The relationship between covid-19 and socio-demographic in London: the three lockdowns in 2020

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Abstract

Declaration

I, Chenxi Zhao, here by declare that this dissertation is all my own original work and that all sources have been acknowledged. It is xxx words in length

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Chapter 1

Introduction

1.1 Background

Covid-19 as a global epidemic, governments in various countries and international organizations have made a lot of efforts. At the beginning, almost all the propaganda was that we would fight against Covid-19 together. However, the fact is that certain people or areas are more susceptible to the virus. For example,'Covid triangle' (three London boroughs) has received a lot of attention due to the high infection and death rate. In Barking and Dagenham, 1 in 16 people was reported to be infected (Andrew Gregory, 2021). 'The virus does discriminate' as well as the adverse impacts of trying to control the pandemic and the economic consequences. Recently published data suggests that the most deprived areas of England have Twice the rate of deaths involving Covid-19 than the most affluent (Palmer, 2021).

In addition to inequalities in spatial areas, we found that death rates were influenced by different factors at different stages of development over time. For example, at first it was thought that the main influencing factor was population density, so many governments required the start of mass quarantine and wearing of masks (Cheng et al., 2020). Later on it was found that there was also a strong correlation with some socio-demographic factors and social factors. This inequality of covid-19 cases should be worthy of attention and in-depth research, so that the society and government will continue to work hard to reduce the inequality in population health. This dissertation conducts related research in this context

1.2 Research Question and Objectives

There are many studies on covid-19, but most of them are based on countries and regions. There are very few analyses that have detailed studies on various areas and cities below the country. However, only by understanding the relevant factors in these small areas can we have a more accurate judgment on covid-19 and better reflect on this global epidemic.

In this context, this dissertation will focus on London Middle Layer Super Output Areas (hereinafter referred to as MSOA) level areas and try to discuss the inequality and causes of covid-19 cases. Specifically to discuss the following two issues:

What is the relationship between London's covid-19 case rate and socio-demographic factors?

How is this relationship different in the three lockdowns in 2020?

Chapter 2

Literature Review

2.1 The development and characteristics of the global covid-19

Since the outbreak of the covid-19 in Wuhan, China, the world's perception of covid-19 has changed a lot. Including people's awareness of covid-19 at the beginning, and with the development of covid-19, some trend characteristics have been discovered.

At first it was thought that the virus only occurred in China, but within a few weeks it spread to 213 countries and regions, and more than 5.5 million people were infected (Worldometer, 2020). As of 2020, the number of global cases will exceed 79.2 million, and the number of deaths will exceed 1.7 million (WHO). People realize that this disease is not limited to some regions, but affects the entire world.

It is the biggest disaster that has attacked mankind on a global scale since modern times (WHO, 2020), which has brought many difficult decisions to countries and regional governments as well as schools, businesses and families. How should countries with limited scarce resources allocate it? How does the government guarantee the people's health and basic life? How do companies face constant losses? As you can see, this impact is not only reflected in the infection rate and death rate, but also has a great impact on the social economy and even the social structure. From a localized outbreak to the blockade of the entire country, the world is facing the worst economic recession since the Great Depression. Globally, 155 million full-time jobs were lost in the first quarter of 2020, rising to 400 million in the second quarter, with lower- and middle-income nations bearing the brunt of the loss. A further 71 to 100 million people are being pushed into severe poverty as a result of the epidemic (IMF, 2020). Even according to simulations, the Human Development Index (HDI) is on the verge of a dramatic and historic fall, undermining six years of development (How COVID-19 is changing the world: a statistical perspective (Volume II) | Population Division, 2021).

In addition to the above-mentioned impacts on various aspects of society, there are some other findings from the perspective of cases. First, there are obvious regional differences. As mentioned above, the case rate in some specific countries or specific regions is surprisingly high. Even covid-19 is described as a heat-seeking missile speeding toward the most vulnerable in society. This means that rich countries or regions and poor countries or regions are experiencing two different epidemics (Schellekens and Sourrouille, 2021).

Secondly, as a long-term epidemic, covid-19 has changed over time and cannot be ignored. In the beginning, according to the data as of May 23, 2020, the paper showed that the cases and death rate were mainly concentrated in high-income countries.

Although developing countries accounted for 85% of the global population, the death toll from covid-19 accounted for only 21%. But the paper argues that this phenomenon of excessive bias towards rich countries is inconsistent with demographics. Models based on infectiousness and mortality indicate that the share of developing countries in global deaths will triple (from 21% to 69%) (Schellekens and Sourrouille, 2021). Facts show that this conjecture is correct. A report published on May 27, 2021 shows that the cumulative mortality rate in developing countries exceeds 50%. This means As time goes by, covid-19 has become an epidemic in developing countries (Schellekens, 2021).

Finally, there are findings related to some external factors, such as: the spread of covid-19 in the global age distribution is relatively slow, but it has a great relationship with demographics. The impact of the environment on the cases is not great Pan et al., 2021).

2.2 Covid-19 situation in London

As of 2020, Europe's cumulative cases and deaths ranks second in the world, accounting for 31% of the world's total (Eurostat). The infection rate in the United Kingdom have always been of concern, because the cumulative number of cases in the United Kingdom is higher than other European countries for most of the time. This article selects the capital London as the research sample to discuss some issues of case rate and social demographics.

London is not only a very representative area, but also a region with its own characteristics. First of all, the epidemic in London is the most serious, with the highest number of confirmed cases in a single day exceeding 40,000 in 2020. And in the first three months of the covid-19, London had the highest proportion of deaths, accounting for 1/5 of the total deaths in England (ONS). Studying an area with a high cases and mortality rate is of great reference value to a certain extent.

Second, London is similar to the global case rate mentioned above. For example, the phenomenon of regional inequality is very serious. Some papers believe that this inequality is mainly due to wealth inequality, because three were in the most deprived quintile of the IMD, two were in the least deprived quintile (ONS). At the same time, A report published by WPI Economics considered for the first time the relationship between the mortality rate in London and the characteristics of the community (poverty, race, and age). According to this paper, we can see that areas with the following characteristics have higher infection rates and mortality rates than other areas: poor, elderly, Asians, and nursing home residents.

Third, there are some characteristics of London that are worthy of our investigation. According to ONS data, the majority of cases from covid-19 are people over 65 years of age. However, the average age of cases in London is younger than that in other parts of England (Weir and Oakley, 2020). This is why in 2020, the UK has almost the

highest excess case rate under 65 years (ONS) in Europe. Finally, some papers believe that with the gradual development of the epidemic, poverty and population density are not as strong as they were at the beginning during this long period of time, and the correlation between obesity and air pollution must also be taken into account. Although their correlation coefficients are not so strong, considering these variables alone seems to be able to predict the case rate that affects covid-19 (Bray, Gibson and White, 2020).

Chapter 3

Data Source and Processing

3.1 Data selection and processing

The data samples are obtained from three public non-profit government official websites, namely London Datastore, ONS and GOV.UK. We think it can be regarded as a reliable source of data. For variable data, 6 datasets of case rate, social demographic factors and privacy related are selected respectively. The dataset of sociodemographic factors includes demographic, economic and spatial aspects. Deprivation related datasets include Index of Multiple Deprivation (IMD) and deprivation index scores in different domains. In terms of time, the data of covid-19 uses the data that was blocked three times in 2020. And the other data uses the latest version of the public data, mainly the data of 2019 and 2011. The data sample is 983 areas of London MSOA level. The dimensions of the data are more complex, including MSOA and LSOA data from London, England and the United Kingdom. Need to select the London data in datasetsand merge it into MSOA data.

In terms of data processing, the following four stages are mainly carried out. In the first step, find the relevant datasets including the 6 datasets of the above mentioned related variables. The MSOA and LSOA correspondence table, and the London shapfile. In the second step, the final dataset is obtained through data processing. And the 19 independent variables are divided into 4 categories according to their characteristics. The specific data processing steps are as follows: firstly, each dataset is cleaned separately. Only useful variables are retained and the format is unified. The original 6 datasets have a total of 76 columns, and the dataset with the largest number of rows is 37270. After processing, 32 columns of useful data are left. Secondly, only the London part of all MSOA data is extracted. Then use the affiliation relationship between LSOA and MSOA to convert LSOA related data into MSOA.. Finally, merge the above data together and remove duplicate columns. A dataset of 984 rows and 22 columns is obtained, which includes 19 independent variables and 3 dependent variables during the 3 lockdown periods. The third and fourth steps of data processing are to process the verification data through different methods, and finally get the data results and visualization charts.

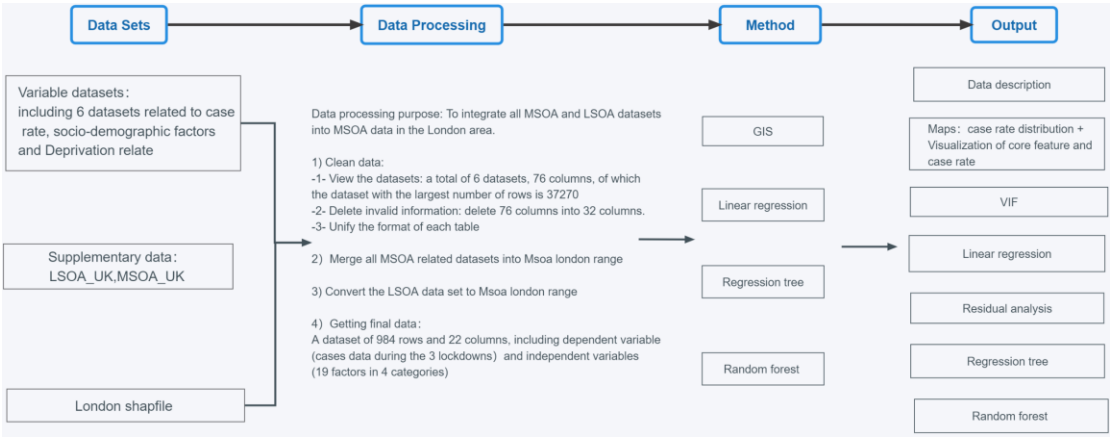


Figure1: Data Framework

3.2 Data explanation

The dependent variable is the new cases by specimen date rolling rate of the weekly dimension in 2020. In order to compare areas or population groupings of different sizes, rates are determined. All current rates on GOV.UK are crude rates expressed per 100,000 population, which means that the count (for example, cases or deaths) is divided by the denominator population and then multiplied by 100,000, with no adjustments for additional factors. (GOV.UK)

In the MSOA data of Covid-19, the smallest unit of time is weekly. Meanwhile, the data selected in this article start with Sunday as the new week. In the case of a non-full week, more than half of the days will be calculated as a week. In other words, in the case of not a full week, if the total number of days between the start date and the start week and the number of days between the end date and the end week is greater than or equal to 4, the start week starts with the week of the start date, and the end week is the complete week. If the total is greater than or equal to 8 days, the start week starts with the week of the start date, and the end week ends with the week of the end date. The time frame studied in this article is the situation of three lockdowns in 2020. The start and end time of each lockdown comes from government and media releases. The specific dates are
as follows:

Description	Start Date（2020）	End Date（2020）
First national lockdown	26th March	23rd June
Second national lockdown	5th November	2nd December
Third national lockdown	21st December	31st December

Table1: Lockdown Timeline

In terms of independent variables, 19 factors in 4 categories are selected.

1) Demography related factors (X1: NUK, X2: O65, X3: Bame)

   X1: NUK is country of birth is not UK. This variable is added because it determines whether people can get the same social rights and benefits. Meanwhile, in covid-19, we have seen that the infection is related to certain groups of people, especially bame and the elderly. (Kakkar, Dunphy and Raza, 2021) Approximately

90% of coronavirus deaths occur in those over the age of 65. (Van Rens and Oswald, 2021). Therefore, proportion of people over 65 (X2: O65) and all bame (Black, Asian and minority ethnic) proportion (X3: Bame) are also considered as variables

2) Economy& house related factors (X4: Income, X5: HP, X6: OO, X7: OML, X8: SR, X9: PR, X10: NR) are mainly divided into three parts: income, house price and tenure.

   X4: Income is a proxy for the percentage of the population that suffers from deprivation as a result of low income. The term "low income" is used to refer to both those who are unemployed and those who are employed but earn a low wage.

   X5: HP uses the median, because the price difference in London is larger. The median is more representative of the overall level than the average. (Laerd Statistics, 2021) Housing related expenditure is an important part of people's life pressure, so here is a breakdown of relevant data for housing scenarios such as renting a house and buying a house.

3) Spatial related factors(X11: Geo, X12: Density).

   X11: Geo is the Geographical Barriers sub-domain, which measures the comprehensive index of Road distance to a post office, a primary school, a general store or supermarket and a GP surge y. X12: Density refers to population density, divided by the total population of the same area by the total area.

4) Deprivation related factors (X13: IMD, X14: Health, X15: AS, X16: Employment, X17: Education, X18: Crime and X19: Environment).

   The Multiple Deprivation Index (IMD) is an overall relative measure of deprivation, which is composed of seven areas of deprivation (such as income, education, etc.) with different weights. It can comprehensively represent the deprivation situation in a region.

   The Health Deprivation and Disability Domain (X14: Health) assesses the likelihood of premature death and the impact of poor physical or mental health on one's quality of life. The domain collects data on sickness, disability, and premature mortality, but not on behavioral or environmental factors that may be predictive of future health deprivation.

   The Adult Skills sub-domain (X15: AS) is a non-overlapping count of adult skills and English language proficiency. The targets are women aged 25-59 and men aged 25-64.

   The Employment Deprivation Domain (X16: Employment) quantifies the percentage of working-age residents who are involuntarily excluded from the labor market in a certain location. This category comprises individuals who wish to work but are prevented from doing so owing to unemployment, illness or disability, or caring duties.

   The Education, Skills and Training Domain (X17: Education) comprehensively represents the comprehensive educational skills from children to adults in a certain area. Including reference to the absenteeism rate of middle school students, the situation of receiving higher education and so on.

   X18: Crime assesses the risk of victimisation, including assault, burglary, theft,

and criminal damage, at the local level.

The Deprivation of a Living Environment Domain (X19: Environment) quantifies the quality of the local environment. Housing quality, air quality, and road traffic accidents are all factors to consider.

Dimensions	Name	Variable Description	Unit	Data Source
	Y1: Cases1	new cases by specimen date rolling rate during the first lockdown	Percentage	GOV.UK, 2020
	Y2: Cases2	new cases by specimen date rolling rate during the second lockdown	Percentage	GOV.UK,2020
	Y3: Cases3	new cases by specimen date rolling rate during the third lockdown	Percentage	GOV.UK,2020
Demography	X1: NUK	country of birth is not UK	Percentage	London Datastore,2011
	X2: O65	proportion of people over 65	Percentage	London Datastore,2019
	X3:Bame	all bame (Black, Asian and minority ethnic) proportion	Percentage	London Datastore,2011
Economy& house	X4: Income	income score (rate)	Percentage	GOV.UK, 2019
	X5: HP	house price	Pounds	ONS, 2019
	X6: OO	owned outright	Percentage	London Datastore,2011
	X7: OML	owned with a mortgage or loan	Percentage	London Datastore,2011
	X8: SR	social rented	Percentage	London Datastore,2011
	X9: PR	private rented	Percentage	London Datastore,2011
	X10: NR	house old spaces with no usual residents	Percentage	London Datastore,2011
Spatial	X11: Geo	geographical barriers sub-domain	Score	GOV.UK, 2019
	X12: Density	population density	Value	London Datastore,2019
Deprivation related	X13: IMD	index of multiple deprivation (IMD)	Score	GOV.UK, 2019
	X14: Health	health deprivation and disability	Score	GOV.UK, 2019
	X15: AS	adult skills sub-domain score	Score	GOV.UK, 2019
	X16: Employment	employment score (rate)	Percentage	GOV.UK, 2019
	X17: Education	education, skills and training score	Score	GOV.UK, 2019
	X18: Crime	crime score	Score	GOV.UK, 2019
	X19: Environment	living environment score	Score	GOV.UK, 2019

Table2: Description of Variables

3.3 Data Descriptive

The overall data distribution is reasonable and no additional processing is required. However, there is a large gap between the maximum and minimum values of some variables, such as the case rate of three lockdowns and X12: Density. It shows that the data distribution of these variables is relatively scattered, and the degree of dispersion is relatively large. This means that there is a big gap between the case rate and population density of different regions. On the other hand, the case rate of the three lockdowns, the median of X5: HP and X12: Density is significantly smaller than the average. This shows that the difference between the top 50% and the bottom 50% of the data is relatively large, and more than half of the data are below the average. While, these data are true and reliable, they just show the characteristics of different data, so no additional processing is done.

Dimensions	Name	Count	Std	Mean	Median	Min	Max
	Y1: Cases1	972	9020.14	578.86	265.30	33.70	281613.70
	Y2: Cases2	983	32480.71	2072.90	1001.30	388.20	1019866.40
	Y3: Cases3	983	49572.99	3163.75	1535.10	503.40	1556563.60
Demography	X1: NUK	983	13.83	36.21	37.17	4.39	69.23
	X2: O65	983	0.05	0.12	0.12	0.02	0.28
	X3:Bame	983	0.19	0.39	0.37	0.04	0.94
Economy& house	X4: Income	983	0.06	0.14	0.13	0.01	0.34
	X5: HP	983	243318.41	526463.37	465000	214000	2850000.00
	X6: OO	983	10.91	21.68	20.60	2.20	53.70
	X7: OML	983	10.22	27.66	28.30	5.90	53.70
	X8: SR	983	16.55	23.68	19.90	0.50	74.10
	X9: PR	983	10.62	24.44	24.30	3.40	57.70
	X10: NR	983	2.77	3.32	2.50	0.50	28.60
Spatial	X11: Geo	983	0.49	-0.60	-0.61	-2.04	0.69
	X12: Density	983	54.14	91.55	79.85	2.89	286.43
Deprivation related	X13: IMD	983	9.45	21.56	21.20	4.06	50.42
	X14: Health	983	0.60	-0.38	-0.29	-3.04	1.04
	X15: AS	983	0.10	0.26	0.26	0.05	0.49
	X16: Employment	983	0.04	0.09	0.08	0.01	0.24
	X17: Education	983	8.72	13.10	11.72	0.21	44.75
	X18: Crime	983	0.44	0.26	0.30	-1.66	1.55
	X19: Environment	983	9.02	29.18	28.95	7.66	61.35

Table3: Description of Data

3.4 Data advantages and limitations

The data set used in this article has the following advantages and disadvantages. First of all, the data comes from the government's public data official website, and the security, authenticity and source of the data are guaranteed to a certain extent. Secondly, the data dimensions of MSOA London range make subsequent results more in line with actual conditions. Because MSOA data has more samples than other dimensions such as ward and borough. The outcomes of aggregate data analysis are well known to be reliant on the size and shape of the zones utilised to convey the data. (Lloyd, 2015) Therefore, MSOA level data can reflect the real situation in a small area. But it is also because the data is more detailed. Some relevant data will not be disclosed, such as the number of mortality in the weekly, population movements, etc. Because this kind of data involves privacy, after communicating with the official email, it is not recommended as a graduate student for academic research. Therefore, the privacy risk data is not involved in this article. At the same time, because of the lack of the above data, the research direction of this paper will not get the maximum fitting result.

Chapter 4

Methodology

This article mainly uses linear regression to study the relationship between covid-19 and social demographic factors, and uses regression trees and random forests for testing and prediction. By comparing the advantages and disadvantages of different methods, we critically look at the results of different methods and models.

In linear regression, VIF is used to deal with multicollinearity, and the confidence of P-value is discussed. Finally residual analysis is performed. In order to achieve a better fitting effect, continuously adjust the range of different indicators and remove outliers in this process.

In the two models of regression tree and random forest, we try to continuously adjust the hyperparameters by using cross-validation and GridSearchCV methods to optimize the model. In this process, the depth and number of the tree are adjusted through max_depth and n_estimators. At the same time, because the dataset has a small sample size, internal nodes such as min_samples_split and min_samples_leaf are not divided.

4.1 Multicollinearity

Multicollinearity refers to the existence of linear correlation between independent variables, that means the relationship between independent variables is strong. Multicollinearity will lead to instability in the estimation of regression coefficients and intercept coefficients, which leads to instability of the model. Therefore, when the multicollinearity is serious, appropriate methods should be adopted to adjust.

In an ordinary least squares regression analysis, **Variance Inflation Factor (VIF)** quantifies the severity of multicollinearity. It represents the ratio of the variance of the regression coefficient estimator to the variance when the independent variables are assumed to be non-linearly correlated. The specific formula is as follows:

$$VIF_k = \frac{1}{1 - R_k^2} \tag{1}$$

The value of VIF is greater than 1. The closer the VIF value is to 1, the lighter the multicollinearity, and vice versa. If the VIF of the independent variable is displayed in an appropriate range, the problem of multicollinearity in the model can be ignored (Voltes-Dorta and Schez-Medina, 2020). Variables with a vif score greater than 5 are considered to have a strong correlation, there may be serious collinearity (Shrestha, 2020). Therefore, this article deletes these variables with vif greater than 5.

4.2 Linear regression

Linear regression is a statistical method for modeling the connection between a scalar response and one or more explanatory variables (also known as dependent and independent variables). Multiple linear regression is a specific example of generic

linear models with only one dependent variable, and is a generalization of simple linear regression with more than one independent variable. Meanwhile, multiple linear regression is a model that uses the best combination of two or more independent variables to predict or estimate dependent variables. (MAXWELL, 1975) The equation is as follows: (when n is the number of observation, k is the number of independent vatiables):

$$y = X\beta + \varepsilon \quad y = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{pmatrix}, X = \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1k} \\ x_{21} & x_{22} & \cdots & x_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nk} \end{pmatrix}, \beta = \begin{pmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_n \end{pmatrix}, \varepsilon = \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_n \end{pmatrix} \quad (2)$$

OLS is used to estimate model parameters since it minimizes the sum of squared errors. As a result, the coefficient matrix can be solved as follows:

$$\hat{\beta} = (X^T X)^{-1} X^T y = Hy \quad (3)$$

After getting the regression equation, we have to test the significance of the regression equation. The significance test here mainly includes four parts. The first is the **F-test**, which is to test whether all independent variables have a significant effect on dependent variable as a whole. And it is a variance test of the regression model as a whole. The second is the significance test of the coefficient of a single variable by the **T-test**. At the same time, the **P-value** is a measure used for T-test and F-test. P-value less than 0.05 means that the variable rejects the null hypothesis and has a significant effect on dependent variable.The third is to judge the goodness of fit through **The coefficient of determination** (R^2) :

$$R^2 = 1 - \frac{SSE}{SST} = 1 - \frac{\sum(y_i - \hat{y})^2}{\sum(y_i - \bar{y})^2} \quad (4)$$

The value is between 0 and 1. The closer to 1, the better the effect of regression fitting, and the closer to 0, the worse the effect. However, the R^2 will increase due to the increase of variables, so the adjusted R^2 is introduced. The adjusted R^2 is useful for comparing a model with and without a particular variable in order to determine whether or not the variable improves the model. The formula is as follows:

$$R^2_{adj} = 1 - \frac{(1-R^2)(n-1)}{n-k-1} \quad (5)$$

Finally, use **residual analysis** to check the linear model. The residual is the difference between the observed value and the fitted value, that is, the difference between the actual observed value and the regression estimate. Normality test, linearity test, independence test, homoscedasticity test and other methods to residual analysis. And remove outliers whose absolute value of standardized residual is greater than 3. Because these values are considered "outliers", they will affect the final results and accuracy of the model (Gray and Woodall, 1994). If there are no obvious outliers, all data will be kept, because they will not affect the r-square too much.

4.3 Regression Tree and Random Forest

The **regression tree(RT)** is traversed by traversing the branches of the tree and selecting the next branch according to the decision of the node. Regression Tree Induction takes a set of training examples as input, determines which attributes are

most suitable for segmentation, and divides the data set, and loops on the divided data set until all training examples are classified, and the task ends.

But the regression tree has a tendency to over-fit, which means that new data cannot be used. Therefore, **random forest(RF)** will be used for optimization. It is a collection of simple regression tree, and the input vector runs on multiple regression trees. For the regression problem involved in this article, the output values of all regression trees are average.

In general, the regression tree constructs a tree structure by subdividing predictors. While, random forest generates a large number of trees at random and then aggregates their forecasts.

Chapter 5

Results

5.1 Covid-19 case rate under different lockdown periods

The following three pictures respectively show the distribution of infection rates during the first, second and third London lockdown. The regional division standard is the MSOA mentioned above. It can be seen that over time, the overall case rate in London is gradually increasing. At the same time, the infection rate in London's North East is getting worse. Specifically, the case rate is mainly concentrated at around 200 in lockdown1, around 1000 in lockdown2, and around 1500 in lockdown3. Therefore, although the case rate has become more and more serious over time, the growth rate has slowed down from lockdown2.

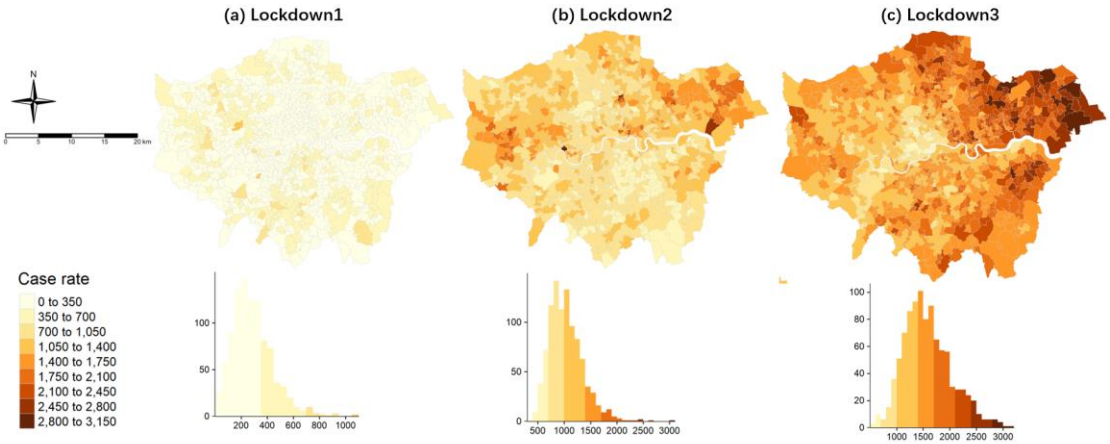


Figure2: Covid-19 case rate distribution maps

5.2 Covid-19 case rate under different regions

The following will show the results of linear regression, regression tree and random forest for each lockdown. As the main method of the article, linear regression will be explained in detail. The model will be fitted in various stages of removing multicollinearity, outliers, residual analysis, etc., to obtain the final model. Regression tree and random forest use hyperparameters and cross-validation methods to continuously optimize tree branches and parameters to get the final model. Compared with regression tree, random forest can be less affected by outliers and can reduce the possibility of overfitting. Therefore, we focus on the results of random forest.

Because each lockdown data will be processed with the same steps as above, there is a certain degree of repetition. Thus, some details of the display will be omitted in the lockdown2 and lockdown3 parts.

5.2.1 The result of the first lockdown

5.2.1.1 Linear regression

In linear regression, the VIF method is first used to sequentially delete independent variables with high multicollinearity. It is found that the VIF of 7 independent variables such as X7: SR, X12: IMD is higher than 5, indicating that the

multicollinearity is very strong and will affect the results of the model. The 7 independent variables whose VIF is higher than 5 are deleted, and 12 independent variables remain. The following table shows the VIF value of the deleted variables:

Variable	X7: SR	X12: IMD	X16: Employment	X15:AS	X1: NUK	X5: OO	X6: OML
VIF	266.163	61.070	24.708	16.912	10.843	7.618	5.195

Table 4: VIF of the deleted variable in lockdown1

Secondly, the fitting of linear regression was performed twice. The first time is the fitting result after removing multicollinearity, and the second time is the final fitting result. Among them, after the first fitting, a residual analysis was carried out. It is found that the overall residual distribution is relatively uniform, and there is no obvious non-linear relationship. However, there are some separate group values, and the final fitting is performed after removing the outliers that will affect the results and accuracy of the model. Normally, the standardized residuals with absolute values greater than 3 in the observations are considered "outliers" (Gray and Woodall, 1994). The fitting result is shown in the figure:

Regression	Multicollinearity processed	Final regression
Number of samples	972	959
Number of independent variables	12	12
R-squared	0.154	0.186
Adj.R-squared	0.144	0.176
F-statistic	14.59	18.04
Prob(F-statistic)	2.42e-28	2.27e-35

Table 5: Linear regression comparison in lockdown1

On the whole, we can see from the table that the sample size after the processing of collinearity and residuals is 959 (13 outliers are deleted), and the independent variable is 12 (7 independent variables with high multicollinearity are deleted). And the final regression, whether it is the reslut of R-squared or Adj.R-squared is better than the previous fitting situation, which are 0.186 and 0.176 respectively. F-statistic is within a reasonable range, Prob (F-statistic) less than 0.05 indicates that the null hypothesis is rejected and the model is significant.

From the perspective of P-value, the values of X4: Income and X10: Density are greater than 0.1, indicating that these two independent variables are not very explanatory for the infection rate during lockdown1. The P-values of X10: NR, X14: Health and X17: Education are between 0.05 and 0.1, indicating at least a 90% confidence level, which is highly significant. The P-values of other independent variables are all less than 0.05, indicating at least 95% confidence level, which means a strong correlation.

From the perspective of coefficients, when all the independent variables take 0, the predicted value of the dependent variable is 297.174. Demographic related factors can affect the case rate more than other factors. Specifically, the coefficients worth paying attention to are X2: O65 (256.1346), X3: Bame (254.0734), X4: Income (-68.8467),

X11: Geo (48.621) and X18: Crime (-34.0174). This shows that with the other independent variables remaining constant, each increase of O65, Bame and Geo by one unit may increase the case rate by 256.134, 254.0734 and 48.621 units. Income and Crime are negatively correlated. When other independent variables remain the same, each increase of one unit of them may reduce the case rate by -68.8467 and -34.0174 units. The coefficient of X5:HP is extremely low, indicating that the impact on the dependent variable is small. The specific regression results are as follows:

Dimensions	Name	Coefficient	Std error	T-value	P-value
Demography	(Intercept)	297.1742	35.843	8.291	0
	X2: O65	256.1346	113.505	2.257	0.024
	X3:Bame	254.0734	29.727	8.547	0
Economy& house	X4: Income	-68.8467	165.173	-0.417	0.677
	X5: HP	-9.87e-05	2.79e-05	-3.541	0
	X9: PR	-3.3659	0.633	-5.317	0
	X10: NR	3.7471	2.18	1.719	0.086
Spatial	X11: Geo	48.621	11.726	4.147	0
	X12: Density	-0.0106	0.095	-0.112	0.911
Deprivation related	X14: Health	25.8371	14.374	1.798	0.073
	X17: Education	-1.5223	0.807	-1.888	0.059
	X18: Crime	-34.0174	14.601	-2.33	0.02
	X19: Environment	1.7739	0.792	2.239	0.025

Table 6: Linear regression result in lockdown1

5.2.1.2 Regression Tree and Random Forest

Use other methods of regression trees and random forests to verify and predict the above results. First, the data is divided into training, verification, and test sets, where the proportion of data is 7: 1.5: 1.5 respectively. Then through cross-validation and GridSearchCV methods to continuously adjust the hyperparameters. In order to adjust the number of iterations and depth of trees to a better value, two parameters are mainly adjusted namely depth and n_estimators. Among them, because the data has more features, max_depth is set to 8. At the same time, in order to ensure the unity of the dataset and the reliability of the results, the dataset of these two methods are the same as the dataset in the final regression. That means using the dataset after removing the outliers. Follow-up lockdown 2 and 3 also follow the same idea and operation method.

In general, these two results are slightly better than linear regression. From the optimization results of the regression tree model, we can see that when best_depth is 4, the best prediction result is 0.2043. At the same time, when n_estimators is 150, the random forest has the best prediction result with a score of 0.28.

From the point of view of feature importance, the importance of 9 features such as X1: NUK and X4: Income in the regression tree is 0, while each feature in the random

forest has a certain importance. At the same time, in the regression tree, the most important feature is the X15: AS of 0.352 related to the economy & house. The importance of X15: AS in the random forest is also the highest at 0.1127.

Dimensions	Regression Tree		Random Forest	
	Core index	best_depth: 4	Core index	n_estimators: 150
	Score	0.2043	Score	0.28
Demography	X1: NUK	0	X1: NUK	0.04202
	X2: O65	0.04703	X2: O65	0.06535
	X3: Bame	0.12319	X3: Bame	0.0853
Economy& house	X4: Income	0	X4: Income	0.02125
	X5: HP	0.05972	X5: HP	0.07466
	X6: OO	0.04864	X6: OO	0.04179
	X7: OML	0	X7: OML	0.04308
	X8: SR	0.07865	X8: SR	0.03518
	X9: PR	0	X9: PR	0.05251
	X10: NR	0.02313	X10: NR	0.05049
Spatial	X11: Geo	0.15365	X11: Geo	0.06849
	X12: Density	0	X12: Density	0.05506
Deprivation related	X13: IMD	0	X13: IMD	0.02563
	X14: Health	0	X14: Health	0.0422
	X15: AS	0.35213	X15: AS	0.11277
	X16: Employment	0	X16: Employment	0.0304
	X17: Education	0	X17: Education	0.05164
	X18: Crime	0.08772	X18: Crime	0.05102
	X19: Environment	0.02614	X19: Environment	0.05115

Table 7: The result of RT and RF in lockdown1

5.2.2 The result of the second lockdown

5.2.2.1 Linear regression

Since the process of processing data will be consistent with that in 5.2.1, some details will be omitted to avoid repetition. In the linear regression within the time range of lockdown2, two linear regression fittings were also performed. The first time is the fitting after removing the multicollinearity variable. The independent variables greater than 5 are deleted here, and it is found that the independent variables that need to be deleted are consistent with those in the lockdown1 model. After processing 19 variables, the remaining 12 independent variables. Then remove the outliers in the residual analysis, which refers to the observations with the absolute value of the standard residuals greater than 3. After the final regression fitting, the results are shown in the table:

Regression	Multicollinearity processed	Final regression
Number of samples	983	974
Number of independent variables	12	12
R-squared	0.163	0.164
Adj.R-squared	0.153	0.153
F-statistic	15.74	15.65
Prob(F-statistic)	9.56e-31	1.50e-30

Table 8: Linear regression comparison in lockdown2

The sample size of the final model was 974 (9 outliers were deleted), and the independent variable was 12 (7 independent variables with high multicollinearity were deleted). And the final regression effect is better than the model before residual analysis, the results of R-squared and Adj.R-squared are 0.164 and 0.153. F-statistic is within a reasonable range, Prob (F-statistic) less than 0.05 indicates that the null hypothesis is rejected and the model is significant.

In terms of P-value, the overall effect is not as good as the model in lockdown1. Among them, the P-value of 7 independent variables such as X5: HP, X10: NR is greater than 0.1, indicating that these independent variables are not very explanatory for the case rate in lockdown2 period. The P-values of the other five independent variables are all less than 0.05, which has a strong correlation.

From the perspective of coefficients, when all the independent variables take 0, the predicted value of the dependent variable is 1050.436. The coefficient of X4: Income is surprisingly high at -2677.65. This means that with other independent variables remaining constant, each additional unit of income may reduce the case rate at lockdown2 by 2677.65 units. At the same time, the variables X3:Bame and X2:O65 related to people also affect the infection rate more than other characteristics, with coefficients of 517.35 and 166.54, respectively. And it is found that the coefficient of X5: HP is also very small, which is the same as lockdown1, indicating that house prices in these two time periods have a small impact on the infection rate. The specific regression results are as follows:

Dimensions	Name	Coefficient	Std error	T-value	P-value
Demography	(Intercept)	1050.436	77.385	13.574	0
	X2: O65	166.5387	246.626	0.675	0.5
	X3:Bame	517.3545	64.656	8.002	0
Economy& house	X4: Income	-2677.65	361.096	-7.415	0
	X5: HP	2.06E-05	6.00E-05	0.344	0.731
	X9: PR	-1.2581	1.372	-0.917	0.359
	X10: NR	-1.8452	4.703	-0.392	0.695
Spatial	X11: Geo	-56.9937	25.387	-2.245	0.025
	X12: Density	-0.4595	0.204	-2.249	0.025
Deprivation related	X14: Health	36.0244	30.815	1.169	0.243
	X17: Education	15.4932	1.812	8.549	0
	X18: Crime	13.5358	31.178	0.434	0.664
	X19: Environment	-1.4238	1.712	-0.831	0.406

Table 9: Linear regression result in lockdown2

5.2.2.2 Regression Tree and Random Forest

Use the same methods and operations as 5.2.1 to fit regression trees and random forests. The specific steps will not be repeated. Unlike lockdown1, the results of RT are far worse than the fit of LR, indicating that this method is not very suitable. The

situation of RF is better than LR. When n_estimators is 150, the score is 0.231. As in lockdown1, the most important feature is also X15: AS, where the importance is 0.18. And it is found that the importance of economy& house related features is generally high.

Dimensions	Regression Tree		Random Forest	
	Core index	best_depth: 2	Core index	n_estimators: 150
	Score	0.0688	Score	0.2312
Demography	X1: NUK	0	X1: NUK	0.06176
	X2: O65	0	X2: O65	0.04718
	X3: Bame	0.09375	X3: Bame	0.09897
Economy& house	X4: Income	0	X4: Income	0.02242
	X5: HP	0	X5: HP	0.04671
	X6: OO	0	X6: OO	0.04262
	X7: OML	0	X7: OML	0.03331
	X8: SR	0.32001	X8: SR	0.06883
	X9: PR	0	X9: PR	0.04195
	X10: NR	0	X10: NR	0.02857
Spatial	X11: Geo	0	X11: Geo	0.04785
	X12: Density	0	X12: Density	0.04962
Deprivation related	X13: IMD	0	X13: IMD	0.0241
	X14: Health	0	X14: Health	0.03317
	X15: AS	0.58624	X15: AS	0.18047
	X16: Employment	0	X16: Employment	0.04554
	X17: Education	0	X17: Education	0.0489
	X18: Crime	0	X18: Crime	0.04179
	X19: Environment	0	X19: Environment	0.03624

Table 10: The result of RT and RF in lockdown2

5.2.3 The result of the third lockdown

5.2.3.1 Linear regression

In the two linear regression fittings in lockdown3, the final fitting result is slightly better than the first one. In this process, the same as lockdown1 and 2 processing standards, still delete the data with vif greater than 5 and the absolute value of the standardized residual greater than 3. In the last fitting, the sample size was 979 (removed 4 outliers), and the independent variable was 12 (removed 7 independent variables with high multicollinearity). And the goodness of fit is slightly better than that before processing the residuals, the r-square is 0.302 and the model is significant. The result is shown in the table:

Regression	Multicollinearity processed	Final regression
Number of samples	983	979
Number of independent variables	12	12
R-squared	0.301	0.302
Adj.R-squared	0.292	0.293
F-statistic	34.74	34.76
Prob(F-statistic)	2.87e-67	2.91e-67

Table 11: Linear regression comparison in lockdown3

Specifically, the P-value performance of each variable is better than lockdown1 and lockdown2. Among them, X11: Geo and X14: Health are not very explanatory for the infection rate during lockdown2, because the p-value is greater than 0.1. While, the remaining 5 independent variables P-values are all less than 0.05, which has a strong correlation.

From the point of view of coefficients, the intercept of the model is 2460.2. It is worth noting that the coefficients of the two negatively correlated independent variables are particularly high, X4: Income is -3573.85, and X2: O65 is -934.49. This means that under the condition that other characteristics remain unchanged, each unit reduction of Income and O65 may increase the case rate by 3573.85 and 934.49 units. At the same time, X5: HP is still the variable with the smallest coefficient of -0.0003. The specific regression results are as follows:

Dimensions	Name	Coefficient	Std error	T-value	P-value
Demography	(Intercept)	2460.206	103.824	23.696	0
	X2: O65	-934.492	331.587	-2.818	0.005
	X3:Bame	189.2974	86.656	2.184	0.029
Economy& house	X4: Income	-3573.85	482.273	-7.41	0
	X5: HP	-0.0003	8.05E-05	-4.242	0
	X9: PR	-7.6214	1.838	-4.146	0
	X10: NR	-19.0532	6.32	-3.015	0.003
Spatial	X11: Geo	-47.694	34.082	-1.399	0.162
	X12: Density	-0.5753	0.275	-2.093	0.037
Deprivation related	X14: Health	57.8922	41.337	1.401	0.162
	X17: Education	17.2098	2.361	7.289	0
	X18: Crime	136.3015	41.858	3.256	0.001
	X19: Environment	-4.6989	2.302	-2.041	0.042

Table 12: Linear regression result in lockdown3

5.2.2.2 Regression Tree and Random Forest

In the process of using RT and RF to test the results, it was found that their scores were higher than those of LR, which were 0.275 (best_depth is 6) and 0.45 (n_estimators is 150). It shows that there is a certain non-linear relationship in this data. X15: AS and independent variables related to economy& house are still the most important features. See the table below for specific data:

Dimensions	Regression Tree		Random Forest	
Demography	Core index	best_depth: 6	Core index	n_estimators: 150
	Score	0.2749	Score	0.4332
	X1: NUK	0.06898	X1: NUK	0.10436
	X2: O65	0.00194	X2: O65	0.03616
	X3: Bame	0.039	X3: Bame	0.04168
Economy& house	X4: Income	0.0005	X4: Income	0.01662
	X5: HP	0.07132	X5: HP	0.06396
	X6: OO	0.15668	X6: OO	0.07425

	X7: OML	0.00794	X7: OML	0.04228
	X8: SR	0.03667	X8: SR	0.03574
	X9: PR	0.01495	X9: PR	0.04435
	X10: NR	0.03231	X10: NR	0.03997
Spatial	X11: Geo	0.06909	X11: Geo	0.04451
	X12: Density	0.0005	X12: Density	0.04485
Deprivation related	X13: IMD	0.0037	X13: IMD	0.01981
	X14: Health	0.01718	X14: Health	0.02838
	X15: AS	0.3915	X15: AS	0.24653
	X16: Employment	0	X16: Employment	0.02435
	X17: Education	0.02417	X17: Education	0.022
	X18: Crime	0.0201	X18: Crime	0.04051
	X19: Environment	0.04346	X19: Environment	0.02969

Table 13: The result of RT and RF in lockdown3

Chapter 6

Discussion

6.1 Discussion on the results of the three lockdowns

The following will compare the results of different time, different models and different regions. The model will select linear regression and random forest for comparative analysis. Because the random forest has more weighted average or arithmetic average than the regression tree, it will be more refined and accurate fitting, so the comparative analysis of the regression tree is omitted.

6.1.1 Comparison of the results of different lockdown periods

As the lockdown time changes, no matter which model is used, the overall fit has improved. The specific trend is a slight decrease from lockdown1 to lockdown2, but a substantial increase in lockdown3. However, there are certain differences in the feature importance rankings of different models. The following will compare the results of linear regression and random forest.

In the linear regression model, overall r-square is increasing. It shows that with the development of Covid-19, the relationship between the independent variable and the case rate is getting bigger and bigger, and the fitting effect is getting better and better. During the first lockdown, all variables could only explain 18.6% of the case rate. In the second lockdown, it dropped to 16.4% by a small margin. In the third lockdown, it increased sharply to 30.2%.

From the perspective of coefficient ranking, whenever X2: O65, X3: Bame and X4: Income are the three independent variables with the largest coefficients. In addition, the coefficients of X14: Health and X11: Geo have also been ranked relatively high. There are also some findings from the perspective of coefficient trends. First of all, with the change of time and the development of covid-19, the correlation of income is getting stronger and stronger, and it is much higher than other factors. In the first lockdown, the coefficient of income ranked third, but it became the highest ranked coefficient in the second and third lockdowns. And in the second and third blockade, the coefficient of income was much higher than the other independent variables, which were -2677.65 and -35663.85, respectively. This means that when other independent variables remain the same, for every unit of income decrease, the case rate will increase by -2677.65 (lockdown2) and -35663.85 (lockdown3) units. Secondly, the coefficient ranking of some variables is decreasing, which means that their importance is gradually decreasing. Such as: X2: O65, X3: Bame and X11: Geo. Finally, the correlation of X14: Health has become stronger and stronger, and the coefficient ranking has also remained at 5 from 6 at the beginning. The detailed results are compared in the table below.

Model Name	Linear Regression					
	Lockdown1		Lockdown2		Lockdown3	
Number of samples	959		974		979	
Number of independent variables	12		12		12	
R^2	0.186		0.164		0.302	
Coefficient (top 6)	X2: O65	256.1346	X4: Income	-2677.65	X4: Income	-3573.85
	X3:Bame	254.0734	X3:Bame	517.3545	X2: O65	-934.492
	X4:Income	-68.8467	X2: O65	166.5387	X3:Bame	189.2974
	X11: Geo	48.621	X11: Geo	-56.9937	X18: Crime	136.3015
	X18: Crime	-34.0174	X14: Health	36.0244	X14: Health	57.8922
	X14: Health	25.8371	X17: Education	15.4932	X11: Geo	-47.694

Table 14: Comparison of linear regression results

In the random forest model, the overall score is also increasing. From 0.28 at the first blockade to 0.433 at the third time.

From the perspective of importance ranking, X15: AS is the most important feature at any time. Even when it is blocked for the third time, the importance is as high as 0.24, far exceeding other features. In addition, X3:Bame has always been ranked second in importance in lockdown1 and lockdown2, which shows that this feature also has a strong correlation with case rate. A similar variable is X12: Density, which has always been ranked fifth in the ranking of the importance of 19 variables.

Model Name	Random Forest					
	Lockdown1		Lockdown2		Lockdown3	
Number of samples	959		974		979	
Number of independent variables	19		19		19	
Score	0.28		0.2312		0.4332	
Importance score (top 6)	X15: AS	0.11277	X15: AS	0.18047	X15: AS	0.24653
	X3:Bame	0.0853	X3: Bame	0.09897	X1: NUK	0.10436
	X11: Geo	0.06849	X8: SR	0.06883	X6: OO	0.07425
	X2: O65	0.06535	X1: NUK	0.06176	X5: HP	0.06396
	X12: Density	0.05506	X12: Density	0.04962	X12: Density	0.04485
	X9: PR	0.05251	X17: Education	0.0489	X11: Geo	0.04451

Table 15: Comparison of random forest results

6.1.2 Comparison of results of different models

We collate the results of two of the three models. It is found that there is a certain score difference, and the order of the coefficients of the features is also different. We can see that the fitting of random forest is better than linear regression during different blockade periods. This shows that the data has a certain non-linear relationship. But this cannot be used as the only basis, because the overall sample size is about 1,000, and the amount of data is not sufficient for the random forest method.

From the perspective of feature importance, the important features of linear regression

are more concentrated than random forests. In the top3 ranking of importance, regressions are all concentrated in Income, Bame and O65, while random forests are mainly concentrated in AS and Bame. Although the importance of random forest ranking does not focus on certain three variables every time the top three, AS ranks first in the three blockades. And Bame has appeared in second place twice, respectively in lockdown1 and lockdown2.

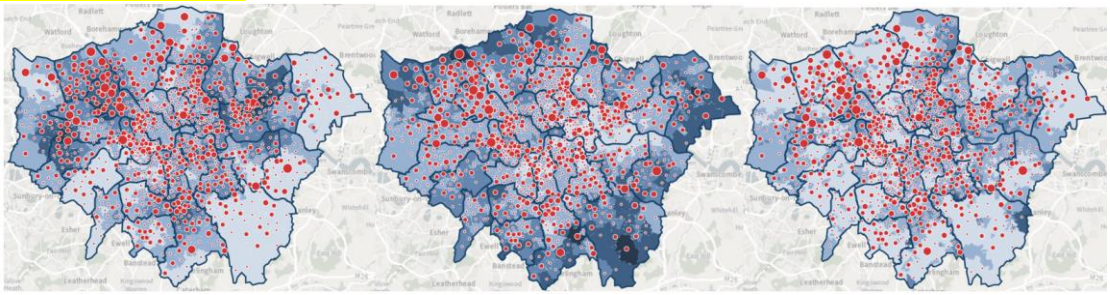
	Model	Score/R^2	Coefficient/Importance (top3)					
Lockdown1	LR	0.186	X2: O65	256.1346	X3:Bame	254.0734	X4:Income	-68.8467
	RF	0.28	X15: AS	0.11277	X3:Bame	0.0853	X11: Geo	0.06849
Lockdown2	LR	0.164	X4: Income	-2677.65	X3:Bame	517.3545	X2: O65	166.5387
	RF	0.2312	X15: AS	0.18047	X3: Bame	0.09897	X8: SR	0.06883
Lockdown3	LR	0.302	X4: Income	-3573.85	X2: O65	-934.492	X3:Bame	189.2974
	RF	0.4332	X15: AS	0.24653	X1: NUK	0.10436	X6: OO	0.07425

Table 16: Comparison of LR and RF results

6.1.3 Visualization of important features

Based on the above comparison, we can know that Income is the most important feature in linear regression, and random forest is AS. Below, the above two characteristics and the case rate of the three lockdown periods are visually displayed.

Picture to be added



6.2 Results of advantages and limitations .

In general, the results has some advantages and disadvantages shown. The advantage is that the data set selects 983 samples of MSOA, which can discuss topics in more detail. Second, using three different methods to verify and compare analysis conclusions, we can look at the results and different models more dialectically. Third, compare and analyze the situation of the three lockdowns in 2020. Then we can know the changing trends of covid-19 at different times.

At the same time, if we make the following improvements, we may get better results. First, supplement the data of the independent variables. Because MSOA is a relatively small area unit, and the week is also a relatively small time division unit. After communicating with the official email, many covid-19-related data involve privacy and are not suitable for academic research for graduate students. In the absence of relevant datasets, the fitting effect cannot be optimized. If we can add other data such as the number of deaths and population movements in the weekly dimension, there will be better results. Secondly, for the latter two methods of machine learning, the amount of data is not very large, and it is impossible to confirm whether the fit is

optimal. Third, although outliers have been deleted in this article, some data does have a large span in different regions and times.

Chapter 6

Conclusion

In 2020, the London case rate has a certain relationship with socio-demographic factors. And mainly concentrated on Income and demography related factors (O65 and Bame). There are also different biases in different methods. Income is the most important factor in linear regression, and AS is the most important feature in regression trees and random forests. In the three lockdowns, the overall fit is increasing. Indicating that with the development of covid-19, these independent variables can better explain the case rate. And with the change of time, the independent variable of income has become more and more important, and the coefficient is much higher than other characteristics.
To be added

Appendix

Appendix A:
The Summary List of All Data Source Employed in this Research

Appendix B
Repository: https://github.com/Audrey-chenxi/CASA_Dissertation_Chenxi-Zhao

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