

The distributional impact of Covid-19

Author(s): Richard Breen and John Ermisch

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Research Article

The distributional impact of Covid-19: Geographic variation in mortality in England

Richard Breen

John Ermisch

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The distributional impact of Covid-19: Geographic variation in mortality in England

Richard Breen¹

John Ermisch²

Abstract

BACKGROUND

By their nature, the impact of epidemics on mortality varies geographically, suggesting that the geographical impact of an epidemic implies a social impact.

OBJECTIVE

To examine the association between two measures of the social composition of a local area and age- and sex-standardised Covid-19 and other mortality in the period 1 March to 31 July 2020. The measures are how deprived an area is and what proportion of its population is non-white.

METHODS

Using spatial autoregressive regression we analyse geographical variation in age- and sex-standardised Covid-19 mortality among English local authorities between 1 March and 31 July 2020 in relation to measures of social composition, and we compare it with mortality from non-Covid sources in the same period, and with all-causes mortality in 2018.

RESULTS

Areas with higher social deprivation have a higher Covid-19 mortality rate, but the association is much weaker than between social deprivation and mortality rates more generally. An area's proportion non-white has a strong positive association with Covid-19 mortality, in contrast to a negative association with 2020 non-Covid and with 2018 mortality.

CONCLUSIONS

Covid-19 mortality is related to the social composition of areas in different ways than current non-Covid mortality or past mortality.

¹ Department of Sociology and Nuffield College, University of Oxford UK.

² Leverhulme Centre for Demographic Science and Nuffield College, University of Oxford, UK.
Email: john.ermisch@sociology.ox.ac.uk.

CONTRIBUTION

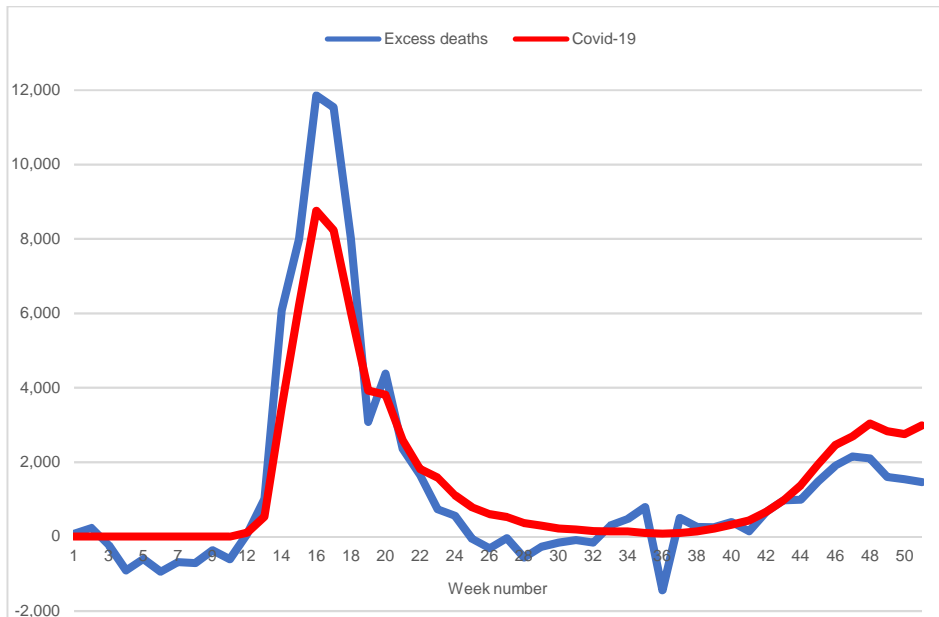
The paper provides the first demonstration of the distinct distributional impact of mortality in relation to the Covid-19 virus by the social composition of areas in England.

1. Introduction

By their nature, the impact of epidemics on mortality varies geographically. This variation often arises from differences in social composition, meaning that the geographical impact of an epidemic implies a social impact. In this paper we analyse geographical variation in Covid-19 mortality in England between 1 March and 31 July 2020. In particular, we focus on the first wave of the English epidemic between 1 March and 31 May 2020 and compare Covid-19 mortality with mortality from non-Covid sources in the same period, and with all-causes mortality in 2018. We focus on two main measures of social composition: how deprived an area is and what proportion of its population is non-white. We also explore the extent to which the geographic variation in Covid-19 mortality is related to the distribution of residential care homes in England, in which Covid-19 mortality was high. Although we provide a parametric structure in which to interpret our spatial regressions, this is a correlational study and the word ‘effect’ should not be interpreted in a causal sense.

Figure 1 illustrates the temporal nature of pandemic mortality in England and Wales. It indicates that Covid-19 mortality was particularly concentrated in April and May, after which it tailed off and remained low until mid-October (week 42), when the ‘second wave’ of the pandemic began to emerge. Indeed, 82% of Covid-19 mortality in England from 1 March to 31 July occurred in these two months, with 9% being in March (all of that after the 13 March), 7% in June, and 2% in July. For this reason, we focus on mortality in the 1 March to 31 May period.³

³ Not only was this 2-month period the major contributor to Covid-19 mortality, but many local geographic areas lack reliable ONS estimates of Covid-19 standardised death rates in the months of March, June, or July, because of few deaths in some areas. For instance, in June (July) there were 3,207 (1,052) Covid-19 deaths spread across 306 Local Authority areas. At present, the geographically disaggregated mortality data is only available until the end of July, but Figure 1 indicates that Covid-19 deaths were very low during August and September. Appendix Table 2 shows estimates of our model for the entire 1 March to 31 July period and for June and July aggregated together.

Figure 1: Weekly excess deaths and Covid-19 deaths, England and Wales^a

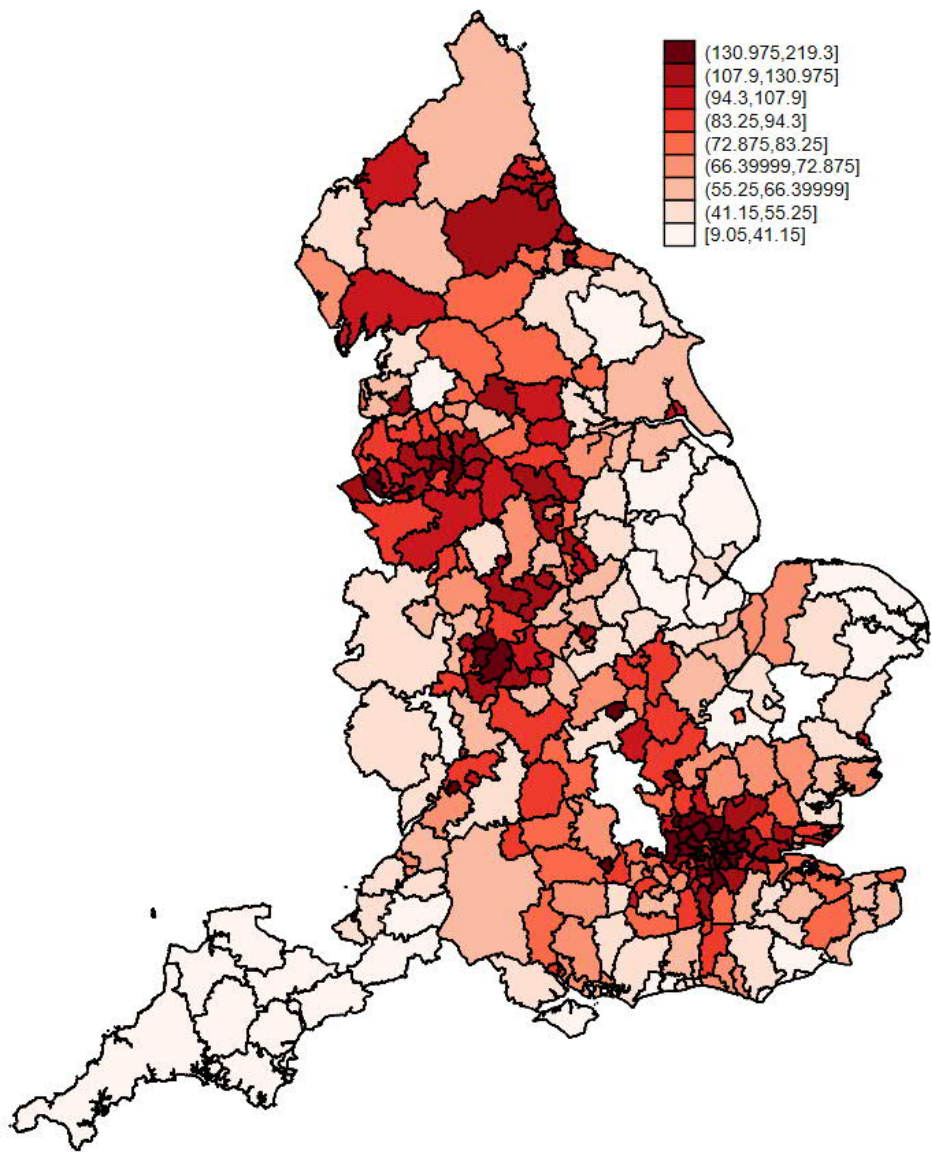
Note: ^a Excess calculated as difference between weekly deaths and the average for that week during 2015–2019.

Source: <https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/datasets/weeklyprovisionalfiguresondeathsregisteredinenglandandwales>.

For comparison, Figure 1 also shows ‘excess mortality’ during the pandemic, defined as the difference between a week’s mortality and the average for that week in the previous 5 years. Excess mortality turned negative in the second half of June and remained so until the end of July: during the period 4 July to 31 July, excess deaths in England and Wales were 2.5% below average deaths during 2015–2019. During the entire period from 1 March to 18 December the correlation coefficient between weekly excess deaths and Covid-19 deaths is 0.958, which suggests that deaths labelled as Covid-19 at death certification are a good indicator of variation in all mortality associated with the 2020 Covid-19 pandemic.

Figure 2 shows the geographical variation in Covid-19 mortality rates standardised by age and sex across 306 English Local Authority areas. Rates are noticeably high around London and in the north-west. Covid-19 mortality rates per 100,000 are lowest in rural areas such as Mid-Devon (15.3), and highest in London boroughs such as Newham (204.3) and Brent (219.3).

Figure 2: Covid-19 age- and sex-standardised mortality rate, 1 March–31 May 2020



Source: Authors' map generated by STATA 15

In this study we find that age- and sex-standardised death rates from Covid-19 in English local authority areas depend strongly on their rates of infection, but even allowing for this, death rates are higher in areas of higher population density. After controlling for population density but not infection rates, the relationship between higher social deprivation and the Covid-19 mortality rate is much weaker than the relationship between social deprivation and mortality rates more generally, including non-Covid mortality in 2020, pointing to the distinctiveness of the distributional impact of Covid-19. Most strikingly, the proportion of an area's population that is non-white has a large positive association with age- and sex-standardised Covid-19 mortality, in contrast to a negative association with 2020 non-Covid mortality and with 2018 mortality. We also find a positive spillover from Covid-19 mortality in neighbouring areas to an area's Covid-19 mortality, which contrasts with the virtual absence of spatial spillover in 2018 mortality and non-Covid 2020 mortality. We find no evidence that the distribution of residential care homes across England accounted for higher Covid-19 mortality in some areas than others. In addition, we find that more dense local areas had a more peaked mortality profile during the English epidemic and that there was a slower immediate post-peak decline in mortality in more socially deprived areas, and a sharper decline in areas with a larger non-white population.

2. Modelling geographic variation in Covid-19 mortality in England

Geographical variation in how many people die from an infection depends on how many people become infected and how many of the infected die. The latter is the 'case fatality rate', defined as the ratio of deaths from a disease to the infected population. Infection rates and case fatality rates will both depend on local circumstances such as the age distribution and health of the population, hospital capacity, living arrangements, etc. The geographic variation in mortality often entails social inequality because of the social composition of different areas. In analysing Covid-19 deaths we begin by taking the infection rate as given and focus on factors shaping the case fatality rate. Later we look in more detail at the infection rate.

The case fatality rate (cfr) for Covid-19 is defined as the ratio of deaths from the disease to the infected population. Letting D_c denote deaths from Covid-19 in an area, I_c the number of people infected, and Pop the area's total population, we have

$$cfr = \frac{D_c}{I_c} = \frac{D_c/Pop}{I_c/Pop}$$

It follows that

$$\frac{D_c}{Pop} = cfr \cdot \left(\frac{I_c}{Pop} \right)$$

This implies

$$\ln \left(\frac{D_c}{Pop} \right) = \ln(cfr) + \ln \left(\frac{I_c}{Pop} \right)$$

We cannot directly observe the infected population, but we know the number of confirmed Covid-19 cases, C , a very imperfect measure of infection in the local area because of limited testing during the first wave of the epidemic. We assume that the infected population is a log-linear function of reported cases in an area plus the influence of infection in neighbouring areas:

$$\ln \left(\frac{I_c}{Pop} \right) = \alpha_0 + \alpha_1 \ln \left(\frac{C}{Pop} \right) + \lambda W \ln \left(\frac{I_c^n}{Pop^n} \right) + e$$

where W is a spatial weighting matrix, $\ln \frac{I_c^n}{Pop^n}$ is a vector of (unobserved) logged infection rates in neighbouring areas, λ is a spatial spillover parameter, and e is a random variable.

It is plausible to assume that the case fatality rate in an area depends on characteristics of the local area, such as its socioeconomic composition:

$$\ln(cfr) = \beta_0 + \sum_{i=1}^k \beta_i X_i + u$$

The X s are characteristics of areas, and the random disturbance u also reflects errors in measuring the cfr at the local area level.

Note that the vector of logged infection rates in neighbouring areas can be expressed as:

$$\ln \left(\frac{I_c^n}{Pop^n} \right) = \ln \left(\frac{D_c^n}{Pop^n} \right) - \ln(cfr^n) = \ln \left(\frac{D_c^n}{Pop^n} \right) - \beta_0 - X^n \beta - u^n$$

where X^n is an $n \times k$ matrix of attributes of neighbouring areas, β is a conformable vector of coefficients, and u^n are residual influences on cfr in neighbouring areas. After substitution, we obtain our main estimation equation:

$$\ln\left(\frac{D_c}{Pop}\right) = \alpha_1 \ln\left(\frac{C}{Pop}\right) + \sum_i \beta_i X_i + \lambda W \ln\left(\frac{D_c}{Pop}\right)^n + \alpha_0 + \beta_0 + u + e - \rho W u^n + \varepsilon$$

where we have omitted the influence of X_i in neighbouring areas which would otherwise arise from substituting the logged infection rate equation for neighbouring areas in the equation for $\ln\left(\frac{D_c}{Pop}\right)$ (i.e., $-\lambda W X^n \beta$), and we ignored the constraint that $\lambda = \rho$ according to the model. In practice it is often difficult to estimate both λ and ρ with precision, and we will focus on a model with λ only because the estimates of β_i are virtually unaffected.⁴ Here $u + e$ is a compound error term and $\alpha_0 + \beta_0$ is the intercept.⁵ We use a spatial weighting matrix W based on contiguity of areas. The Moran test for spatial dependence produces p-values of 0.0000 for all the infection and mortality variables analysed.

3. Variables and data

Our measure of $\frac{D_c}{Pop}$ is the age- and sex-standardised Covid-19 mortality rate by local authority areas (LAs for short).⁶ In our main analysis, these are computed for deaths occurring between 1st March 2020 and 31 May 2020, distinguishing Covid-19 deaths from other deaths. Our analysis initially focuses on 135 English upper tier local authorities (unitary authorities, metropolitan districts, counties, and London boroughs) for which we also have data on confirmed Covid-19 cases and social deprivation measures, but we later expand this to 306 local authority districts. ‘Confirmed cases’ are the cumulative number in each local authority up to 31 May: this includes positive tests

⁴ In every equation we estimate, the estimates of the β_i parameters are very similar in the specification with only the ‘spatially lagged dependent variable’ and in the model with both it and residual spatial autocorrelation. Also, model selection based on pseudo- R^2 favours the model with the ‘spatially lagged dependent variable’ only. Furthermore, for the β_i parameters estimated with a decent degree of precision, estimation of a model which also includes $\lambda W X^n \beta$ produces only small changes in the estimates of β_i .

⁵ Correlation between measurement errors in infection and area social composition amounts to assuming that e in the equation for infections is correlated with the X_i variables, which of course leads to inconsistent parameter estimates of the model as specified.

⁶ Age-standardised mortality rates for each sex are standardised to the 2013 European Standard Population. They allow for differences in the age structure of populations and therefore allow valid comparisons to be made between geographical areas, the sexes, and over time. Table 2 of the UK Office of National Statistics (ONS) publication *Deaths Involving COVID-19 By Local Area and Deprivation: Deaths Occurring Between 1 March And 31 July 2020 In England And Wales* (28 August 2020) indicates the confidence intervals around the estimates. <https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/bulletins/deathsinvolvedcovid19bylocalareasanddeprivation/deathsoccurringbetween1marchand31july2020>. The mortality data is provisional based on registrations up to 31 July 2020, and could be revised in subsequent weeks.

in the community as well as in hospitals. Infection data in the recent September–October surge in infections during which wider testing occurred suggests that actual infection during March–April was an order of magnitude higher than the confirmed case data indicate. Cases are converted to $\frac{C}{Pop}$ using the latest (mid-2018) local authority population estimates, and population density is computed using the same population estimates. The correlation between the LA's age- and sex-standardised Covid-19 mortality rate per 100,000 population and the LA's confirmed cases per 1000 population is 0.6.

Our primary variables for the measure of the socioeconomic composition of an area are the Office of National Statistics' (ONS) indices of an area's relative deprivation, measured pre-pandemic in 2019. (<https://www.gov.uk/government/statistics/english-indices-of-deprivation-2019>). Higher values indicate more deprivation in an area.⁷ We also include the proportion of the LA population who are non-white, based on population estimates by ONS for 2016. (<https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/populationcharacteristicsresearchtables>). The mean proportion non-white in our larger sample is 0.11 (SD = 0.13). Many, but not all, of the large values are in London; six non-London LAs, including Leicester, Birmingham, and Manchester, have proportions larger than 0.30, compared with 25 in London. We also include population density as one of our predictors because, as a consequence of unreported infections, the population density of the area may affect measured mortality through an impact of density on infection, even when controlling for reported cases.

At the 2011 Census, about 3% of the population aged 75–84 and 14% of that aged 85 or older were in care homes. During the period of analysis, the cumulative percentage of deaths in care homes rose from 22% in mid-March to 30% in the week ending 15 May, remaining at 29% by the end of May. We obtained information on the number of residential care homes in LA areas from the Elderly Accommodation Counsel's current *Residential Care Home Directory In The UK* (<http://www.housingcare.org/elderly-uk-residential-care-homes.aspx>.) From these numbers we compute the LA's care home density by dividing by its area. This variable enters the analysis at a later stage. Means and standard deviations of all variables are shown in Appendix Table A-1.

4. Covid-19 case fatality rate

We regress the log of the Covid-19 mortality rate on the log of reported cases in the area, the log of an area's deprivation index score, the log of an area's population density, the

⁷ We considered the overall index as well as its health and income components. The three measures are highly correlated, and analyses using the health and income components yielded no new insights concerning mortality.

proportion of the population who are non-white, and the weighted log Covid-19 mortality rate in contiguous areas. According to the model, the parameters associated with these variables are the effects on the log of the case fatality rate. Estimation of the model is carried out by generalised method of moments using the *spregress* commands in Stata 15.1. For the average deprivation score, the parameter estimates for Covid-19 mortality are shown in the first column of Table 1.

Table 1: Estimation results: Age- and sex-standardised mortality per 100,000 (n = 135)

Parameter	1 Covid19 Mortality (se)	2 Other mortality (se)	3 Overall mortality 2018 (se)
α_1	0.59 (0.09)	0.02 (0.02)	0.03 (0.01)
$\beta \ln(\text{ave. score})$	-0.09 (0.06)	0.22 (0.02)	0.24 (0.02)
$\beta \ln(\text{pop. Density})$	0.11 (0.03)	0.02 (0.01)	0.02 (.01)
$\beta \text{ Proportion non-white}$	1.01 (0.22)	-0.19 (0.10)	-0.33 (0.08)
$\lambda W \ln\left(\frac{D}{Pop}\right)^n$	0.04 (0.01)	0.01 (0.01)	0.01 (0.003)
$\alpha_0 + \beta_0$	0.40 (0.42)	4.54 (0.12)	5.93 (0.08)
Pseudo R ²	0.672	0.500	0.698
Wald test of spatial terms, p-value	0.007	0.002	0.012

*se refers to the robust standard error allowing for heteroskedasticity.

The estimate of α_1 is 0.6; this is the elasticity of the case fatality rate with respect to the rate of reported cases in an area. In addition, population density is associated with higher mortality, with an elasticity of 0.1. The elasticity of Covid-19 mortality with respect to the average deprivation score is negative (-0.1), which indicates that less deprived areas have higher Covid-19 death rates.⁸ This finding contrasts with the simple positive bivariate relationship between social deprivation decile and Covid-19 mortality shown in the ONS publication *Deaths Involving COVID-19 By Local Area And Deprivation* (1 May 2020, Figure 7) and replicated below in column 4 of Table 3 for the

⁸ We note again (see footnote 5) that correlation between measurement errors in infection and social composition would affect the interpretation of the parameter estimates.

longer period of this study. Areas with a higher proportion non-white have much higher Covid-19 mortality, which is consistent with analysis of deaths involving COVID-19 by ethnic group for England and Wales in ONS (2020b): “Our statistical modelling shows that a large proportion of the difference in the risk of COVID-19 mortality between ethnic groups can be explained by demographic, geographical and socioeconomic factors, such as where you live or the occupation you’re in. It also found that although specific pre-existing conditions place people at greater risk of COVID-19 mortality generally, it does not explain the remaining ethnic background differences in mortality.” Covid-19 mortality in neighbouring areas is associated with higher Covid-19 mortality in the local authority, but the spillover effect is small.

We can compare the results for the Covid-19 case fatality rate with those in column 2 of Table 1, which shows the impact of the same variables on mortality from causes other than Covid-19 during the 1 March to 31 May 2020 period. More Covid-19 infections increase other mortality, but the elasticity is only 0.02 and imprecisely estimated. In contrast to Covid-19 mortality, more social deprivation in an area markedly increases other mortality (an elasticity of 0.2) but population density only has a small impact. The third column shows the association of the variables with the age-and-sex-standardised all-causes mortality rate in 2018. We chose 2018 because this is a period in which Covid-19 accounted for no deaths and here it plays the role of a robustness check (the 2018 data refers to annual mortality and so the mean of the measure is very different). We include the Covid-19 case rate from 2020 in model 3, even though we know it should not be relevant – and its coefficient is indeed small. As for other mortality in 2020, more social deprivation is linked to higher 2018 mortality with a similar elasticity. For other mortality in 2020 and for mortality in 2018, a higher proportion non-white reduces mortality, and there appears to be no spillover effect to speak of.

5. Infections and mortality

What drives geographical differences in infections? Table 2 shows the impacts of population density, which is likely to influence the spread of infection, infection in neighbouring areas (reported cases), deprivation scores, and the proportion non-white on the log of the confirmed cases per 100,000 people. We compare models with the overall deprivation score or with one of its components, the health deprivation score and the income deprivation score. Population density is a moderately important factor, with more densely populated LAs having a higher infection rate (elasticity = 0.08), but infection is strongly related to the indicators of social deprivation. There is no evidence of a consistent association of infection with the ethnic composition of the population, a result

that is in line with analysis of the ONS COVID infection survey (ONS 2020a), which also found imprecise estimates of the impact of ethnic background on infection.

Table 2: Estimation results: Confirmed cases per 100,000 ('Infection') (N = 135)

Parameter	1	2	3
	Ln cases (se)	Ln cases (se)	Ln cases (se)
ln(population density)	0.08 (0.04)	0.06 (0.04)	0.07 (0.04)
β Proportion non-white	-0.16 (0.29)	0.08 (0.30)	-0.17 (0.29)
$\lambda W \ln \left(\frac{C}{Pop} \right)^n$	0.04 (0.02)	0.03 (0.02)	0.04 (0.02)
β ln(ave. score)	0.26 (0.07)		
β ln(health score)		0.56 (0.13)	
β ln(income score)			0.29 (0.09)
Constant	4.15 (0.23)	4.41 (0.21)	5.62 (0.40)
Pseudo R ²	0.206	0.227	0.208
Wald test of spatial terms, p-value	0.016	0.040	0.017

Note: se refers to the robust standard error allowing for heteroskedasticity.

6. Are the patterns for Covid-19 unusual?

Now we turn to the question of how socioeconomic and ethnic composition affect Covid-19 mortality differently from other mortality. We saw some evidence of this in Table 1, but a cleaner comparison is provided by the estimation of the reduced form of the model (i.e., substituting the infection equation into the mortality equation, thereby eliminating $\frac{C}{Pop}$ from the regression equation). Because we no longer need data on reported cases we can use the larger sample of 306 local authorities (on which Figure 1 is based). The results are shown in Table 3 where we regress the log of the age- and sex-standardised death rates on population density and the local area social composition predictors. Once again, we consider Covid-19 deaths from 1 March to 31 May 2020, non-Covid-19 deaths in the

same period, and all deaths in 2018. Appendix Table 2 shows similar results for the Covid-19 mortality rate during the 5-month period 1 March to 31 July.

Table 3: Estimation results: Mortality per 100,000 (N = 306)

Parameter	1 Covid19 mortality (se)	2 Other mortality (se)	3 Overall mortality 2018 (se)	4 Covid19 mortality (se)	5 Covid19 mortality (se)
$\beta \ln(\text{ave. score})$	0.11 (0.05)	0.23 (0.01)	0.25 (0.01)	0.38 (0.06)	0.13 (0.05)
β Proportion non-white	0.70 (0.19)	-0.27 (0.07)	-0.40 (0.06)		
$\beta \ln(\text{pop. density})$	0.19 (0.03)	0.02 (0.01)	0.02 (0.01)		0.24 (0.02)
$\lambda W \ln \left(\frac{D}{Pop} \right)^n$	0.13 (0.02)	0.015 (0.004)	0.006 (0.002)	0.08 (0.02)	0.14 (0.02)
Intercept	2.23 (0.23)	4.62 (0.06)	6.04 (0.05)	2.94 (0.20)	1.87 (0.17)
Pseudo R ²	0.487	0.441	0.659	0.084	0.473
Wald test of spatial terms, p-value	0.000	0.000	0.006	0.000	0.000

Note: se refers to the robust standard error allowing for heteroskedasticity.

Comparing the results for the three models, four differences are evident. First, the elasticity of the mortality rate with respect to area social deprivation is about 0.25 for both non-Covid mortality and 2018 mortality, but half that size (0.1) for Covid-19 mortality. When we do not control for either population density or proportion non-white (column 4) the Covid elasticity increases to 0.38, indicating that it is the correlations of density and proportion non-white with social deprivation that produces the appearance of a large social deprivation ‘effect’ when the social deprivation index is the only covariate. Second, population density strongly affects Covid-19 mortality but has little impact on other mortality. Third, there is a moderately strong spillover effect from Covid-19 mortality in neighbouring areas on an area’s Covid-19 mortality rate, but only weak effects from neighbouring areas’ mortality on other mortality, either in 2020 or 2018. Column 5 indicates that exclusion of the proportion non-white inflates the estimated association of Covid-19 mortality with density and the estimated spillover effect.

Fourth, there is a clear difference concerning the proportion non-white. For all deaths in 2018 and non-Covid mortality in 2020 this variable has a large negative coefficient, while for Covid mortality it has a very large positive effect. Such an ‘ethnic effect’ on Covid-19 mortality is therefore different from previous mortality experience.

Taken together, Tables 1–3 strongly suggests that the strong impact of the non-white proportion on an area's Covid-19 mortality is through higher mortality among the infected, but not through more infection (Table 2), although caution should be exercised here because the non-white population may have been less likely to be tested. The estimated impacts of population density and social deprivation on Covid-19 mortality in Table 3 are through both more infection and higher mortality among the infected in denser areas.

7. Association of Covid-19 mortality with care home density

We could think of the Covid-19 mortality rate as being a weighted average of the mortality rates for care home residents and others so that $\frac{D_c}{Pop} = (\frac{D_c}{Pop})_0 + s_{ch}[(\frac{D_c}{Pop})_{ch} - (\frac{D_c}{Pop})_0]$, where s_{ch} is the share of resident population in care homes, and $(\frac{D_c}{Pop})_{ch}$ and $(\frac{D_c}{Pop})_0$ are the mortality rates for care home residents and others respectively. If s_{ch} is an increasing function of the density of care homes in the LA, then we would expect Covid-19 mortality in an LA to be higher in LAs with a higher density of care homes. The simple spatial regression in column 1 of Table 4 is consistent with that hypothesis, but adding population density to the model (col. 2) switches the sign on the coefficient of care home density, and that continues to be the case in the full model (col. 3). In the column 1 model, care home density was substituting for population density because population density and care home density are highly correlated: a coefficient of 0.6. Thus, we do not find that controlling for care home density alters our main findings, and its negative association with Covid-19 mortality is difficult to interpret in terms of our original reason for its inclusion in the model.

Table 4: Covid-19 mortality and care home density

Parameter	1 Covid19 mortality (se)	2 Covid19 mortality (se)	3 Covid19 mortality (se)
β care home density	0.66 (0.19)	-0.42 (0.18)	-0.36 (0.18)
β ln(ave. score)			0.12 (0.05)
β Proportion non-white			0.57 (0.18)
β ln(pop. density)		0.28 (0.02)	0.23 (0.03)
$\lambda W \ln\left(\frac{D}{Pop}\right)^n$	0.08 (0.02)	0.12 (0.02)	0.12 (0.02)
Intercept	3.93 (0.09)	2.10 (0.15)	2.06 (0.23)
Pseudo R ²	0.056	0.480	0.500
Wald test of spatial terms, p-value	0.000	0.000	0.000

Note: se refers to the robust standard error allowing for heteroskedasticity.

8. Dynamics of mortality during the pandemic

In this section we break down mortality during the main months of the first wave of the epidemic in England and study how an area's social composition affects monthly mortality. First, we examine the associations of Covid-19 and non-Covid mortality with social and ethnic composition in each of the two main months of the epidemic, April and May. Table 5 shows that the associations during April are similar to those found with the 3-month March-to-May aggregation (cf. Table 3). But during May, Covid-19 mortality rates were more strongly related to social deprivation than in April, and the association with the non-white population changed from positive to negative, which may suggest more vulnerable members of ethnic minorities died during the upsurge in mortality during April.⁹ The model in the third column adds the April Covid-19 mortality rate to the model. Its coefficient indicates considerable persistence in an LA's Covid-19 mortality rate from April to May (and a lower measured impact of population density). By contrast, the associations of social composition with other mortality are relatively stable over April and May, and similar to those in Table 3. Estimates of June–July Covid-19 mortality, the reliability of which is suspect, indicate a negative association with the proportion non-

⁹ The sample is slightly smaller for the May analysis of Covid-19 mortality because of the absence of Covid-19 rate estimates for a few low density LA's.

white and a stronger association with social deprivation than in the March–May period (Appendix Table A-2), which is similar to the May and April comparison.

Table 5: Estimation results: Covid-19 mortality per 100,000 (N = 306)

Parameter	1 Covid April (se)	2 Covid May (se)	3 Covid May (se)	4 Other April (se)	5 Other, May (se)	6 Other May (se)
$\beta \ln(\text{ave. score})$	0.07 (0.05)	0.34 (0.08)	0.32 (0.07)	0.21 (0.02)	0.28 (0.02)	0.21 (0.03)
β Proportion non-white	0.76 (0.20)	-0.72 (0.27)	-1.24 (0.26)	-0.22 (0.11)	-0.41 (0.10)	-0.42 (0.08)
$\beta \ln(\text{pop. density})$	0.21 (0.03)	0.10 (0.04)	-0.02 (0.04)	0.04 (0.01)	-0.02 (0.01)	-0.02 (0.01)
$\beta \ln(\text{April mortality})$			0.57 (0.09)			0.29 (0.06)
$\lambda W \ln \left(\frac{D}{Pop} \right)^n$	0.15 (0.02)	0.16 (0.04)	0.07 (0.04)	0.03 (0.01)	0.00 (0.01)	0.00 (0.01)
Intercept	1.76 (0.24)	0.94 (0.29)	-0.16 (0.03)	3.52 (0.10)	3.47 (0.09)	2.40 (0.25)
Pseudo R ²	0.493	0.111	0.262	0.270	0.366	0.448
Wald test of spatial terms, p-value	0.000	0.000	0.049	0.000	0.701	0.728

Note: se refers to the robust standard error allowing for heteroskedasticity.

Next, we examine the rate of change in the age-and-sex-standardised total mortality rate up to the peak of the first wave of the English epidemic in April and the subsequent rate of decline after the peak in May and June. Analysis of the log total mortality change over each two-month interval is again carried out using a spatial autoregression model with a spatially lagged dependent variable and a spatial weighting matrix based on contiguity of areas. The parameter estimates for population density in Table 6 indicate that higher population density increases the slope of male mortality during the upsurge (March to April) and reduces it after the peak, thereby producing a more peaked mortality profile. This result is consistent with predictions of the spatial SIR model of Bisin and Moro (2020). There is also evidence of a slower immediate post-peak decline in mortality in more socially deprived areas, and a sharper decline in areas with a larger non-white population. Similar results obtain for female mortality change. The May to June change of mortality is not associated with any of these variables, the only systematic element being spatial autocorrelation.

Table 6: Estimation results: log change in total male mortality per 100,000 (N = 306)

Parameter	March–April (se)	April–May (se)	May–June (se)
$\beta \ln(\text{pop. density})$	0.05 (0.01)	−0.08 (0.01)	0.00 (0.01)
$\beta \ln(\text{ave SD score})$	0.00 (0.03)	0.08 (0.04)	−0.02 (0.04)
$\beta \text{ Proportion non-white}$	0.01 (0.10)	−0.62 (0.14)	0.03 (0.12)
$\lambda (W(\ln(D/Pop)_{t+1} - \ln(D/Pop)_t))$	0.35 (0.08)	0.35 (0.07)	0.33 (0.16)
<i>Intercept</i>	−0.02 (0.12)	−0.06 (0.14)	−0.11 (0.13)
Pseudo R ²	0.139	0.447	0.012
Wald test of spatial terms, p-value	<0.0001	<0.0001	<0.0001

Note: se refers to the robust standard error allowing for heteroskedasticity.

9. Discussion

A number of new findings emerge from our analysis. First, the distribution of Covid-19 mortality is quite different from that of non-Covid deaths in the same months or all-cause mortality in 2018. The strong effect of density on Covid-19 mortality but not our other mortality measures is consistent with Covid-19 being a transmissible viral infection. We find evidence for a negative association between area social deprivation and Covid-19 mortality once we control for infection (reported cases) and population density, in contrast to the findings for non-Covid-19 mortality and all causes mortality in 2018. Thus, Covid-19 mortality appears to be socially selective in the opposite direction to mortality generally. But, second, Covid-19 infections are higher in more socially deprived areas, so that, when not controlling for infections, Covid-19 mortality increases with the social deprivation of the area, but not as steeply as non-Covid mortality or 2018 mortality. Third, there appears to be a positive spillover of Covid-19 mortality from neighbouring areas to Covid-19 death rates, whereas for other mortality there is little spillover from other areas, again consistent with Covid-19 being a transmissible viral infection. Fourth, an area's ethnic composition is important for all three measures of mortality, but a higher proportion non-white increases age- and sex-standardised Covid-19 mortality substantially, in contrast to negative associations with 2020 non-Covid mortality and

2018 mortality. Finally, once we control for area population density we find no evidence that the distribution of residential care homes across England accounted for higher Covid-19 mortality in some areas than in others.

References

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Appendix

Table A-1: Covid-19 mortality during 1 March to 31 July and other variables

Variable	Obs	Mean	Std. Dev.	Min	Max
April	306	54.7	27.1	4.8	154.9
May	299	20.5	9.3	1.8	52.55
March–May	306	83.6	37.6	9.05	219.3
March–July	304	93.5	39.5	12.9	227.2
June–July	296	9.8	7.3	0.4	54.9
ln(density)	306	6.6	1.4	3.22	9.69
ln(ave. score)	306	2.9	0.4	1.71	3.81
Prop. nonwhite	306	0.1	0.1	0.00	0.68
Caredensity	306	0.2	0.2	0.00	1.33

Table A-2: Covid-19 mortality during 1 March to 31 July

Parameter	1 1 March–31 July (se) N=304	2 1 March–31 May (se) N=304	3 1 June–31 July (se) N=296
β ln(ave. score)	0.16 (0.05)	0.13 (0.05)	0.52 (0.09)
β Proportion non-white	0.44 (0.17)	0.62 (0.16)	-0.47 (0.39)
β ln(pop. density)	0.20 (0.03)	0.19 (0.02)	0.05 (0.05)
$\lambda W \ln \left(\frac{D}{Pop} \right)^n$	0.12 (0.02)	0.12 (0.01)	0.36 (0.06)
Intercept	2.18 (0.21)	2.21 (0.20)	-0.36 (0.34)
Pseudo R ²	0.487	0.479	0.134
Wald test of spatial terms, p-value	0.000	0.000	0.000

Note: se refers to the robust standard error allowing for heteroskedasticity.