)	30,022 (17.2)	10,054 (23.9)	10,672 (23.8)
PM_{2.5} annual average (µg/m³)				
≥ 5.05 to < 7.76	27,675 (22.8)	37,213 (21.3)	7,760 (18.5)	8,332 (18.6)
≥ 7.76 to < 8.91	26,197 (21.6)	36,485 (20.9)	8,293 (19.7)	8,852 (19.7)
≥ 8.91 to < 9.88	26,148 (21.5)	36,075 (20.7)	7,774 (18.5)	8,382 (18.7)
≥ 9.88 to < 10.9	23,720 (19.5)	34,519 (19.8)	8,239 (19.6)	8,803 (19.6)
≥ 10.9 to < 14.4	17,700 (14.6)	30,035 (17.2)	9,934 (23.7)	10,544 (23.5)
Care homes per 1,000 population				
0	19,472 (16.0)	27,122 (15.6)	6,703 (16.0)	7,196 (16.0)
≥ 0.040 to < 0.145	19,445 (16.0)	28,106 (16.1)	7,013 (16.7)	7,537 (16.8)
≥ 0.145 to < 0.265	24,181 (19.9)	35,164 (20.2)	8,769 (20.9)	9,340 (20.8)
≥ 0.265 to < 0.438	27,244 (22.4)	39,027 (22.4)	9,203 (21.9)	9,793 (21.8)
≥ 0.438 to < 4.23	31,098 (25.6)	44,908 (25.8)	10,312 (24.6)	11,047 (24.6)

Supplementary Table 3. Excess death rates, percent increase in mortality and posterior probabilities for Middle Super Output Areas in England.

	Mean	Median	Range	Inter-quartile range
Excess death rate (M), per 100,000 males over 40	200	174	-337 – 1482	88.1 – 283
Excess death rate (F), per 100,000 females over 40	163	131	-240 - 1662	48.1 - 235
Percent increase in mortality (M)	48.0	42.0	-38.0 – 249	21.8 – 67.5
Percent increase in mortality (F)	40.9	34.9	-42.4 - 333	14.8 – 60.0
Posterior probability that excess rate is greater than zero (M)	0.844	0.917	0.034 – 1.00	0.767 – 0.982
Posterior probability that excess rate is greater than zero (F)	0.776	0.845	0.012 – 1.00	0.651 – 0.953

M – male; F – female.

Supplementary Table 4. One-variable-at-a-time models for community characteristics.

Age is included in all the models.

Variable	n-tile	Males		Females	
		Mean	95% credible interval	Mean	95% credible interval
Population on income support	1 (lowest)	ref	ref	ref	ref
	2	1.04	1.01 – 1.08	1.00	0.97 – 1.03
	3	1.10	1.07 – 1.13	1.04	1.00 – 1.07
	4	1.15	1.12 – 1.19	1.07	1.03 – 1.10
	5 (highest)	1.23	1.19 – 1.27	1.16	1.12 – 1.20
	% of variation contributed by variable	7.49	5.48 – 9.72	4.05	2.64 – 5.69
Population density	1 (lowest)	ref	ref	ref	ref
	2	1.06	1.03 – 1.10	1.04	1.01 – 1.07
	3	1.10	1.07 – 1.14	1.05	1.01 – 1.08
	4	1.11	1.07 – 1.14	1.10	1.06 – 1.14
	5 (highest)	1.16	1.12 – 1.21	1.12	1.07 – 1.16
	% of variation contributed by variable	3.67	2.13 – 5.47	2.06	1.01 – 3.38
Population non-White	1 (lowest)	ref	ref	ref	ref
	2	1.04	1.01 – 1.07	1.05	1.01 – 1.08
	3	1.07	1.04 – 1.10	1.05	1.02 – 1.09
	4	1.12	1.09 – 1.16	1.12	1.08 – 1.16
	5 (highest)	1.26	1.21 – 1.32	1.21	1.16 – 1.26
	% of variation contributed by variable	9.56	6.59 – 12.9	5.59	3.40 – 8.14
Overcrowded homes	1 (lowest)	ref	ref	ref	ref
	2	1.05	1.02 – 1.07	1.02	0.99 – 1.06
	3	1.09	1.06 – 1.12	1.06	1.03 – 1.09
	4	1.16	1.13 – 1.20	1.10	1.07 – 1.14
	5 (highest)	1.28	1.23 – 1.32	1.19	1.15 – 1.24
	% of variation contributed by variable	10.45	7.69 – 13.49	4.89	3.05 – 6.98
NO ₂	1 (lowest)	ref	ref	ref	ref
	2	1.05	1.01 – 1.08	1.04	1.00 – 1.07
	3	1.09	1.06 – 1.13	1.04	1.01 – 1.08
	4	1.14	1.09 – 1.18	1.12	1.07 – 1.16
	5 (highest)	1.22	1.16 – 1.28	1.17	1.12 – 1.23
	% of variation contributed by variable	6.90	4.07 – 10.24	4.21	2.19 – 6.68
	1 (lowest)	ref	ref	ref	ref

PM_{2.5}	2	1.06	1.02 – 1.11	1.04	1.00 – 1.08
	3	1.13	1.07 – 1.18	1.06	1.01 – 1.12
	4	1.18	1.11 – 1.24	1.10	1.04 – 1.17
	5 (highest)	1.29	1.21 – 1.38	1.19	1.11 – 1.28
	% of variation contributed by variable	11.2	6.01 – 17.4	4.77	1.83 – 8.69
Care home per 1,000 population	1 (lowest)	ref	ref	ref	ref
	2	1.10	1.06 – 1.13	1.13	1.09 – 1.16
	3	1.12	1.09 – 1.15	1.18	1.14 – 1.22
	4	1.14	1.11 – 1.18	1.21	1.18 – 1.25
	5 (highest)	1.21	1.17 – 1.24	1.27	1.22 – 1.31
	% of variation contributed by variable	5.95	4.28 – 7.82	8.76	6.62 – 11.09

NO₂ – nitrogen dioxide; PM_{2.5} – particulate matter 2.5 µ diameter

Supplementary Table 5. Correlation between community characteristics for Middle Super Output Areas in England: Kendall's Tau coefficients between covariates (quintiles), n = 6,791 MSOAs.

	Population on income support	Population density	Non-White population	Overcrowding	NO ₂	PM _{2.5}	Care homes per 1000 population*
Population on income support	1						
Population density	0.37	1					
Population non-White	0.21	0.56	1				
Overcrowding	0.55	0.61	0.61	1			
NO₂	0.26	0.59	0.67	0.56	1		
PM_{2.5}	0.04	0.39	0.55	0.42	0.55	1	
Care homes per 1000 population*	-0.04	-0.17	-0.17	-0.16	-0.20	-0.16	1

*All MSOAs with a care home density of 0 (n=1,535 MSOAs) are in quintile 1. Quintile 2 has reduced number of MSOAs (n=1,182 MSOAs)

Supplementary Table 6. Mutually adjusted multivariable models for all MSOA characteristics. Age is included in all the models.

Variable	Quintile	Males		Females	
		Mean	95% credible interval	Mean	95% credible interval
Population on income support	1 (lowest)	ref	ref	ref	ref
	2	1.02	0.99 – 1.05	0.97	0.94 – 1.01
	3	1.04	1.01 – 1.08	1.00	0.96 – 1.03
	4	1.07	1.03 – 1.12	1.02	0.97 – 1.06
	5 (highest)	1.11	1.06 – 1.17	1.09	1.03 – 1.14
Population density	1 (lowest)	ref	ref	ref	ref
	2	1.02	0.99 – 1.05	1.01	0.98 – 1.05
	3	1.02	0.98 – 1.06	1.00	0.96 – 1.04
	4	0.99	0.95 – 1.03	1.03	0.98 – 1.07
	5 (highest)	0.99	0.95 – 1.04	1.00	0.95 – 1.06
Population non-White	1 (lowest)	ref	ref	ref	ref
	2	1.01	0.98 – 1.04	1.03	1.00 – 1.07
	3	1.02	0.99 – 1.06	1.02	0.98 – 1.06
	4	1.03	0.99 – 1.08	1.06	1.01 – 1.12
	5 (highest)	1.08	1.02 – 1.15	1.09	1.02 – 1.16
Overcrowded homes	1 (lowest)	ref	ref	ref	ref
	2	1.02	0.99 – 1.05	1.01	0.98 – 1.05
	3	1.03	0.99 – 1.07	1.02	0.97 – 1.06
	4	1.07	1.02 – 1.12	1.02	0.97 – 1.07
	5 (highest)	1.12	1.05 – 1.20	1.06	0.99 – 1.13
NO₂	1 (lowest)	ref	ref	ref	ref
	2	1.01	0.97 – 1.05	1.02	0.98 – 1.05
	3	1.02	0.97 – 1.07	1.00	0.95 – 1.05
	4	1.00	0.95 – 1.06	1.03	0.97 – 1.10
	5 (highest)	1.02	0.95 – 1.09	1.05	0.97 – 1.12
PM_{2.5}	1 (lowest)	ref	ref	ref	ref
	2	1.00	0.96 – 1.05	0.99	0.95 – 1.04
	3	1.03	0.97 – 1.09	0.98	0.92 – 1.04
	4	1.02	0.95 – 1.10	0.98	0.91 – 1.05
	5 (highest)	1.07	0.98 – 1.17	1.02	0.93 – 1.11
Care homes per 1,000 population	1 (lowest)	ref	ref	ref	ref
	2	1.09	1.06 – 1.12	1.12	1.08 – 1.16
	3	1.13	1.09 – 1.16	1.19	1.15 – 1.22
	4	1.15	1.12 – 1.18	1.22	1.19 – 1.26
	5 (highest)	1.21	1.18 – 1.25	1.27	1.23 – 1.31
% of variation contributed by all variables		18.2	15.0 – 21.8	15.3	12.8 – 18.2
% of variance explained by local clustering for model with all variables		31.4	28.7 – 34.2	19.2	17.2 – 21.3
% of variance explained by local clustering for model with no variables		40.4	37.6 – 42.4	22.3	20.5 – 23.9

Supplementary Table 7. Mutually adjusted multivariable models for all MSOA characteristics, results of sensitivity analyses. Age is included in all the models.

a) Penalised complexity prior.

Variable	Quintile	Males		Females	
		Mean	95% credible interval	Mean	95% credible interval
Population on income support	1 (lowest)	ref	ref	ref	ref
	2	1.02	0.99 – 1.05	0.97	0.94 – 1.00
	3	1.04	1.01 – 1.08	0.99	0.96 – 1.03
	4	1.07	1.03 – 1.12	1.00	0.97 – 1.06
	5 (highest)	1.11	1.06 – 1.16	1.09	1.03 – 1.14
Population density	1 (lowest)	ref	ref	ref	ref
	2	1.02	0.99 – 1.05	1.01	0.98 – 1.05
	3	1.01	0.98 – 1.06	1.00	0.96 – 1.04
	4	0.99	0.96 – 1.03	1.03	0.98 – 1.07
	5 (highest)	0.99	0.95 – 1.04	1.00	0.95 – 1.05
Population non-White	1 (lowest)	ref	ref	ref	ref
	2	1.01	0.98 – 1.04	1.03	1.00 – 1.07
	3	1.02	0.99 – 1.06	1.02	0.98 – 1.06
	4	1.03	0.99 – 1.08	1.07	1.02 – 1.12
	5 (highest)	1.08	1.02 – 1.15	1.10	1.03 – 1.17
Overcrowded homes	1 (lowest)	ref	ref	ref	ref
	2	1.02	0.99 – 1.05	1.01	0.98 – 1.05
	3	1.03	0.99 – 1.07	1.02	0.98 – 1.06
	4	1.07	1.02 – 1.12	1.02	0.97 – 1.07
	5 (highest)	1.12	1.05 – 1.20	1.06	0.99 – 1.14
NO₂	1 (lowest)	ref	ref	ref	ref
	2	1.01	0.97 – 1.05	1.02	0.98 – 1.06
	3	1.02	0.98 – 1.07	1.00	0.96 – 1.05
	4	1.01	0.95 – 1.06	1.03	0.98 – 1.09
	5 (highest)	1.02	0.95 – 1.09	1.05	0.98 – 1.13
PM_{2.5}	1 (lowest)	ref	ref	ref	ref
	2	1.00	0.96 – 1.05	0.99	0.95 – 1.04
	3	1.03	0.97 – 1.09	0.98	0.93 – 1.04
	4	1.02	0.95 – 1.09	0.98	0.91 – 1.05
	5 (highest)	1.07	0.98 – 1.17	1.02	0.93 – 1.12
Care homes per 1,000 population	1 (lowest)	ref	ref	ref	ref
	2	1.09	1.06 – 1.12	1.12	1.08 – 1.16
	3	1.13	1.10 – 1.17	1.18	1.15 – 1.22
	4	1.15	1.12 – 1.18	1.22	1.18 – 1.26
	5 (highest)	1.21	1.18 – 1.25	1.27	1.23 – 1.31
% of variation contributed by all variables		18.8	15.0 – 23.3	15.9	12.9 – 19.2

b) Priors on the hyperparameters τ_v and τ_u : $\log\text{Gamma}(0.5, 0.05)$.

Variable	Quintile	Males		Females	
		Mean	95% credible interval	Mean	95% credible interval
Population on income support	1 (lowest)	ref	ref	ref	ref
	2	1.02	0.99 – 1.05	0.97	0.94 – 1.00
	3	1.04	1.01 – 1.08	0.99	0.96 – 1.03
	4	1.07	1.03 – 1.12	1.01	0.97 – 1.06
	5 (highest)	1.11	1.06 – 1.17	1.09	1.03 – 1.14
Population density	1 (lowest)	ref	ref	ref	ref
	2	1.02	0.99 – 1.05	1.01	0.98 – 1.05
	3	1.01	0.98 – 1.06	1.00	0.96 – 1.03
	4	0.99	0.95 – 1.03	1.03	0.98 – 1.07
	5 (highest)	0.99	0.95 – 1.04	1.00	0.95 – 1.05
Population non-White	1 (lowest)	ref	ref	ref	ref
	2	1.01	0.98 – 1.04	1.03	1.00 – 1.07
	3	1.02	0.99 – 1.06	1.02	0.98 – 1.06
	4	1.03	0.99 – 1.08	1.06	1.01 – 1.12
	5 (highest)	1.08	1.02 – 1.15	1.09	1.03 – 1.16
Overcrowded homes	1 (lowest)	ref	ref	ref	ref
	2	1.02	0.99 – 1.05	1.01	0.98 – 1.05
	3	1.03	0.99 – 1.07	1.02	0.98 – 1.06
	4	1.07	1.02 – 1.12	1.02	0.97 – 1.08
	5 (highest)	1.12	1.05 – 1.20	1.06	0.99 – 1.14
NO₂	1 (lowest)	ref	ref	ref	ref
	2	1.01	0.97 – 1.04	1.02	0.98 – 1.05
	3	1.02	0.97 – 1.06	1.00	0.96 – 1.05
	4	1.00	0.95 – 1.06	1.03	0.97 – 1.09
	5 (highest)	1.02	0.95 – 1.09	1.05	0.97 – 1.12
PM_{2.5}	1 (lowest)	ref	ref	ref	ref
	2	1.00	0.96 – 1.05	0.99	0.95 – 1.04
	3	1.03	0.97 – 1.09	0.98	0.92 – 1.04
	4	1.02	0.95 – 1.10	0.98	0.91 – 1.05
	5 (highest)	1.08	0.98 – 1.17	1.02	0.93 – 1.12
Care homes per 1,000 population	1 (lowest)	ref	ref	ref	ref
	2	1.09	1.06 – 1.12	1.12	1.08 – 1.16
	3	1.13	1.09 – 1.16	1.18	1.15 – 1.22
	4	1.15	1.12 – 1.18	1.22	1.19 – 1.26
	5 (highest)	1.21	1.18 – 1.25	1.27	1.23 – 1.31
% of variation contributed by all variables		18.6	14.8 – 23.1	15.8	12.8 – 19.0

c) Excluding care homes per 1,000 population

Variables	Quintile	Males		Females	
		Mean	95% credible interval	Mean	95% credible interval
Population on income support	1 (lowest)	ref	ref	ref	ref
	2	1.03	1.00 – 1.06	0.98	0.95 – 1.02
	3	1.06	1.02 – 1.10	1.01	0.97 – 1.05
	4	1.09	1.05 – 1.14	1.03	0.99 – 1.08
	5 (highest)	1.13	1.08 – 1.19	1.10	1.05 – 1.17
Population density	1 (lowest)	Ref	ref	ref	ref
	2	1.02	0.99 – 1.05	1.01	0.98 – 1.05
	3	1.01	0.98 – 1.05	0.99	0.95 – 1.03
	4	0.98	0.94 – 1.03	1.01	0.97 – 1.06
	5 (highest)	0.98	0.94 – 1.03	0.99	0.94 – 1.04
Population non-White	1 (lowest)	ref	Ref	ref	ref
	2	1.02	0.99 – 1.05	1.04	1.00 – 1.07
	3	1.03	1.00 – 1.07	1.03	0.99 – 1.07
	4	1.05	1.00 – 1.11	1.08	1.03 – 1.13
	5 (highest)	1.10	1.04 – 1.17	1.11	1.04 – 1.19
Overcrowded homes	1 (lowest)	ref	ref	ref	ref
	2	1.02	0.98 – 1.05	1.01	0.98 – 1.05
	3	1.02	0.98 – 1.06	1.01	0.97 – 1.06
	4	1.06	1.01 – 1.11	1.01	0.96 – 1.06
	5 (highest)	1.10	1.03 – 1.17	1.03	0.96 – 1.11
NO₂	1 (lowest)	ref	ref	ref	ref
	2	1.01	0.97 – 1.04	1.02	0.98 – 1.05
	3	1.01	0.97 – 1.06	0.99	0.95 – 1.04
	4	1.00	0.95 – 1.06	1.03	0.97 – 1.09
	5 (highest)	1.0	0.94 – 1.08	1.04	0.96 – 1.11
PM_{2.5}	1 (lowest)	ref	ref	ref	ref
	2	1.00	0.96 – 1.05	0.99	0.95 – 1.03
	3	1.02	0.96 – 1.08	0.97	0.91 – 1.02
	4	1.00	0.93 – 1.07	0.96	0.89 – 1.03
	5 (highest)	1.04	0.95 – 1.13	0.98	0.89 – 1.08
% of variation contributed by all variables		13.7	10.1 – 17.9	8.46	5.91 – 11.4

d) Excluding care homes per 1,000 population and deaths in care homes

Covariate	Quintile	Males		Females	
		Mean	95% credible interval	Mean	95% credible interval
Population on income support	1 (lowest)	ref	ref	ref	ref
	2	1.05	1.02 – 1.09	1.02	0.99 – 1.06
	3	1.09	1.05 – 1.13	1.08	1.04 – 1.13
	4	1.13	1.08 – 1.18	1.14	1.09 – 1.20
	5 (highest)	1.19	1.14 – 1.25	1.25	1.18 – 1.32
Population density	1 (lowest)	ref	ref	ref	ref
	2	1.01	0.98 – 1.05	1.03	0.99 – 1.06
	3	1.01	0.97 – 1.05	1.02	0.98 – 1.06
	4	0.97	0.93 – 1.01	1.03	0.98 – 1.08
	5 (highest)	0.97	0.92 – 1.02	0.99	0.94 – 1.05
Population non-White	1 (lowest)	ref	ref	ref	ref
	2	1.00	0.97 – 1.03	1.01	0.98 – 1.05
	3	0.99	0.96 – 1.03	0.98	0.94 – 1.02
	4	0.99	0.95 – 1.04	1.03	0.98 – 1.09
	5 (highest)	1.06	0.99 – 1.13	1.05	0.98 – 1.12
Overcrowded homes	1 (lowest)	ref	ref	ref	ref
	2	1.02	0.98 – 1.05	1.02	0.99 – 1.06
	3	1.03	0.99 – 1.07	1.00	0.96 – 1.04
	4	1.07	1.02 – 1.12	1.02	0.96 – 1.07
	5 (highest)	1.12	1.04 – 1.19	1.07	0.99 – 1.15
NO₂	1 (lowest)	ref	ref	ref	ref
	2	1.01	0.97 – 1.05	0.98	0.95 – 1.02
	3	1.02	0.97 – 1.07	0.97	0.92 – 1.02
	4	1.01	0.95 – 1.07	0.99	0.94 – 1.05
	5 (highest)	1.04	0.97 – 1.11	1.02	0.94 – 1.10
PM_{2.5}	1 (lowest)	ref	ref	ref	ref
	2	1.01	0.96 – 1.05	0.98	0.94 – 1.03
	3	1.02	0.96 – 1.08	0.96	0.90 – 1.02
	4	1.02	0.95 – 1.10	0.96	0.89 – 1.04
	5 (highest)	1.06	0.96 – 1.16	0.98	0.88 – 1.08
% of variation contributed by all variables		21.8	16.7 – 27.7	25.2	19.6 – 31.5

e) Both sexes combined

Variables	Quintile	Mean	95% credible interval
Population on income support	1 (lowest)	ref	ref
	2	0.99	0.97 – 1.02
	3	1.01	0.98 – 1.04
	4	1.03	1.00 – 1.06
	5 (highest)	1.07	1.03 – 1.11
Population density	1 (lowest)	ref	ref
	2	1.02	0.99 – 1.04
	3	1.01	0.98 – 1.04
	4	1.01	0.98 – 1.04
	5 (highest)	1.00	0.96 – 1.04
Population non-White	1 (lowest)	ref	ref
	2	1.02	0.99 – 1.04
	3	1.02	0.99 – 1.05
	4	1.05	1.01 – 1.09
	5 (highest)	1.09	1.04 – 1.14
Overcrowded homes	1 (lowest)	ref	ref
	2	1.01	0.98 – 1.03
	3	1.01	0.98 – 1.04
	4	1.02	0.98 – 1.06
	5 (highest)	1.06	1.00 – 1.11
NO₂	1 (lowest)	ref	ref
	2	1.01	0.98 – 1.04
	3	1.01	0.98 – 1.05
	4	1.02	0.97 – 1.06
	5 (highest)	1.03	0.97 – 1.09
PM_{2.5}	1 (lowest)	ref	ref
	2	1.00	0.96 – 1.03
	3	1.00	0.95 – 1.05
	4	0.99	0.94 – 1.05
	5 (highest)	1.03	0.96 – 1.11
Care homes per 1,000 population	1 (lowest)	ref	ref
	2	1.09	1.06 – 1.12
	3	1.13	1.11 – 1.16
	4	1.16	1.13 – 1.18
	5 (highest)	1.20	1.18 – 1.23
% of variation contributed by all variables		14.3	11.6 – 17.5

Supplementary Table 8. Pearson's product moment correlation, excess deaths across MSOAs by numbers of samples.

a) Males

Stage1, Stage 2	20,20	50,50	50,100	100,100
50,50	0.99495			
50,100	0.99491	0.99995		
100,100	0.99329	0.99842	0.99847	
200,200	0.99246	0.99764	0.99758	0.99922

b) Females

Stage1, Stage 2	20,20	50,50	50,100	100,100
50,50	0.99494			
50,100	0.99491	0.99996		
100,100	0.99354	0.99857	0.99862	
200,200	0.99275	0.99777	0.99782	0.99926

Supplementary Table 9. Mean absolute difference in excess deaths across MSOAs by numbers of samples.

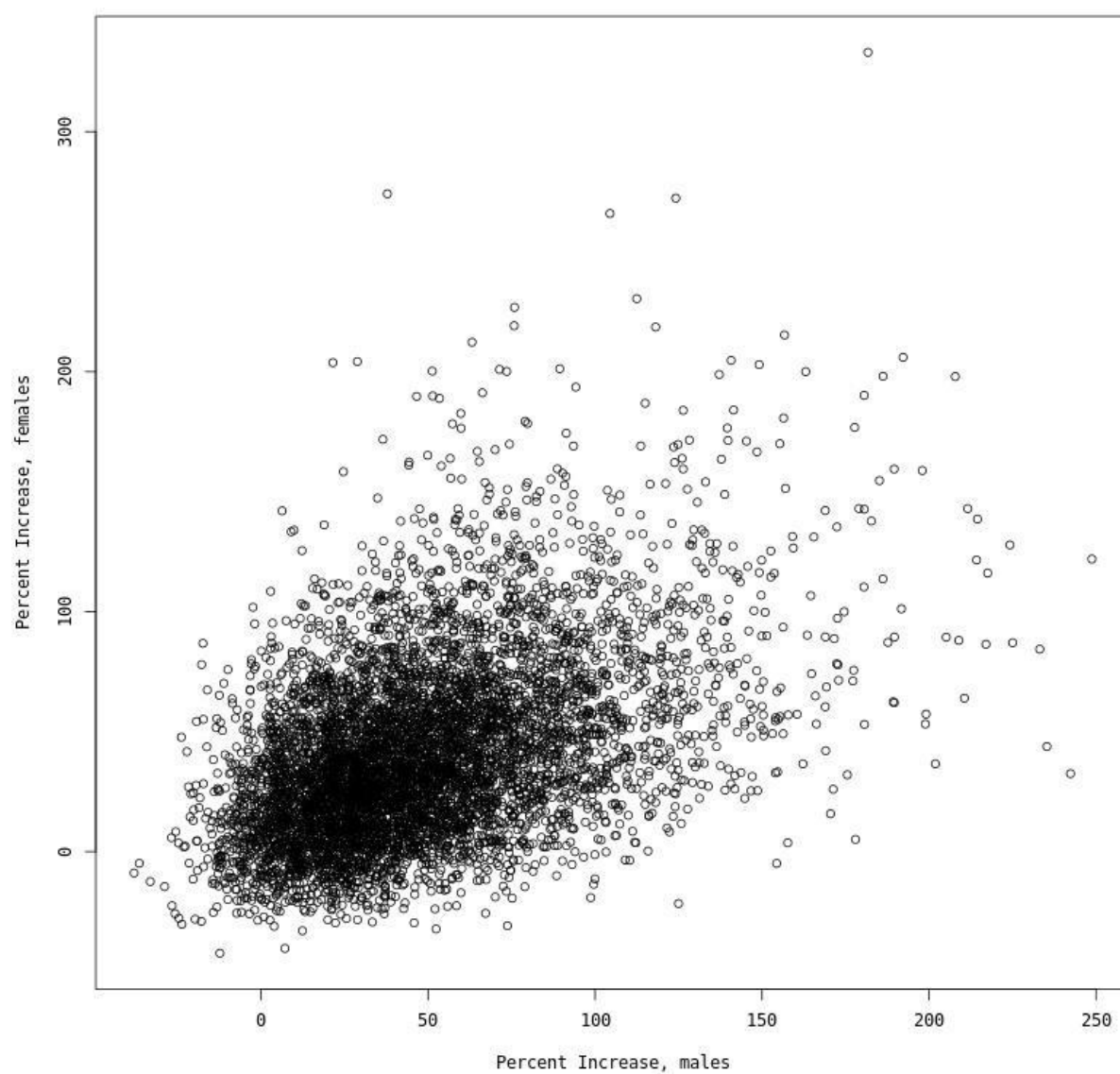
a) Males

Stage1, Stage 2	20,20	50,50	50,100	100,100
50,50	0.240			
50,100	0.241	0.0244		
100,100	0.276	0.135	0.133	
200,200	0.294	0.165	0.163	0.0941

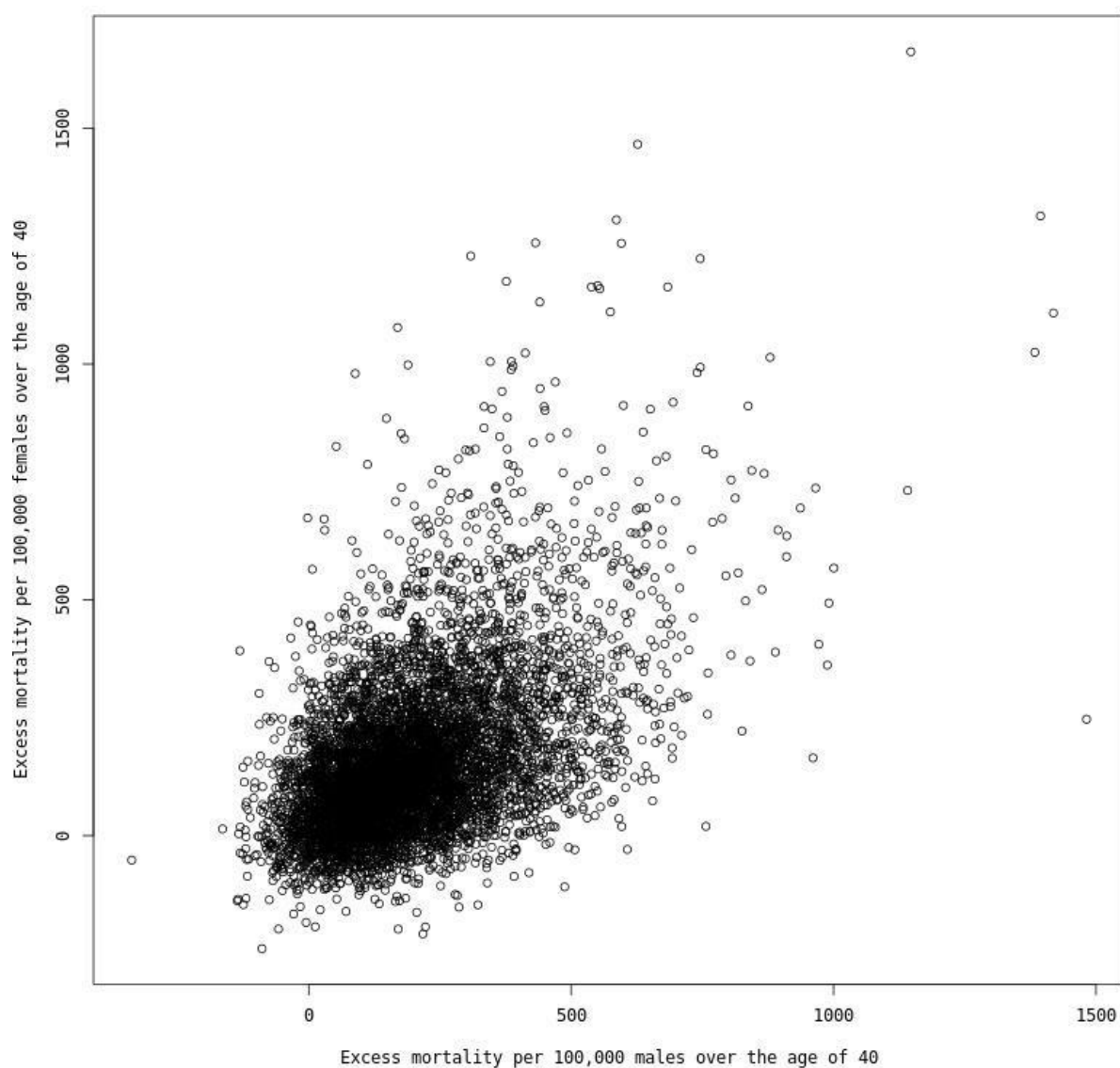
b) Females

Stage1, Stage 2	20,20	50,50	50,100	100,100
50,50	0.277			
50,100	0.278	0.0262		
100,100	0.314	0.150	0.147	
200,200	0.334	0.187	0.185	0.107

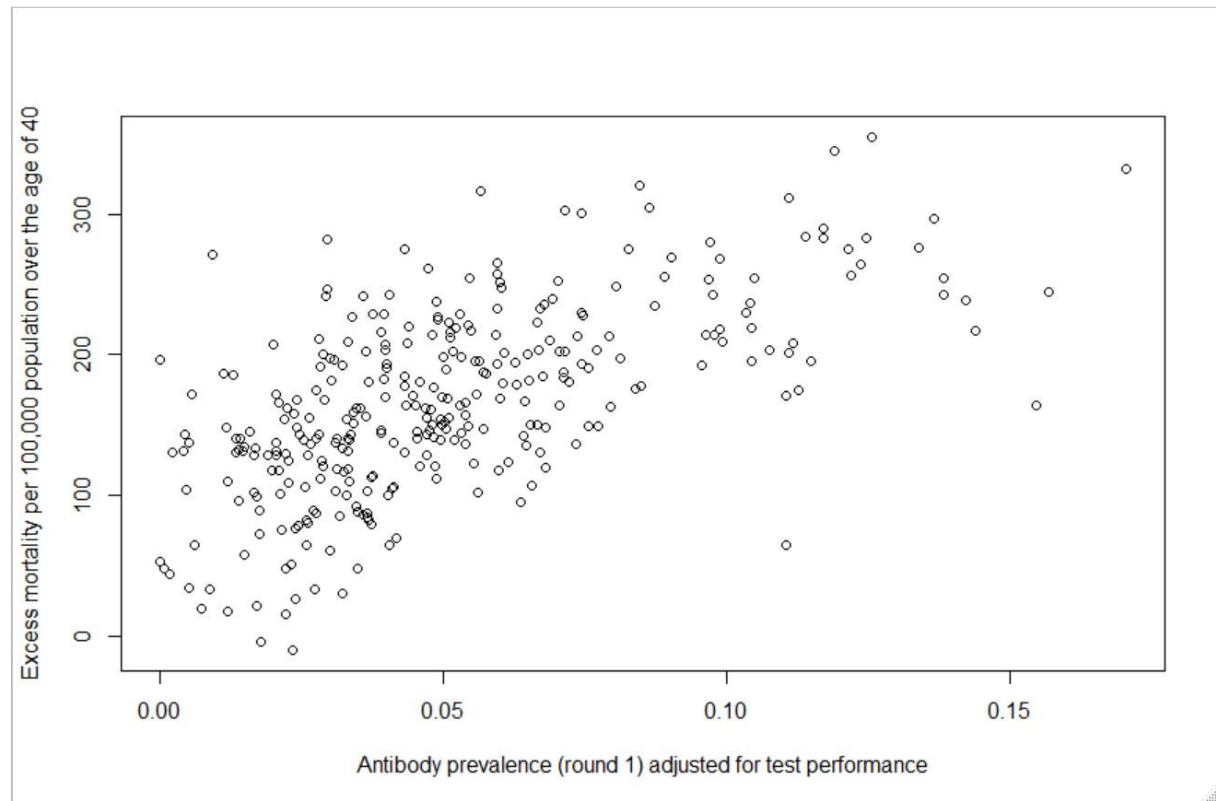
Supplementary Fig. 1. Scatter plot showing male vs female percent increase in deaths age 40 and over for 6,701 Middle Super Output Areas in England. Spearman's rank correlation coefficient 0.44



Supplementary Fig. 2. Scatter plot showing male vs female excess mortality rate per 100,000 males/females age 40 and over for 6,701 Middle Super Output Areas in England. Spearman's rank correlation coefficient 0.45



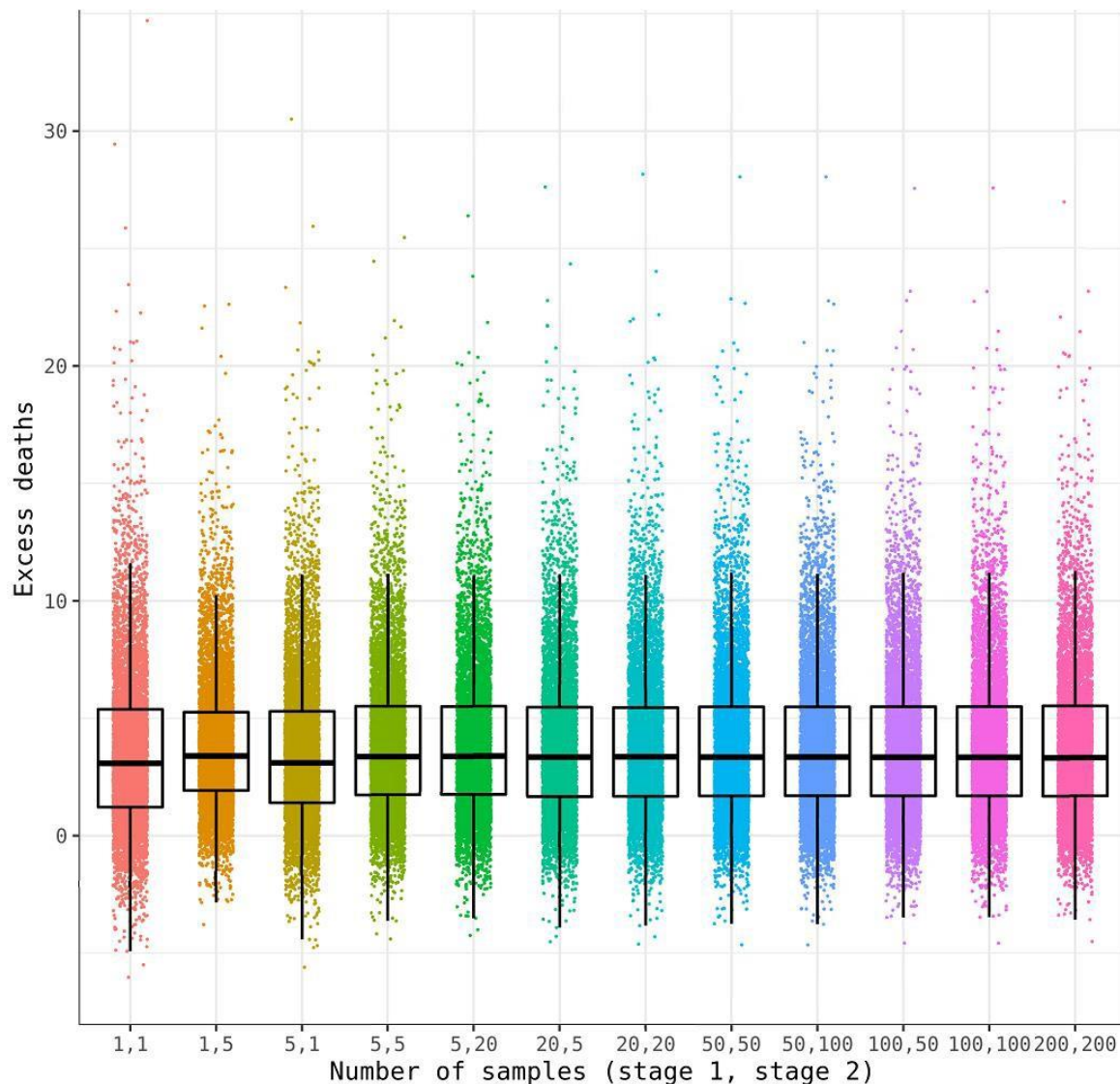
Supplementary Fig. 3. Plot of the excess mortality rate (excess deaths per 100,000 population over the age of 40, both sexes combined) against the sero-prevalence rates from REACT 2 study (round 1, June 20th – July 13th 2020, Ward et al., 2021¹) at Lower Tier Local Authority level (n = 317). Spearman's rank correlation 0.501. R-squared 0.391



¹ Ward H, Atchison C, Whitaker M, Ainslie KEC, Elliott J, Okell L, Redd R, Ashby D, Donnelly C, Barclay W, Darzi A, Cooke G, Riley S, Elliott P. SARS-CoV-2 antibody prevalence in England following the first peak of the pandemic. *Nat Commun* 12, 905 (2021). <https://doi.org/10.1038/s41467-021-21237-w>

Supplementary Fig. 4. Box plots with scatter showing how excess deaths varies with numbers of samples used in stage 1 and stage 2 of model. Data are presented as scatter plots showing posterior mean excess mortality for MSOAs (n= 6,791 MSOAs) with box and whiskers plot superimposed showing, for excess mortality across MSOAs: median (centre line); interquartile range (IQR, 25th to 75th percentiles) (bounds of box); largest value no further than 1.5 * IQR from the box (top of upper whisker); and smallest value no further than 1.5*IQR from the box (bottom of lower whisker). (A) Excess mortality in males; (B) Excess mortality in females.

A). Males



B) Females

