# Area level deprivation and monthly COVID-19 cases: The impact of government policy in England

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ABSTRACT

This paper aims to understand the relationship between area level deprivation and monthly COVID-19 cases in England in response to government policy throughout 2020. The response variable is monthly reported COVID-19 cases at the Middle Super Output Area (MSOA) level by Public Health England, with Index of Multiple Deprivation (IMD), ethnicity (percentage of the population across 5 ethnicity categories) and the percentage of the population older than 70 years old and time as predictors. A GEE population-averaged panel-data model was employed to model trends in monthly COVID-19 cases with the population of each MSOA included as the exposure variable. Area level deprivation is significantly associated with COVID-19 cases from March 2020; however, this relationship is reversed in December 2020. Follow up analysis found that this reversal was maintained when controlling for the novel COVID-19 variant outbreak in the South East of England. This analysis indicates that changes in the role of deprivation and monthly reported COVID-19 over time cases may be linked to two government policies: (1) the premature easing of national restrictions in July 2020 when cases were still high in the most deprived areas in England and (2) the introduction of a regional tiered system in October predominantly in the North of England. The analysis adds to the evidence showing that deprivation is a key driver of COVID-19 outcomes and highlights the unintended negative impact of government policy.

## 1. Introduction

The UK reported its first case of COVID-19 on the 31st of January 2020. As cases continued to rise, on the March 23, 2020, the government declared a national lockdown in Britain. Since then, the English government have enforced a broad spectrum of interventions, under rapidly changing, unprecedented circumstances (Health Foundation, 2021 [1]; Batty et al., 2020). Whilst there is no counterfactual to measure the success of these policies, each policy has been underpinned by much speculation as to its timeliness, extent, and subsequent effectiveness. Two policies in particular stand out as particularly contentious. First, the decision to ease national lockdown measures from the 4th of July 2020

coupled with the subsequent introduction of local restrictions predominantly in the North and the Midlands of England. These local restrictions were introduced by the government to contain the disease while minimising the severe economic effect of national lockdowns (Varsavsky et al., 2021). Secondly, the introduction of the three-tiered system of local COVID-19 Alert Levels on the 14th of October 2020 due to increasing cases in North West and North East regions of England. With both policies, Northern leaders felt that the introduction of local restrictions would be both ineffective and economically unfair due to the higher proportion of deprived communities in these areas (Daras et al., 2021; ; Zhang et al., 2021). Initially, Liverpool City Region was the only area in the alert level 'very high' (Health Foundation, 2021). However,

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several areas in the North East and North West were placed in Tier 2[2] and subsequently moved to Tier 3 in the following months.

At the same time, the pandemic has highlighted the existing systemic health inequalities in the UK (Daras et al., 2021); Kontopantelis et al. (2021); McNamara et al. (2020); Health Foundation, 2021; Buchan et al. (2017). Early analysis (March 1st to April 17th, 2020) found that, adjusting for age, deaths in the most deprived areas of England have been more than double those in the least deprived. While the uneven impact of the virus is highlighting systemic inequality in Black and Asian communities (Cabinet Office, 2017). Kontopantelis et al. (2021) found that in terms of deaths directly attributable to COVID-19 infection and deaths resulting from the national public health response, there were markedly different impacts across England and Wales at the Government Regional level (GOR). Figures by the Office for National Statistics (2020) also found that within regions deprived communities have been disproportionately impacted. The causes behind these patterns are complex and interlinked (Bibby et al., 2020; Zhang et al., 2021). Such factors include economic circumstances whereby people in more disadvantaged communities are not able to comply with requirements to work from home due to their occupation, but also some communities being less inclined to comply with restrictions due to mistrust of authorities (Harris, 2020; Daras et al., 2021; Zhang et al., 2021).

The risk factors leading to COVID-19 cases, hospitalisation, and mortality exist therefore not only at the individual level: neighbourhood-level factors and their interactions with individual-level factors are also responsible for the observed disparities (KC et al., 2020; Daras et al., 2021). Lack of access to health care, unemployment, occupation type, less education, and poor housing conditions significantly increase the risk of COVID-19 infection (Bilal et al., 2021. KC et al., 2020; Shah et al., 2020). The varying levels of vulnerability between people and places is increasingly shown to have important consequences for individual and community responses to the pandemic (Daras et al., 2021; Harris, 2020). These vulnerabilities can be studied collectively as neighbourhood or area level deprivation (KC et al., 2020). Area level deprivation has a strong spatial patterning in England (Fig. 1). Uneven regional development, a deeply entrenched and persistent feature of English society (Martin et al., 2016), means that while areas of deprivation exist in all regions of the UK, the top 10 most deprived communities are consistently located in the North West and North East of England (Buchan et al., 2017). At the same time area level deprivation has been shown to be an important determinant of a variety of health outcomes across England (Morrissey, 2015; Buchan et al., 2017).

While there is now an increasing evidence base on the role of deprivation on COVID-19 outcomes, no research has examined the impact of the UK governments COVID-19 policies explicitly on this relationship. This paper examines the role of area level deprivation on monthly reported COVID-19 cases throughout 2020 at the middle super output area (MSOA) in England. The use of a population-averaged panel data model is important as it allows us to explore the how changes government lockdown policy may have impacted this relationship Given the significant disproportionate COVID-19 mortality rates reported in more deprived communities during the early stages of the pandemic (Daras et al., 2021), it is hypothesised that higher monthly cases will be observed in the most deprived MSOAs throughout all phases of the UK government's response to the COVID-19 pandemic in 2020.

This paper argues that the focus on cases rather than hospitalisations or mortality allows the full extent of COVID-19 across the population rather than clinical outcomes alone. Of course, all three outcomes are related, people living in areas with the highest rates of cases and thus

exposure will be most at risk of hospitalisation and mortality; while reported COVID-19 cases are effectively modelling hospitalisation rates at the start of the pandemic, as generally only those who were hospitalised were tested. However, as the pandemic continued, and testing became more prevalent further biases may have been introduced due to differences in COVID-19 testing rates across areas and changing testing guidelines and regimes. These biases will be further compounded by the variation in the willingness to be tested across different demographic and socioeconomic groups (Smith et al., 2020). Although data at the time of writing this paper was not available for COVID-19 testing at the MSOA level, data was available on COVID-19 testing at the Local Authority level. To avoid modelling issues associated with ecological fallacy, data on testing rates at the Local Authority District level were not included in the formal time series analysis. However, as a means of providing contextual information on the changes in the Governments testing regime throughout 2020 and reported COVID-19 cases, the trend in COVID-19 testing by IMD quintile is presented. If the testing regime is driving reported it is hypothesised that a higher number of tests to be carried out in the most deprived quintile in the early months of the pandemic, matching evidence that COVID-19 cases were significantly associated with deprivation in March and April 2020 (Office for National Statistics, 2020).
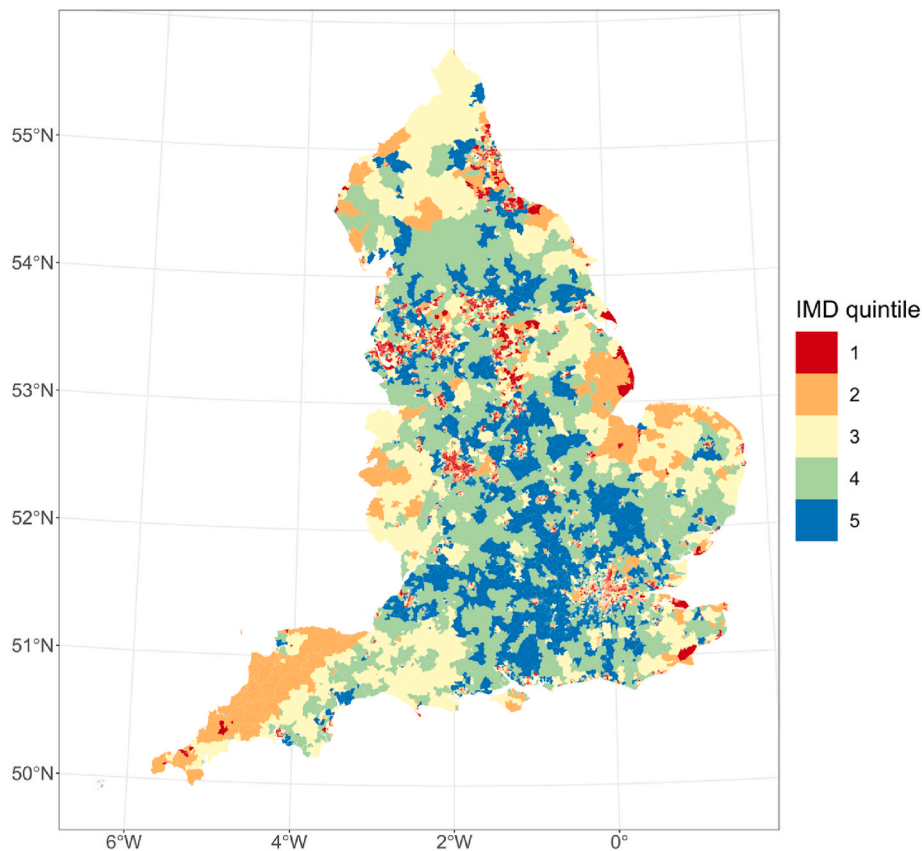
## 2. Data and methods

### 2.1. Data

COVID-19 Cases: Monthly reported cases COVID-19 cases were obtained from Public Health England at the Middle Super Output Area (MSOA) level. MSOA level is the lowest spatially disaggregated data with available monthly reported COVID-19 cases from March 2020. There are 6790 MSOAs in England. Monthly reported cases are reported for each MSOA when more than three daily cases are reported at the MSOA level. Daily reported COVID-19 data is available from the month ending Saturday the 7th of March 2020. However, two issues arise with the daily COVID-19 case data. First, not every IMD quintile had reported COVID-19 cases for the first 4 weeks of reporting. Second, daily cases were again very low at the MSOA level at various points across 2020. Second, daily cases were zero for many MSOAs at various points during 2020. This meant that model convergence was not possible using weekly data. The daily case data was aggregated to monthly cases for the purpose of this analysis.

Index of Multiple Deprivation (IMD): Determinants of health can be studied collectively as neighbourhood or area level deprivation (KC et al., 2020). Data from the IMD for England 2019 (Office for National Statistics, 2019) was linked to PHE cases. The purpose of the IMD is to measure the multiple facets of deprivation at the small area level and may be seen as a method to conceptualise 'disadvantaged areas' with respect to spatial concentrations of disadvantaged persons (Morrissey, 2015). The MSOA ranked closest to 1 is the most deprived, with higher numbered rankings indicating less deprived areas (MHCLG, 2019). The IMD is partially based on census data and a combination of data derived from other sources such as the Inland Revenue, the Department of Health, and the Department of Transport. The IMD 2019 was constructed by combining seven general welfare domain scores weighted as followed: income (22.5%), employment (22.5%), housing and disability (13.5%), education, skills and training (13.5%), barriers to housing and services (9.3%), crime (9.3%), and living environment (9.3%). As such the IMD provides a composite indicator of the socio-economic determinants previously identified to be key factors associated with a range of COVID-19 outcomes (Harris, 2020; Daras et al., 2021).

Population Age Structure: The percentage of the population over 70 years of age for each MSOA was taken from the Office of National Statistics (ONS) population estimates (Office for National Statistics, 2019). The percentage of the population aged over 70 was included in the model to account for the government's national shielding policy.

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[2] These areas included Cheshire; Greater Manchester; Derbyshire; Lancashire; West Yorkshire; South Yorkshire; Durham; Northumberland; Tyne and Wear; Tees Valley; West Midlands; Leicestershire; and Nottinghamshire (https://lordsl ibrary.parliament.uk/covid-19-local-alert-levels-three-tier-system-for-engl and/).

**Fig. 1.** Map of Middle Super Output level (MSOA) areas showing the distribution of the Index of Multiple Deprivation quintiles. The most deprived areas (Q1) are shown in red and the least deprived (Q5) are shown in blue. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Ethnicity Structure: The percentage of the population identifying as White, Black, Asian, Mixed and Other Ethnicity for each MSOA was obtained from the England and Wales Census of Population (2011) (ONS, 2011). Ethnicity was included to adjust for the complex interact between ethnicity and deprivation in England, and the higher observed rates of COVID-19 hospitalisation and mortality in non-white communities.

COVID-19 Testing: As noted above, PHE and NHS testing evolved and increased over time, and this will directly impact reported cases across areas and groups. However, data was not available for COVID-19 testing at the MSOA level, to account for changes in COVID-19 testing over time. However, data is currently available at the Local Authority Level. As a means of providing contextual information on the changes in the Governments testing regime throughout 2020 and reported COVID-19 cases, a correlation analysis of the relationship between cases and testing across time by Local Authority Level IMD quintile is presented.

Government Office Region: A government office region (GOR) variable was included to explore if the outbreak of the Novel COVID-19 variant in the Southeast of England in November 2020, a wealthier area of England impacted the role of area level deprivation on COVID-19 cases overtime. GORs align with European NUTS I regional areas. There are 9 GORs in England, of which the South East has the second highest regional gross disposable household income after London (Office for National Statistics, 2020).

### 3. Methods

A time series analysis was undertaken using a GEE Poisson population-averaged (or marginal) panel-data model in Stata. GEEs were developed by Zeger and &Liang (1986, 1988) as a means of testing

hypotheses regarding the influence of factors on binary and other exponentially (e.g., Poisson, Gamma, negative binomial) distributed response variables collected within subjects across time. A population-averaged panel-data model was chosen due to time-invariant predictors and strong likelihood of autocorrelated residuals over time (Hubbard et al., 2010). Population-averaged approach models the mean response across a population of units at each time point as a function of time. A longitudinal Poisson based PA model the marginal expectation of the response, $\mu_{ij}$, depends on covariates through a known link function, which in the case of a Poisson model is defined as a Log-Link:

$$Log(\mu_{ij}) = \beta_0 + \beta_1 X_{1ijt} + \beta_2 X_{2ijt} + \dots + \beta_p X_{pijt} \qquad (1)$$

With each response modelled as a function of $t$ and further covariates. The marginal variance of $Y_{ij}$ depends on the marginal mean according to:

$$Var(Y_{ijt}) = \varphi\mu_{ijt} \text{ (overdispersion when } \varphi > 1) \qquad (2)$$

where v ($\mu_{ij}$) is a known 'variance function' and $\varphi$ is a scale parameter that may need to be estimated.

To obtain a marginal probability, GEE uses a quasi-likelihood approach which separately models the mean response across all clusters and the within-cluster association, assuming the primary interest is in the mean response and the within-cluster correlation (Ballinger, 2004). The within-cluster correlation is specified through a working correlation whose parameters are estimated by methods of moments (Zeger and &Liang, 1986; 1988). It also assumes the observations in different clusters are independent. The pattern of variances and covariances is specified by a working correlation structure. Three models were specified at the MSOA level:

- Model 1: The relationship between IMD quintiles and monthly COVID-19 cases in England
- Model 2: The relationship between IMD quintiles and monthly COVID-19 cases in England adjusted for ethnicity and age structure.
- Model 3: The relationship between IMD quintiles and monthly COVID-19 cases in England adjusted for ethnicity and age structure and includes time (months)-IMD quintile interactions.

Where the outcome measure is monthly reported cases of COVID-19 for each MSOA, *j*. Predictor variables included area level deprivation as measured by the English Index of Multiple Deprivation (IMD) represented as quintiles, the percentage of non-white identifying residents in the MSOA represented as quintiles, the percentage of the population over 70 years old in the MSOA and time measured as month. The exposure variable was specified as the population of each MSOA.

An exchangeable correlation structure was specified as it is the most appropriate when the data structure is one of repeated measures on the same sampling units using the same measurement approach on all occasions. As noted above a log-link function was used due as the dependent variable is a count variable. Incidence rate ratios were calculated for all models. Margins are statistics calculated from predictions of a previously fit model and summarize the average responsive change of dependent variable related to every one-unit increase of a covariate (Williams, 2012). Margins were calculated and plotted to present the interaction between monthly cases and IMD Quintile for Model 3.

## 4. Results

Descriptive statistics (sum, mean, minimum and max) are presented in Table 1 for monthly and IMD Quintile cases across each MSOA. Cases began to rise from August 2020 and reached a peak for 2020 in December 2020. Table 2 also indicates that cases were highest in the most deprived IMD quintiles.

The analysis continues by exploring deprivation at the MSOA level and the length of time that each MSOA spent in lockdown from March 2020 to December 2020. Fig. 2, a bivariate plot, presents the spatial distribution of deprivation and the amount of time each MSOA spent under lockdown restrictions. We include time spent in local lockdown, national lockdown, or tiers 2, 3 or 4. In this plot we use the Index of Multiple Deprivation rank to denote deprivation level in the area. In this plot bluer areas are more deprived, redder areas have experienced longer periods of lockdown restrictions and the brown areas are more deprived and have experienced longer periods of lockdown. Fig. 2 indicates that the North West of England has the longest period of lockdown and contains MSOAs with high levels of deprivation.

**Table 1**
Descriptive Statistics for monthly and IMD Quintile cases, sum, mean, minimum and max (Source PHE England).

| Month | Sum Cases | Mean | Min | Max |
|---|---|---|---|---|
| March | 10,450 | 5 | 3 | 21 |
| April | 87,954 | 6 | 3 | 82 |
| May | 67,026 | 6 | 3 | 62 |
| June | 14,168 | 5 | 3 | 74 |
| July | 8176 | 6 | 3 | 74 |
| August | 18,249 | 5 | 3 | 74 |
| September | 81,198 | 8 | 3 | 322 |
| October | 506,373 | 17 | 3 | 1001 |
| November | 498,041 | 19 | 3 | 163 |
| December | 614,952 | 24 | 3 | 216 |
| **IMD Quintile** | **Sum Cases** | **Mean** | **Min** | **Max** |
| QIMD 1 | 506,602 | 17 | 3 | 880 |
| QIMD 2 | 426,749 | 16 | 3 | 1001 |
| QIMD 3 | 353,399 | 14 | 3 | 952 |
| QIMD 4 | 316,266 | 13 | 3 | 811 |
| QIMD 5 | 303,571 | 13 | 3 | 367 |

Fig. 3 presents reported COVID-19 cases at the MSOA level and IMD quintile from March 2020 to the 31st of December 2020. Cases in the most deprived MSOAs were higher than average from March to May 2020; however, the relative difference between deprivation levels and cases really begins to grow once government lockdown policy begins to ease on the 1st of June, with the phased reopening of schools. From mid-July onwards, cases in the most deprived MSOAs began to increase substantially, with cases reaching approximately 43,000 at the start of October 2020, compared to 15,000 cases in the least deprived MSOAs at the same time. However, this pattern was reversed in November 2020 with MSOAs in the four least deprived quintiles reporting higher cases than MSOAs in Quintile 1. Using data from Public Health England on reported COVID-19 two key timepoints in this relationship are identified:

1. July 2020 when reported COVID-19 cases in the most deprived MSOAs start to rapidly increase; and
2. November/December 2020 when reported COVID-19 cases in the least deprived MSOAs start to rapidly increase and overtake cases in the most deprived MSOAs

As a means of providing contextual information on the changes in the Governments testing regime throughout 2020 and reported COVID-19 cases, Fig. 4 presents the number of tests carried out by IMD quintile from March 2020 to December 2020 at the Local Authority District (LAD) level. Fig. 4 indicates that the number of COVID-19 tests carried out were similar across all quintiles until August 2020 when testing increased rapidly in the most deprived LADs (IMD 1). Here we see that testing and cases mirrored each other at the LAD level, most likely in response to the government deployed rapid local testing across local hotspots in the North of England in August and in the South East of England in November.

Next, a series of GEE Poisson models controlling for time and MSOA population size included as an exposure variable, were run to examine whether the relationship between MSOA IMD and COVID-19 was statistically significant. Model 1 (Table 2) shows that the incidence of monthly COVID-19 cases was 32% less per month (IRR 0.68, 95% CI 0.67, 0.69) in the least deprived areas (QIMD 5) compared to the most deprived areas (QIMD 1). Model 2 includes the percentage of the population of each MSOA that are older than 70 years old and the percentage of the population identifying as Black, Asian, Mixed and Other relative to White. Adjusting for the percentage of people over the age of 70 and ethnicity in each MSOA (Model 2, Table 2) the direct of the relationship between area level deprivation and monthly reported COVID-19 cases remains the same; however, adjusting for ethnicity and age attenuates the association between deprivation and reported COVID-19 at the MSOA level, with each quintile reporting a decreased incidence rate compared to the unadjusted model. The IRR shows that the incidence of reported COVID-19 cases was 18% less per day (IRR 0.82, 95%CI 0.80, 0.87) in QIMD 5 compared to the most deprived areas (QIMD 1) over time. As hypothesised, the higher the percentage of the population aged over 70 years old has a negative association with monthly COVID-19 cases (IRR 0.98, 95%CI 0.98, 0.98). Regarding ethnicity, controlling for deprivation and age, MSOAs with a higher percentage of the population reporting as Asian (IRR 1.007 95%CI 1.006, 1.0067) and Other (IRR 1.002 95%CI1.0007, 1.003) ethnicity have the highest cases relative to MSOAs; while MSOAs with a higher percentage of people reporting as Mixed (IRR 0.98 95%CI 0.98, 0.981) and Black (IRR 0.99 95%CI 0.99, 0.99) had lower reported COVID-19 cases (Table 2).

Model 3 (Table 2) builds on Model 2 by explicitly estimating the relationship between area level IMD and time by including interactions between time (as measured in months) and IMD quintiles. That is, the effect of IMD is allowed to vary by month (or equivalently, the effect of month to vary by IMD quintile). Including time and IMD as an interaction in Model 3 sees the relationships between deprivation and monthly

**Table 2**
Relationship between quintiles of neighbourhood deprivation as measured by the Index of Multiple Deprivation and COVID-19 Monthly Cases at the MSOA Level (N = 6790).

| Model 1 | | | | | Model 2 | | | | Model 3* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Deprivation Quartile | IRR | SE | 95% CI | | IRR | SE | 95% CI | | IRR | SE | 95% CI | |
| QIMD 1: Reference Quintile most deprived MSOAs as measured by the IMD 2019 | | | | | | | | | | | | |
| QIMD 2 | 0.895 | 0.002 | 0.890 | 0.899 | 0.923 | 0.002 | 0.919 | 0.927 | 1.088 | 0.031 | 1.030 | 1.150 |
| QIMD 3 | 0.773 | 0.002 | 0.769 | 0.777 | 0.855 | 0.002 | 0.851 | 0.859 | 1.059 | 0.032 | 0.998 | 1.124 |
| QIMD 4 | 0.703 | 0.002 | 0.699 | 0.707 | 0.822 | 0.002 | 0.818 | 0.827 | 1.006 | 0.033 | 0.944 | 1.073 |
| QIMD 5 | 0.681 | 0.002 | 0.677 | 0.685 | 0.802 | 0.002 | 0.797 | 0.806 | 1.049 | 0.033 | 0.986 | 1.116 |
| % Population over 70 | | | | | 0.969 | 0.000 | 0.969 | 0.970 | 0.969 | 0.000 | 0.968 | 0.969 |
| Reference Percentage of Population Reporting as White | | | | | | | | | | | | |
| Other | | | | | 1.002 | 0.001 | 1.001 | 1.003 | 1.002 | 0.001 | 1.001 | 1.003 |
| Mixed | | | | | 0.980 | 0.001 | 0.978 | 0.981 | 0.981 | 0.001 | 0.979 | 0.982 |
| Black | | | | | 0.995 | 0.000 | 0.995 | 0.996 | 0.995 | 0.000 | 0.994 | 0.995 |
| Asian | | | | | 1.007 | 0.000 | 1.007 | 1.007 | 1.007 | 0.000 | 1.007 | 1.007 |

* IRR for interaction between time (month) and IMD quintile not presented in Table due to space considerations. The relationship is presented graphically in Fig. 3.
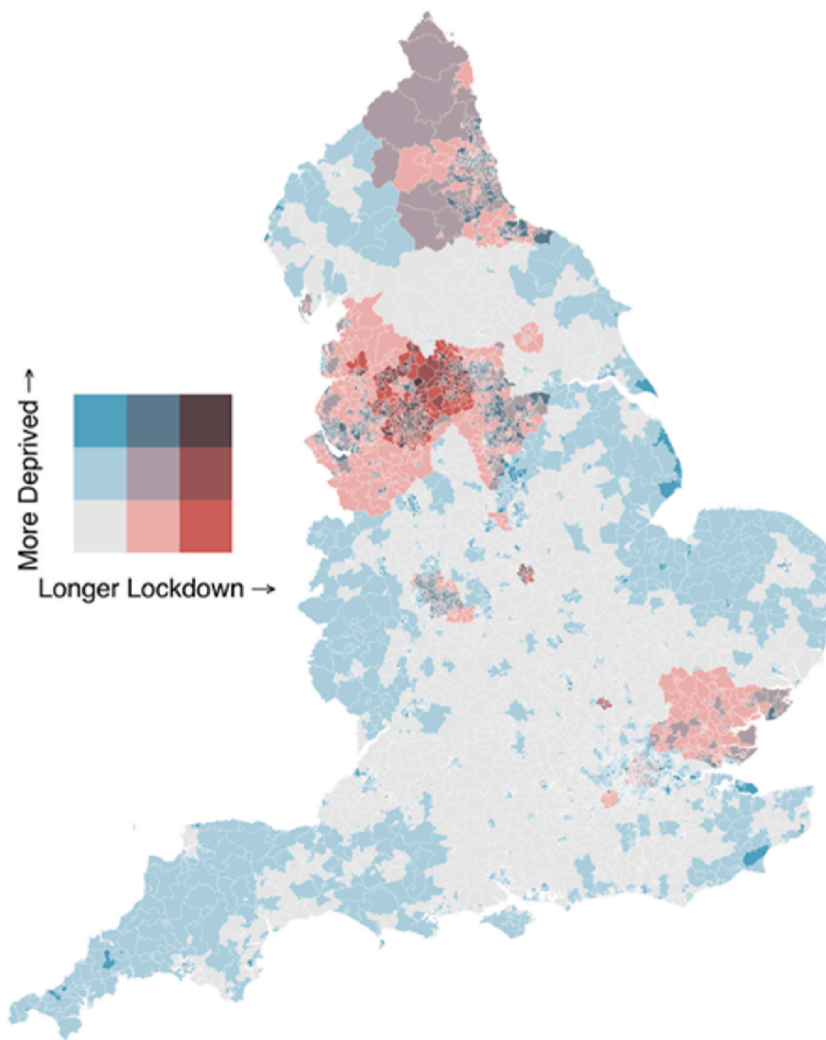


**Fig. 2.** Bivariate plot of spatial distribution of deprivation and the amount of time each region has spent under lockdown restrictions.

reported cases reverse. Including the interaction variable, Model 3 indicates that MSOAs in Quintile 2 reports the highest level of monthly COVID-19 cases (IRR 1.08, 95%CI 1.03, 1.15; IRR 1.05, 95%CI 0.99, 1.12) relative to the least deprived area. While MSOAs in Quintile 3, 4 and Quintile 5 all report higher COVID-19 relative to MSOAs in Quintile 1 (IRR 1.06, 95%CI 0.99, 1.12; IRR 1.006, 95%CI 0.94, 1.07; IRR 1.04,
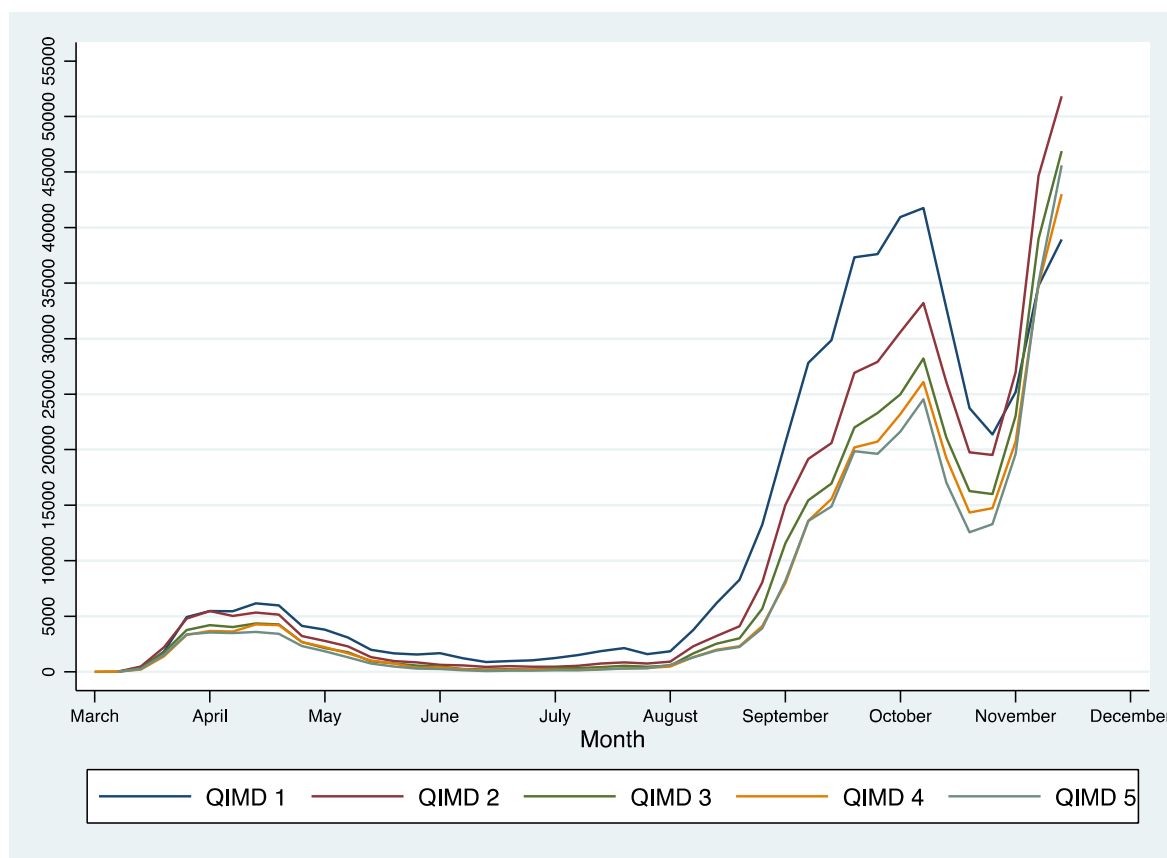
**Fig. 3.** Observed Cases by IMD Quintile over time and Observed Cases by IMD Quintile (Source PHE England).

95%CI 0,98 1.12); however, these relationships are not significant relative to MSOAs in the most deprived quintile.

The marginal effects of IMD quintile were calculated at each time-point for monthly COVID-19 cases with 95% Confidence Intervals (Fig. 5). Fig. 5 indicates that cases are higher, but in line with other quintiles in more deprived MSOAs from April 2020; however, from July 2020, the marginal effect of living in MSOAs with high levels of area level deprivation had a much higher positive effect on monthly reported COVID-19 cases. This effect begins to decrease from October 2020 and by December 2020 MSOAs less deprived areas had much higher predicted monthly cases.

The emergence of the novel SARS-CoV-2 variant, VOC 202012/01.

A novel SARS-CoV-2 variant, VOC 202012/01, emerged in the South East of England in November 2020 (Davies et al., 2021). The variant increased in incidence during the second national lockdown (5th November – 2nd December 2020) and continued to spread following the lockdown despite many of the most affected areas being under the then highest level of restrictions (Davies et al., 2021). Concern over this variant led the UK government to place parts of these three regions under stronger restrictions starting on 20th December 2020, and eventually to impose a third national lockdown on 5th January 2021. To control for the rise in reported monthly cases in the South East of England due to the variant that emerged in this region in November 2020, government office region was included as a covariate in preliminary analysis. However, the analysis found that the pattern observed between deprivation and reported COVID-19 cases did not change with the introduction of the regional variable. Thus, to maintain a parsimonious model GOR region as a fixed effect was not included in the final analysis.

Lastly, further covariates included in preliminary model specifications included population, housing density and percentage of the population by ONS defined occupation grouping at the MSOA level. However, none of these covariates were found to be significantly associated with reported COVID-19 cases, nor did they demonstrate any degree of attenuation between the independent variable of interest, quintile of IMD and the outcome variable. A simple correlation analysis found that housing density and occupational grouping were highly correlated with IMD at the MSOA level, which may explain their lack of significance in these models. As such these covariates were not included in the final model.

## 5. Discussion

Modelling the socio-economic consequences of a shock such as the global pandemic and subsequent policy responses across space is vital to inform future policy decision-making (Bok et al., 2018; Li et al.,). This is particularly true in areas and communities identified as being highly vulnerable to the impact of the pandemic (Harris, 2020; Daras et al., 2021). We use a population-averaged panel data approach to understand the relationship between area level deprivation and COVID-19 cases. We find that during the first three months of the pandemic cases were higher in the most deprived MSOAs and remained higher than average as the country began to ease out of lockdown from June 2020. This finding is in line with previous international research (Shah et al., 2020). However, this analysis indicates a steep rise in cases in the most deprived MSOAs relative to the least deprived MSOAs from July 2020.

Here we propose that the government policy of easing the national lockdown when cases were still high in the most deprived MSOAs lead to an increase in cases in the North of England and subsequent economic policies to stimulate the retail and hospitality sectors exacerbated this trend. These low wage sectors where physical contact with individuals is necessary (Office for National Statistics, 2020) form the backbone of many Northern cities employment (Harris and Brunsdon, 2021). The introduction of the governments 'Eat Out, To Help Out' is an example of
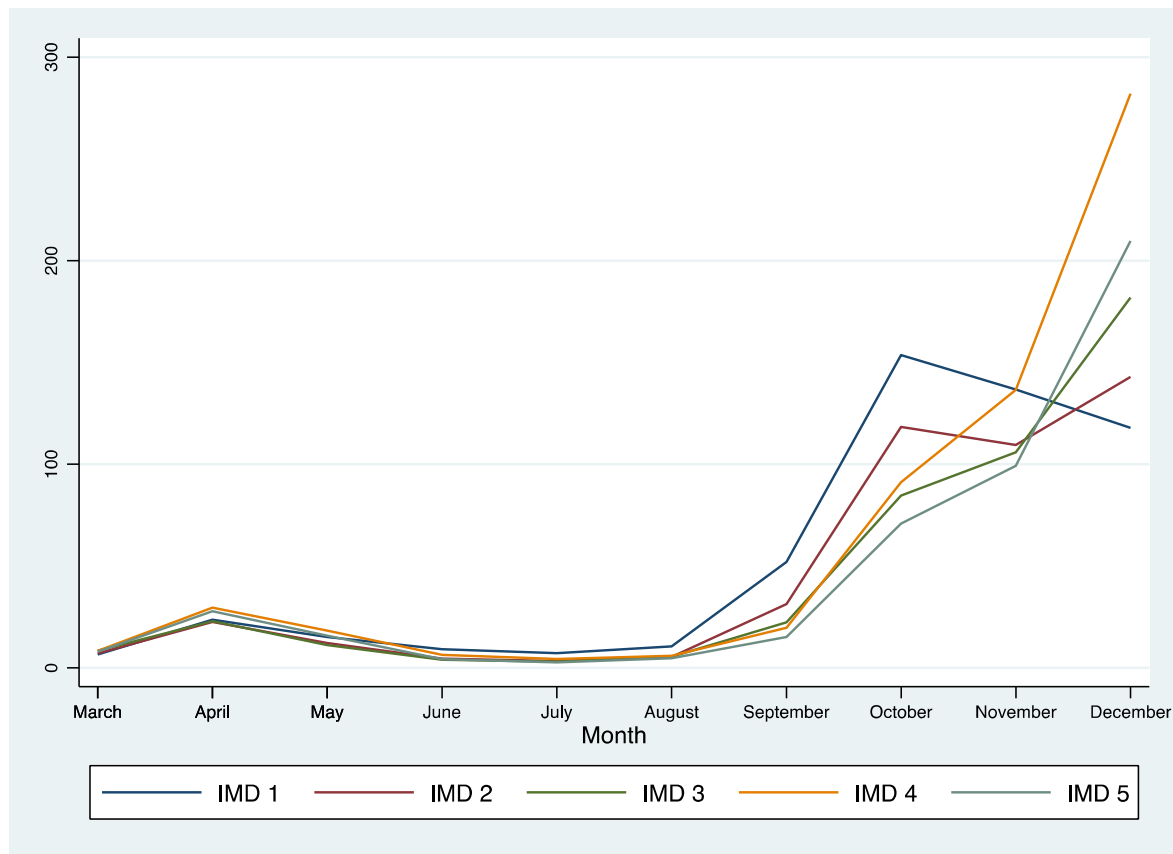
**Fig. 4.** Number of COVID-19 tests by IMD quintile March 2020 to the end of December 2020 (Source PHE England).

the emphasis placed on these sectors (González-Pampillón et al., 2021; Fetzer, 2020). The scheme subsidized 50% off the cost of food and non-alcoholic drinks for an unlimited number of visits in participating restaurants on Mondays-Wednesdays from August 3rd to August 31st, 2020 (Fetzer, 2020). Recent research on the impact of this scheme indicates that encouraging people to eat out in restaurants in the wake of the first 2020 COVID-19 wave in the United Kingdom has had a large causal impact in accelerating the subsequent second COVID-19 wave (Fetzer, 2020).

The analysis also indicates that this relationship is reversed throughout November and December. Local lockdowns from July 2020 and the subsequent introduction of a regional tiered system in the North and Midlands of the country were introduced by the government to contain the disease while minimising the severe economic effect of national lockdowns (Varsavsky et al., 2021). However, this meant that many of the most deprived areas in the country endured the longest lockdowns (Fig. 2). In contrast, MSOAs in the south of England, areas with much lower levels of deprivation, had longer periods of time without national or local lockdown measures. Furthermore, analysis controlling for the possible role of the novel SARS-CoV-2 variant that emerged in the South East of England in November 2020, a region with low area level deprivation (Fig. 1) did not change the observed relationship between reported cases and area level deprivation. Here we suggest that although situated as a wholly spatial response to containing COVID-19, devoid of wider socio-economic considerations, the series of local lockdowns and tiered system inadvertently reversed the previously observed relationship between area level deprivation on COVID-19 cases at the MSOA level in England.

The protective nature of the local lockdowns and tiered regional system in deprived areas suggest that the spread of Covid-19 can be contained through local policies. However, these local strategies were required due to the socioeconomic circumstances of these communities

and their inability or lack of willingness to adhere to government policy. This was further exacerbated with a focus on getting the retail and hospitality sectors, two low wage sectors with high levels of physical contact, open. To prevent a cycle of lockdowns being necessary in poorer areas, recovery strategies and control measures need to be tailored to differing populations and resources should be allocated proportionate to need (Daras et al., 2021). Policies that are aimed at low wage sectors need to be considered in terms of who may be exposed given their socio-demographic circumstances. However, it is important to note that as the pandemic continues the strategy followed by the UK government has continued to be centrally led, without proportionate concern for local communities.

The analysis presented in this paper focuses on the role of deprivation at the area level and the most parsimonious model was used. However, even using a relatively crude indicator of ethnicity, the percentage of the population reporting as White, Black, Asian, Mixed and Other ethnicity compared to work for example by Harris and Brunsdon (2021) on this specific topic, also adds to the evidence of the disproportionate impact of COVID-19 among non-white communities in England and the growing evidence base also indicates that there are important differences between the non-white community (Harris and Brunsdon, 2021; Department of Health and Social Care, 2021). In February 2021, the Department of Health and Social Care published findings that show that "areas with higher numbers of Asian ethnicity individuals were associated with increased prevalence" (Department of Health and Social Care, 2021). Further research by Harris and Brunsdon (2021) find that in the first wave, the disease disproportionately affected Black people; however, as the pandemic has progressed, the Pakistani but also the Bangladeshi and Indian groups have had the highest exposure. This analysis adds to the evidence base that the Asian population reported higher levels of COVID-19 cases across space and time. Like Harris and Brunsdon (2021) we recommend further analysis of this
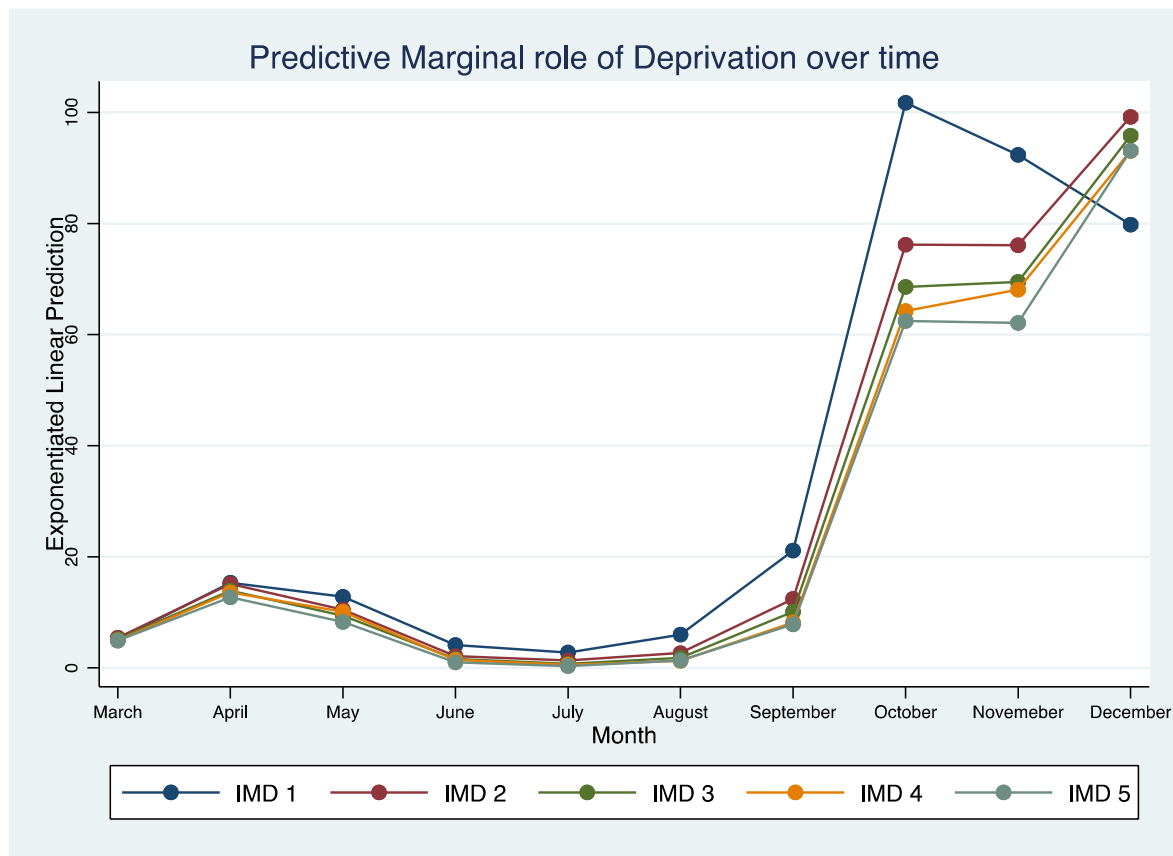
**Fig. 5.** Predictive Marginal role of MSOA level Deprivation on monthly COVID-19 cases over time.

complex relationship as the social, economic, and cultural impacts of the COVID-19 pandemic becomes more apparent.

### 5.1. Study limitations

Regarding the choice of outcome measure, reported COVID-19 cases, for the purpose of this paper, a focus on cases rather than hospitalisation or mortality is important for two reasons. First, focusing on just hospitalisations or deaths would censor the actual full public health impact of the pandemic across communities. Second, as the aim of this paper is to understand the underpinning role that area level deprivation plays on COVID-19 outcomes, community level cases are a much better reflection of this relationship. However, it is important to note two important issues associated with using reported COVID-19 cases. First, using reported COVID-19 cases means that we are effectively modelling hospitalisation rates at the start of the pandemic, as generally only those who were hospitalised were tested. Thus, COVID-19 cases are likely to be an underestimate of COVID-19 at the start of the pandemic. Second, as the pandemic continued, and testing became more prevalent further biases may have been introduced due to differences in COVID-19 testing rates across areas and changing testing guidelines and regimes. As a means of providing contextual information on COVID-19 testing across quintiles, Fig. 2 indicates that COVID-19 testing was similar across all quintiles until August 2020 when rates of testing increased in the most deprived UTLAs (IMD 1) in response to increasing COVID-19 cases in the North of England. This trend was reversed in November and December 2020, with the outbreak of the novel SARS-CoV-2 variant emerged in the South East of England (Davies et al., 2021). In terms of impact on this analysis, if testing proceeded cases than the relationship between deprivation and COVID-19 explored in this paper remains. We believe this is the case, as research has shown that unlike other countries, the UK did not provide community wide testing (Yoo et al., 2020) and that local

testing on a large scale emerged in response to local outbreaks once identified. However, in terms of accounting for the role of testing in this analysis, as it stands, COVID-19 testing numbers are only available at the Upper Tier Local Authority area. To prevent the well-known modelling biases associated with using data across different levels, the model did not adjust for COVID-19 testing. As such, the results presented here, like all modelled results, need to be interpreted with caution, with future analysis recommended to unpick the complex relationship between recorded cases and testing when such data becomes available.

Regarding research design, a population averaged panel data approach was used as is considered best practice in epidemiology (Hubbard et al., 2010). However, it is important to note that this approach only accounts for autocorrelation across time and does not account for spatial autocorrelation. However, while much work has been done in the broader spatial literature to finesse spatial panel data models (Elhorst, 2012, 2014, 2014), with off the shelf software such as Stata and R encompassing packages to compute these models, such models and software packages do not readily exist for a Spatial Panel Count Data to date. As such these results will suffer from issues of spatial autocorrelation. Given the increased interest in count data models to model the COVID-19 pandemic, it is hoped that such models will be developed in a timely fashion.

### Author credit statement

Karyn Morrissey: conceptualisation; methodology; analysis; project administration; writing original draft, reviewing and editing, Fiona Spooner: methodology; analysis, writing original draft, reviewing and editing, James Salter: data acquisition; analysis; reviewing and editing, Gavin Shaddick: funding acquisition; analysis.

## Acknowledgement

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