Does accessibility to vaccination centres influence vaccine uptake?[[1]](#footnote-1)

# Authors

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# Abstracts

UK government’s vaccination programme outlined everyone in the UK to be within 10 miles of nearest vaccination centres, and NHS England will be asked to go to a local vaccination centre to drive up to 45 minutes each way. However, “people’s access to vaccination centres fluctuates over time as a result of day-to-day variations in time-use and mobility patterns, and time to travel varies substantially during the day, between days and across individuals.” This study employed a time-weighted cumulative opportunity approach, measuring accessibility within a given travel time. Exploring “how far people ‘ought’ to travel” to vaccinate using a multi-modal trip planner to calculate door-to-door travel times by car and public transportation in accessibility analysis. Spatially fuzzy clustered regression, accounting for spatial heterogeneity who received first dose vaccines in young adults aged between 25 to 50 years old, was deployed to estimate spatially varying coefficients of covariates across England. It provided rigorous spatial clustering results with group-wise regression coefficients. In effect, spatial disparities of COVID-19 vaccination centres and inequalities in education, income, and employment would be led to unequal access to COVID-19 vaccines for England.

**Keywords (max. 6): Accessibility, COVID-19, Vaccine uptake, Inequalities in access to vaccines.**

# Paper structure

## Introduction (ALL)

1. Research background and motivation

* Geographic accessibility to health facilities, measuring travel impedance between patients and providers (Neutens, 2015).
* UK vaccination programme with timelines (Department of Health & Social Care, 2020).
* Geographic difference in vaccine uptake for England (UK government, 2021).
* Uptake by young adults aged between 25 to 50 years old.

1. Factors influencing vaccine uptake – BAME communities, economic deprivation, occupational characteristics, and less accessible geographical areas – remote areas compare to urban centres.

* COVID-19 vaccine coverage varies with local factors, including socioeconomic deprivation, ethnicity, age, religion, and household tenure. Based upon the estimated odd-ratios to analyse the linked vaccination data from National Immunisation Management System (NIMS) to the ONS Public Health Data Asset (PHDA) over NHS number (Office for National Statistics, 2021a).
* However, it has been paying less attention to a barrier to access the COVID-19 vaccine even though travel (and other reasons) takes 13% of the reasons for not taking a COVID-19 vaccine based on the Opinions and Lifestyle Survey (COVID-19 module) survey (Office for National Statistics, 2021b).

1. Research questions

* To what extent has accessibility played a role in spatial variation in vaccination rates?

## Related works (WDL & ALL)

1. Measuring accessibility to health facilities (WDL)

* From the perspective of the provision of health facilities
  + How many people can reach a given facility within a given travel time and/or travel impedance function?
* From the perspective of the demand of people and where they live
  + How afford is it for people in zone to access one or more facilities given a travel time threshold and/or impedance function?
* Methods
  + Provisional approach – two-step catchment floating area (2SCFA) to calculate the provide-to-population ratio (PPR).
  + Demand approach – cumulative opportunity measure to facilitate the number of opportunities within a certain cut-off travel distance or time.
  + Why was the demand approach for measuring accessibility used in this paper?
    - People were not constrained to go to the nearest opportunity – the NHS option gave multiple options to choose the regional vaccination centres.
    - In other words, it is not essential to vaccinate in catchment areas. People can book their jab on available capacity at a given day and time.

1. Factors influencing vaccine uptake (ALL)

* To the extent of how differences in accessibility to vaccination centres influence vaccine uptake for England.
* Also, addressing other variables known to influence vaccination rates – needs to present a simple conceptual model of what can help explain spatial differences in vaccination rates. Here some engagement with the public health literature on modelling of vaccination uptake – for COVID-19 or other diseases – is essential.

## Data & methods (WDL)

* Calculating accessibility using cumulative opportunity measures
  + Exploring how affordable to access the regional vaccination centres at a given location (Deboosere and El-Geneidy, 2018; El-Geneidy et al., 2016). Cut-off time beyond which opportunities are inaccessible (Kelobonye et al., 2020).
  + Drawing the isochron maps to measure variances in accessible vaccination centres from each MSOA unit within 15 min to 90 min, by car and public transportation. Also, it allows a maximum of 1,000m walking distance to access/egress public transport.
  + In effect, an isochron map was generated using an open-source multimodal trip planner, Open Trip Planner (OTP) for the R package (Morgan et al., 2019). By calculating every route within travel time thresholds based on built network graphs incorporated with public transport schedules (see Figure 1).
  + OTP imported OpenStreetMap© (OSM) data for routing on street and path networks that incorporated imported General Transit Feed Specification (GTFS) feeds. GTFS national data retrieved from the bus open data service, operated by the UK government (UK government, 2019).
* Deploying a count-based modelling approach controlling for spatial effects
  + A global negative binomial regression model with spatial lags
  + Spatially clustered regression (SCR) and spatially fuzzy clustered regression (SFCR) model
* SFCR model (Sugasawa and Murakami, 2021) was selected to estimate the grouping parameters and group-wise regression models simultaneously, and its performance seemed to be better than the Geographically Weighted Negative Binomial Regression (GWNBR) model.
  + The proposed model accounts for spatial heterogeneity for modelling spatially varying regression coefficients to impose that the geographically neighbouring locations are likely to belong to the same groups.
  + A tuning parameter λ, in terms of a penalty parameter, controls the strength of the penalty term in a fused LASSO approach to shrink regression coefficients in neighbouring areas toward 0, which results in spatially clustered regression coefficients (Li and Sang, 2019). Two parameters were asked to pre-set the number of groups *G*, and spatial similarity ϕ corresponding to weak (0.1), moderate (0.6), and strong spatial correlation (1) in covariates.
  + In this paper, we have tested three moderate spatial correlation parameters – 0.5, 0.6, and 0.75, and confirmed ϕ*=*0.5 shows the best while *K*=7 on the maximum number of iterations to 200 to consider the spatial patterns (see Table 1 and Figure 2).

## Analysis results (WDL)

* Table 2 provides the model fit for the negative binomial regression models. IRR (incidence rate ratios) is the exponential of the coefficient.
  + It denotes the corresponding multiplicative change of influence arising from a one-unit change in the explanatory variable. For instance, share of households in lowest household income quintile at national level, an IRR value of 0.964 in negative binomial regression model controlling for spatial effects, would imply that an explanatory variable is associated with a 3.6% decrease (96.4%) in first dose vaccine uptake for England.
* Factors positively influencing vaccine uptake (IRR > 1)
  + Share of the higher education qualification, lower middle class, part-time workers, median ages of the resident population, number of accessible vaccination centres by public transportation within 60 min, and the average vaccine uptake in adjacent areas (i.e., spatial lag).
* Factors negatively influencing vaccine uptake (IRR < 1)
  + Share of low-income households, household with no car, number of accessible vaccination centres by car (within 45min), and minor ethnic groups.
* Moran’s I was used to assess the spatial autocorrelation of the NB model’s residual value, and it allows us to investigate a Poisson regression approach for modelling spatial count data (see Table 1).
* Spatially varying coefficients in covariates explain spatial differences in vaccine uptake for England (Table 3).
  + Figure 2 illustrates the spatial distribution of generated clusters using the SFCR model.

* + Table 4 described the characteristics contributing to vaccination uptake across England, and articulated inequalities in access to vaccines by clusters.
* Intermediate factors based on SFCR model estimation results, would have different influences on vaccine uptake by clusters (Table 3)
  + Consistent variables: Share of low-income, households with no car, part-time workers, and median ages of the resident population.
  + Intermediate variables: Share of the lower middle class, number of accessible vaccination centres by car (within 45 min) and public transportation (within 60 min). Subsequently, share of part-time workers and ethnic minority groups in a few groups.
* Inequalities in access to COVID-19 vaccines for England – categories (Table 4)
  + Outstanding accessibility (to vaccination centres) but below average vaccine uptake in G3 (London) and G7 (West County): those areas were shown to have above-average accessibility but had lower uptake.
  + Poorer accessibility to vaccination centres, but above average uptake in G1, G5, and G6: excess mortality was observed in the first wave of the pandemic in early 2020.
  + Lower than average accessibility will likely lead to poor vaccine uptake in G2 and G4.
    - Poor access to vaccination centres served as access barriers that may influence vaccine uptake.

## Discussion and conclusions (ALL)

* UK Government’s vaccine programme has failed to effective vaccine rollout, which might be influenced by inequalities in access to COVID-19 vaccines. In other words, the effects of the unequal spatial distribution of vaccination centres in England.
* The effectiveness of walk-in centre strategy (starts from 25 June 2021) paves the way to increase vaccine uptake.
  + Does walk-in centre strategy contribute to increasing uptake for England? To address this question, this study thus investigates the rise of vaccine uptake for 24 June 2021, when interventions have been implemented.

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Table 1. Average BIC replicated 5 times by different tuning parameter ϕ.

|  |  |  |  |
| --- | --- | --- | --- |
| Number of groups | Average BIC for replicated 5 times | | |
| ϕ = 0.5 | ϕ = 0.6 | ϕ = 0.75 |
| 2 | 84991.33 | 86169.00 | 86634.51 |
| 3 | 81914.15 | 84245.99 | 85567.48 |
| 4 | 80785.99 | 82995.52 | 84420.96 |
| 5 | 79188.19 | 81639.91 | 83804.62 |
| 6 | 78400.88 | 80418.48 | 83409.12 |
| 7 | **77459.85** | 80019.75 | 83114.52 |
| 8 | 77969.50 | 80634.55 | 83188.14 |

Table 2. IRRs (incident rate ratios) and model fit for the negative binomial regression models.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Domains | Variables | IRR (SE) | | | |
| **NB** | **NB with accessibility** | **NB with**  **spatial lag** | **NB with both** |
| Income | Share of households in lowest household income quintile at national level | 0.959\*\*\* (0.001) | 0.957\*\*\* (0.001) | 0.964\*\*\* (0.001) | 0.964\*\*\* (0.001) |
| Qualification | Share of 3 & 4 or above | 1.029\*\*\* (0.002) | 1.029\*\*\* (0.002) | 1.027\*\*\* (0.001) | 1.025\*\*\* (0.001) |
| Occupation | Share of Social Grade C1 (lower middle class) | 1.006\*\*\* (0.002) | 1.008\*\*\* (0.002) | 1.008\*\*\* (0.002) | 1.008\*\*\* (0.002) |
| Accessibility | Number of accessible vaccination centres within 45 min on a weekday by car | - | 0.993\*\* (0.002) | - | 0.994\*\* (0.002) |
| Number of accessible vaccination centres within 60 min on a weekday at 12 pm by public transportation | - | 1.002 (0.002) | - | 1.008\*\*\* (0.002) |
| Share of households with no car | 0.96\*\*\* (0.002) | 0.961\*\*\* (0.002) | 0.975\*\*\* (0.002) | 0.972\*\*\* (0.002) |
| Activity commitment | Share of part-time workers in the resident population aged 16-74 | 1.038\*\*\* (0.002) | 1.036\*\*\* (0.002) | 1.03\*\*\* (0.002) | 1.03\*\*\* (0.002) |
| Population Health | Median ages of the resident population | 1.038\*\*\* (0.002) | 1.037\*\*\* (0.002) | 1.026\*\*\* (0.002) | 1.025\*\*\* (0.002) |
| Ethnicity | Share of Chinese resident population | 0.975\*\*\* (0.001) | 0.974\*\*\* (0.001) | 0.979\*\*\* (0.001) | 0.979\*\*\* (0.001) |
| Share of Other Asian resident population | 0.983\*\*\* (0.001) | 0.984\*\*\* (0.001) | 0.99\*\*\* (0.001) | 0.991\*\*\* (0.001) |
| Share of African resident population | 0.991\*\*\* (0.002) | 0.992\*\*\* (0.002) | 0.994\*\*\* (0.001) | 0.995\*\* (0.001) |
| Share of Caribbean resident population | 0.978\*\*\* (0.002) | 0.978\*\*\* (0.002) | 0.988\*\*\* (0.001) | 0.988\*\*\* (0.001) |
| Spatial lag effects | Average vaccine uptake in adjacent areas |  |  | 1.063\*\*\* (0.001) | 1.063\*\*\* (0.002) |
| Model criteria information | Log-likelihood | -44006.57 | -44000.81 | -43183.36 | -43171.96 |
| AIC | 88037.000 | 88030.000 | 86393.000 | 86374.000 |
| BIC | 88062.955 | 88051.425 | 86416.525 | 86393.735 |
| Theta | 162.770 | 163.060 | 212.060 | 212.830 |
| Moran's I of residuals | | 0.520 | 0.521 | 0.221 | 0.221 |

**Note: \*p<0.5; \*\*p<0.01; \*\*\*p<0.001.**

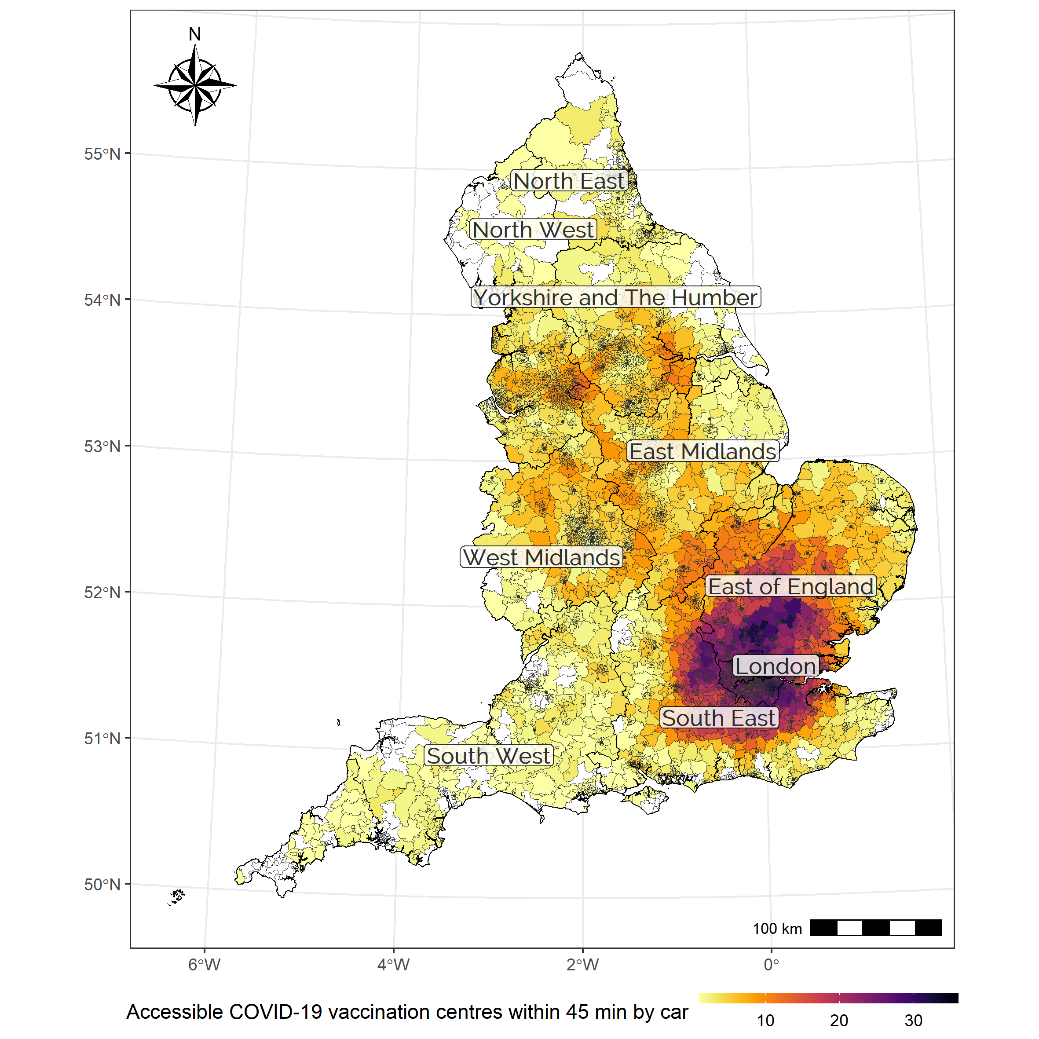
Table 3. IRRs (incident rate ratios) and model fit (at *K*=7 over 200 maximum iterations) for the spatially fuzzy clustered regression model.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Domains | Variables | G1 | G2 | G3 | G4 | G5 | G6 | G7 |
| Income | Share of households in lowest household income quintile at national level | 0.980 | 0.971 | 0.896 | 0.965 | 0.978 | 0.937 | 0.964 |
| Qualification | Share of 3 & 4 or above | 1.016 | 1.031 | 1.091 | 1.034 | 1.028 | 1.014 | 1.013 |
| Occupation | Share of Social Grade C1 (lower middle class) | 0.985 | 1.007 | 1.061 | 1.044 | 1.001 | 1.000 | 0.994 |
| Accessibility | Number of accessible vaccination centres within 45 min on a weekday by car | 0.984 | 1.018 | 1.000 | 1.060 | 0.977 | 0.959 | 0.991 |
| Number of accessible vaccination centres within 60 min on a weekday at 12 pm by public transportation | 1.019 | 0.992 | 0.966 | 0.980 | 1.020 | 0.988 | 1.018 |
| Share of households owning no car | 0.949 | 0.958 | 0.991 | 0.983 | 0.930 | 0.974 | 0.923 |
| Activity commitment | Share of part-time workers in the resident population aged 16-74 | 1.039 | 1.038 | 1.046 | 1.069 | 1.021 | 0.995 | 1.023 |
| Population Health | Median ages of the resident population | 1.032 | 1.036 | 1.003 | 1.066 | 1.006 | 1.035 | 1.018 |
| Ethnicity | Share of Chinese resident population | 0.976 | 0.956 | 0.989 | 0.962 | 0.981 | 0.928 | 0.970 |
| Share of Other Asian resident population | 0.995 | 0.960 | 1.009 | 0.988 | 0.989 | 1.006 | 0.964 |
| Share of African resident population | 0.973 | 0.993 | 1.007 | 0.984 | 1.006 | 0.897 | 1.000 |
| Share of Caribbean resident population | 0.927 | 0.965 | 0.994 | 0.985 | 0.974 | 0.999 | 0.973 |
| Model criteria information | Log-likelihood | -38653.160 | | | | | | |
| AIC | 77330.320 | | | | | | |
| BIC | 77356.135 | | | | | | |
| Theta | 913.129 | 587.355 | 430.199 | 424.243 | 831.948 | 819.016 | 869.485 |

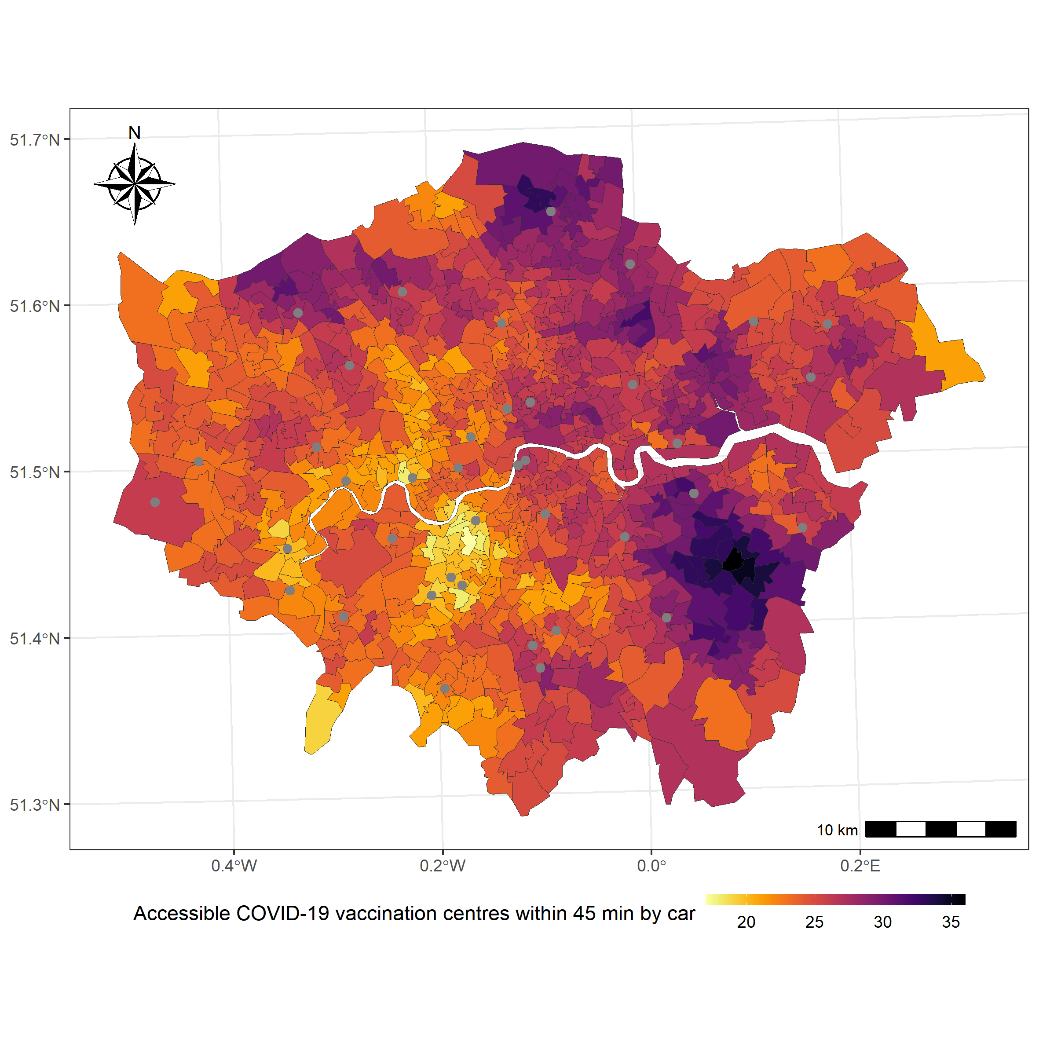
**Note: heterogeneous responses (compared to NB estimation results) are shaded in darker grey.**

Table 4. Inequalities in access to vaccines by clusters.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Groups | Number of consecutive MSOAs | Number of COVID-19 vaccination centres | Vaccination centres per 100,000 inhabitants | People who received 1st dose vaccinations (%) | Number of accessible vaccination centres by car within 45min | Number of accessible vaccination centres by public transportation within 60min | Categories (accessibility x vaccine uptake) |
| Mean (SD) | Mean (SD) | Mean (SD) |
| G1 | 1098 | 21 | 0.67 | 0.71 (0.1) | 6.35 (8.31) | 1.52 (2.58) | Poor but good |
| G2 | 995 | 25 | 0.78 | 0.66 (0.11) | 5.45 (8.77) | 1.35 (2.94) | Poor and poor |
| G3 | 1,114 | 47 | 1.14 | 0.62 (0.1) | 18.62 (13.09) | 3.9 (5.04) | Outstanding but poor |
| G4 | 815 | 29 | 1.12 | 0.63 (0.12) | 6.15 (7.76) | 1.27 (2.7) | Poor and poor |
| G5 | 1,054 | 22 | 0.67 | 0.69 (0.09) | 6.61 (9.51) | 1.37 (3.06) | Poor but good |
| G6 | 1,175 | 31 | 0.90 | 0.7 (0.11) | 6.92 (8.57) | 1.45 (2.8) | Poor but good |
| G7 | 540 | 23 | 1.25 | 0.65 (0.12) | 9.28 (12.64) | 2.47 (4.31) | Outstanding but poor |
| England | 6,791 | 198 | 0.91 | 0.67 (0.11) | 8.58 (10.85) | 1.9 (3.54) |  |

**Note: Red shaded presents the above than average, while blue shaded presents the below than average.**Map

Description automatically generated

Map

Description automatically generated**Note: Grey dots represent the location of 198 COVID-19 (mass) vaccination centres across England.**

Figure 1. Number of accessible COVID-19 vaccination centres within 45 min by car (left) and 60 min by public transportation (right) for England (above) and zoomed to London (below).

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|  |

Figure 2. Changes in BIC criterion by tuning parameter in the range of pre-set numbers [2,8] on the maximum number of iterations.

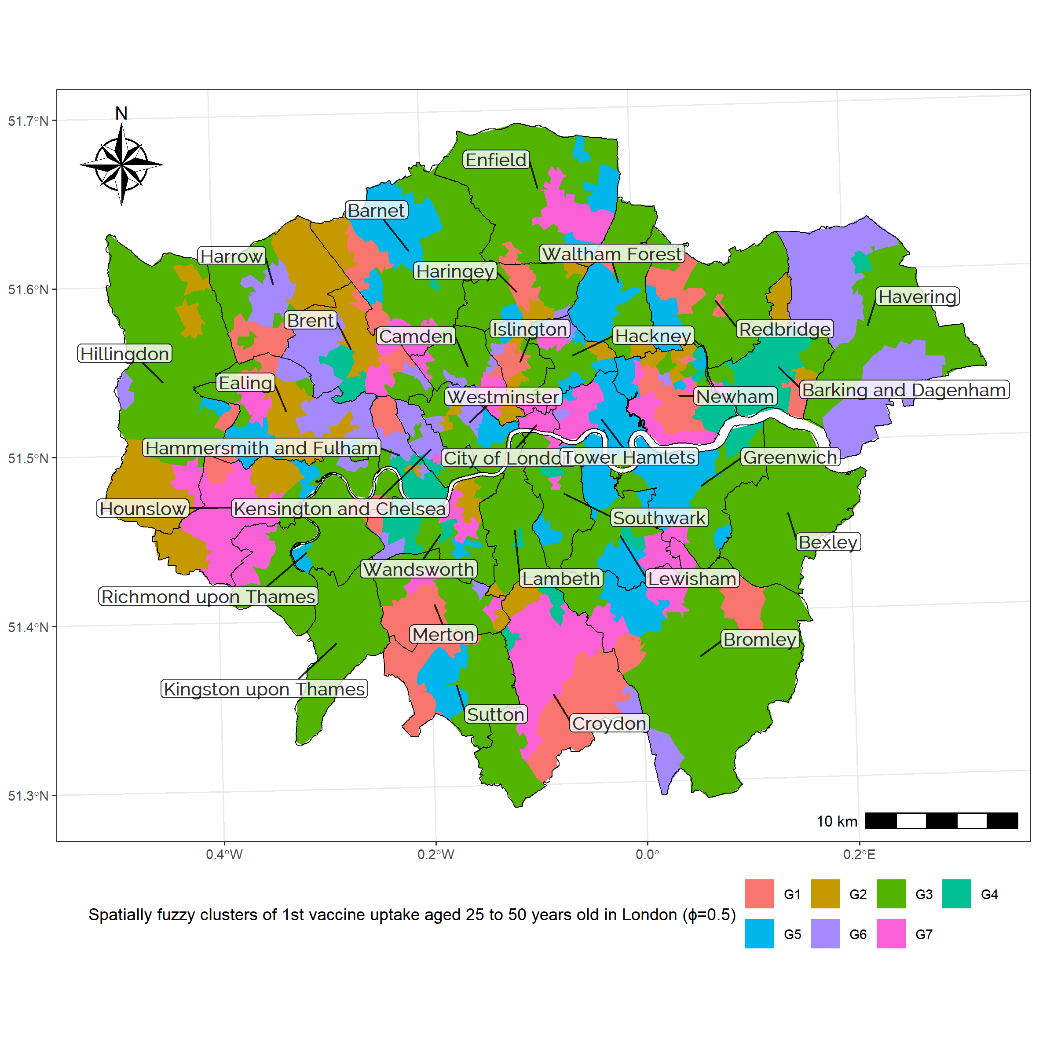
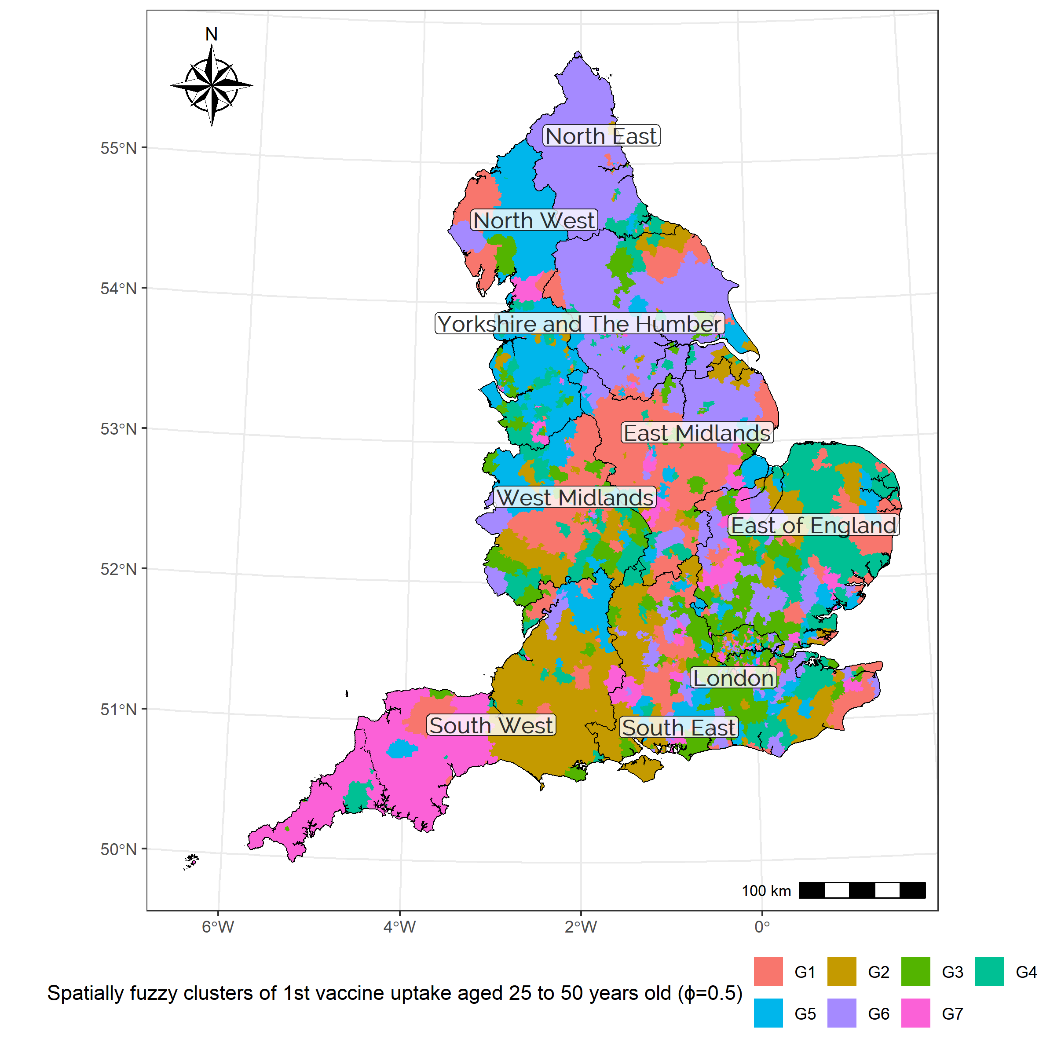


Figure 3. Spatial distribution of generated clusters for England (left) and zoomed to London (right) by 1st vaccine uptake over 25.

* G1: Dominant in Midlands.
* G2: Dominant in South West – East County as remote areas.
* G3: Dominant in London as urban centres.
* G4: Dominant in East of England as remote areas.
* G5: Dominant in North West.
* G6: Dominant in North East and Yorkshire.
* G7: Dominant in South West – West County.

# Appendix

## Why 45min for car?

* “While people might be asked to drive up to 45 minutes each way to one of a series of large regional vaccination centres, they could wait for a more local appointment if needed.”
* From the centroid of 6791 MSOAs to nearest vaccination centres by car; arriving at least one vaccination centres within 10 miles in all MSOAs.

|  |  |  |
| --- | --- | --- |
|  | Distance (km) | Duration (min.) |
| Median | 9.8 | 13.53 |
| Mean | **13.75** | **16.4** |
| SD | 12.51 | 11.44 |

## Why 60min for public transportation at pm 12?

* Considering the maximum coverage of vaccination centres within travel time thresholds, and avoid the peak-time hours of day, due to the fact that walk-in appointments for vaccinations are sometimes available, but they not guaranteed in peak times.
* From the centroid of 6791 MSOAs to nearest vaccination centres by public transportation.

*Tuesday*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Duration (min.) | am 8 | am 10 | pm 12 | pm 2 | pm 4 | pm 6 |
| Median | 34.69 | 33.67 | 34.00 | 34.25 | 35.42 | 34.07 |
| Mean | 58.49 | 48.29 | 48.79 | 47.39 | 48.40 | 48.35 |
| SD | 107.31 | 65.23 | 66.07 | 50.43 | 51.31 | 34.07 |
| Coverage of MSOA | 5,688 | 5,786 | 5,830 | 5,831 | 5,827 | 5,820 |
| Coverage(%) | 0.84 | 0.85 | 0.86 | 0.86 | 0.86 | 0.86 |

*Saturday*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Duration (min.) | am 8 | am 10 | pm 12 | pm 2 | pm 4 | pm 6 |
| Median | 34.67 | 33.57 | 34.00 | 34.22 | 35.30 | 34.08 |
| Mean | 58.54 | 47.40 | 47.83 | 46.66 | 47.53 | 47.67 |
| SD | 110.27 | 60.18 | 57.81 | 41.60 | 42.22 | 45.32 |
| Coverage of MSOA | 5,681 | 5,773 | 5,820 | 5,821 | 5,817 | 5,813 |
| Coverage(%) | 0.84 | 0.85 | 0.86 | 0.86 | 0.86 | 0.86 |

1. Paper prepared for submission to the journal of [*Social Science & Medicine*](https://www.journals.elsevier.com/social-science-and-medicine). [↑](#footnote-ref-1)
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