Effects of the abolishment of London Western Charging Zone on traffic flow and vehicle emissions

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Abstract

This paper applies the regression discontinuity method to evaluate the effects of the removal of London western charging zone (WCZ) scheme on the traffic flow characteristics and traffic-related emissions, based on the data of 525 road sections. First of all, continuity of the confounders is assessed. Results indicate that all the confounders are continuous at the cut-off. Then, the impacts of implementing and abolishing the WCZ scheme are investigated. Results indicate that the overall traffic volume is reduced by 31% after implementing the WCZ scheme. On the contrary, the overall traffic volume in the concerned area is increased by 26% after the abolishment. For the environmental effects, results indicate that the traffic-related NO_X and CO_2 emissions are reduced by 29% and 33% respectively after implementing the WCZ scheme and bounced back by 24% and 21% respectively after the abolishment. These imply that there are moderate residual effects for the removal of WCZ scheme on the traffic volume and traffic-related CO_2 emission. However, the residual effect on the traffic-related NO_x emission is marginal.

Keywords: London congestion charging scheme; London western charging zone scheme; regression discontinuity method; vehicle emissions; residual effect

1. Introduction

To resolve the traffic congestion problem, the London congestion charging (LCC) scheme was introduced in Inner London in February 2003. It covered the area within the London Inner Ring Road. The area of concern was known as 'original charging zone'. In February 2007, the LCC scheme was extended to the west of the original charging zone. The extended area was known as "Western Charging Zone" (WCZ) (Santos et al., 2008; Santos and Shaffer, 2004). **Figure 1** shows the areas covered by the two congestion charging schemes in London. In 2003, the charge was £5 per day (for the time period between 7:00 a.m. and 6:30 p.m. on Monday to Friday). It was then increased to £10 per day in 2011. One of the primary purposes of LCC scheme was to increase the level of satisfaction of the communters in London by alleviating the traffic congestion and reducing the travel time and delay. For example, Transport for London (TfL) reported that the number of cars entering the charging area was reduced by 21% and the average journey speed was increased from 13 km/h to 17 km/h, one year after the introduction of LCC scheme in 2003 (TfL, 2006). After the introduction of WCZ scheme, the number of cars entering the concerned area was reduced by 10-15%. However, the frequency of traffic jam in the original charging zone was increased by 4% (TfL, 2009). According to a local survey in 2010, 62% of residents and commuters in the WCZ raised the criticism against the scheme. In response to the pressures from different stakeholders, the WCZ scheme was called off in December 2010.

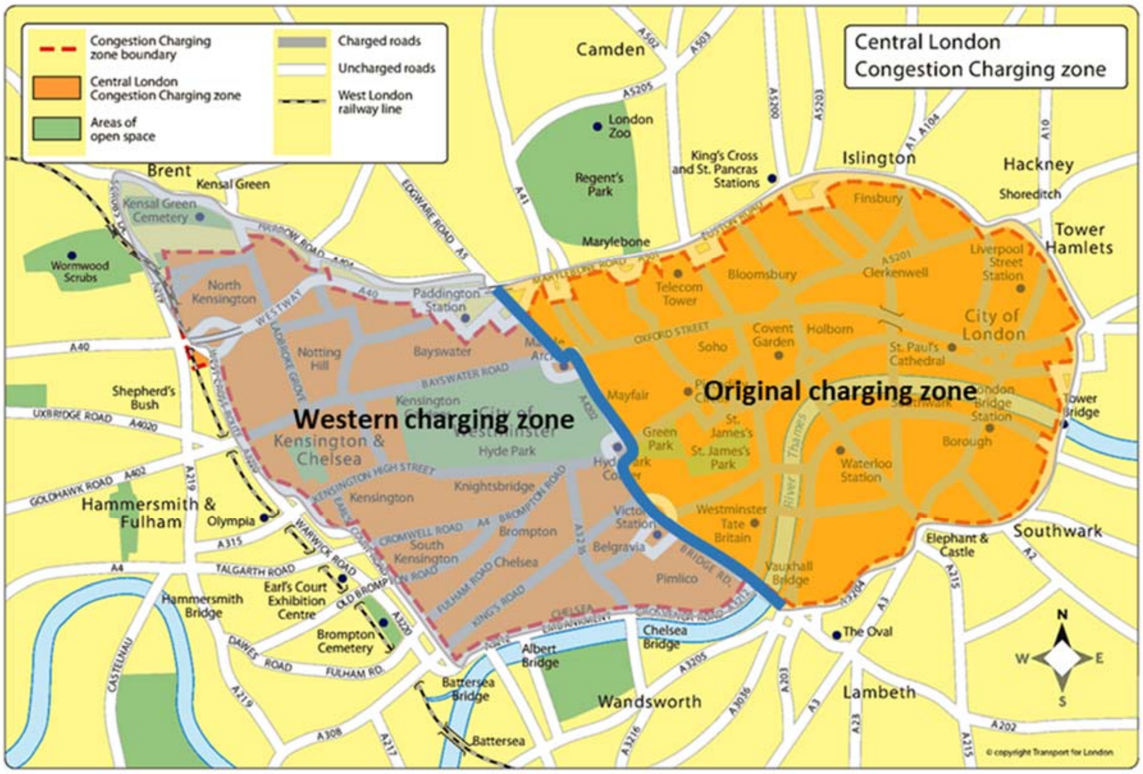


Figure 1. **Illustrations of the original charging zone and western charging zone in London**

(*Source: US Federal Highway Administration, 2017*

https://ops.fhwa.dot.gov/publications/fhwahop08047/02summ.htm)

Many studies evaluated the impacts of the LCC scheme on the traffic flow patterns, both within and around the charging area, during the charging periods (Santos et al., 2008; Santos and Shaffer, 2004; TfL, 2006; Beevers and Carslaw., 2005a; Larson and Sasanuma., 2006; Johansson et al., 2009; Liu et al., 2017; Jou et al., 2010; Fields et al., 2009; Li et al., 2012b). In addition, the economic and social impacts of the LCC scheme were also investigated (Prud'homme and Bocarejo, 2005; Santos and Bhakar., 2006; Quddus et al., 2007b; Givoni, 2011; Noland et al., 2007; Li et al., 2012a; Tang, 2016). For example, an economic appraisal indicated that the LCC scheme was cost effective (Prud'homme and Bocarejo, 2005). For the social impacts, number of injuries of car occupants reduced remarkably after the introduction of LCC scheme. However, the LCC scheme was associated with the increase in the number of bicycle-related injuries (Noland et al., 2007; Li et al, 2012a; Ding et al., 2021a, 2021b).

In addition, the environmental impacts of the LCC scheme were investigated (Percoco, 2015; Atkinson et al., 2009; Beevers and Carslaw., 2005a; Tonne et al., 2008; Jones et al., 2012; Litman 2005; Daniel and Bekka., 2000; Atkinson et al., 2009; Quddus et al., 2007a; Pan et al., 2019; Jagers et al., 2017; Dijkema et al., 2008). For example, Beevers and Carslaw (2005a) assessed the effects of the LCC scheme on traffic-related emissions, based on comprehensive traffic data, using an emission model. Results indicated that the emission level in Central London significantly reduced after the introduction of LCC scheme. Also, overall air quality in Central London was improved (Atkinson et al., 2009). Despite that, air quality in the surrounding area was worsened (Percoco, 2015).

To sum up, the LCC scheme played an important role in relieving the traffic congestion in Central London. In addition, it was benefital to the economy, environment and social well-being. However, it is rare that the effects of the removal of LCC scheme is attempted. Indeed, effect of a political intervention, e.g. financial subsidization and carbon trading, could persist for a considerable time period after its abolishment, known as residual effect (Wang et al., 2009; Ramiah et al., 2017). However, as revealed in prior studies, the traffic volume and traffic-related emission might bounce back after abolishing the congestion charging scheme. Hence, it is worth investigating the presence of residual effect of congestion charging scheme, and the increases in traffic volume and traffic-related emission (if the residual effect does not exist). In this study, the regression discontinuity approach is applied to evaluate the effects of implementing and abolishing the WCZ scheme on the traffic flow characteristics and traffic-related emissions, with which the effects of possible confounders are controlled. Results should be indicative to the government authorities for the development of robust decision support tool of future transport demand management strategies.

The remainder of this paper is organized as follows. Method and data used in this study are described in Section 2 and Section 3 respectively. Analysis results are presented in Section 4. Finally, Section 5 provides the concluding remarks, policy recommendations and the way forward.

2. Method

To estimate the effects of implementing and abolishing the WCZ, with which the possible confounding factors are controlled, the regression discontinuity approach is used. The regression discontinuity method is used to evaluate the effect of an intervention when randomized control is not feasible in the empirical study, by assigning a cutoff above or below which the intervention, e.g. congestion charging scheme, is implemented. This approach has been widely used in the public policy studies (Percoco, 2015; Atkinson et al., 2009; Calonico et al., 2014; Lee and Lemieux., 2008). In such design, whether an entity would receive the "treatment" depends on the value of an observable (and measureable) covariate, with respect to a designated cutoff. A key feature of the regression discontinuity approach is the presence of a "sudden jump" of the outcome variable when the value of a covariate (also known as "running variable") reaches the cutoff. This is referred to as "discontinuity" and should be independent from any potential confounder. Then, the treatment effect is can be estimated using the local-polynomial nonparametric regression approach.

2.1. Regression discontinuity model

Using the regression discontinuity approach, the treatment effect τ is estimated using the following expression (Imbens and Lemieux, 2008; Hahn et al., 2001; Hahn et al., 1999),

$$\tau(h_n) = \mu_+(h_n) - \mu_-(h_n) \quad (1)$$

given that $\mu_+(h_n) = \lim_{x \downarrow x_0} \mu(\mathrm{x}), \mu_-(h_n) = \lim_{x \uparrow x_0} \mu(\mathrm{x}), \mu(\mathrm{x}) = E[Y_i|X_i = X]$ (2)

Then, the treatment effect τ can be specified as,

$$\tau(h_n) = E[Y_i(1) - Y_i(0)|X_i = X_0] \quad (3)$$

where scalar regressor X_i is a running variable (in this study, it refers to the Euclidean distance between a point and the boundary of congestion charging zone) that determines the treatment assignment.

Notations are given as follows:

(1) X_0 is the forcing variable. It is set to be 0 since the cutoff is the boundary of congestion charging zone;

(2) Entity *i* is assigned to the treatment group (congestion charge imposed) when $X_i > X_0$, otherwise, it would be assigned to the control group (no congestion charge imposed);

(3) $Y_i(1)$ and $Y_i(0)$ denote the potential outcomes with and without treatment respectively;

(4) h_n is a positive bandwidth sequence.

The regression discontinuity approach can be depicted in **Figure 2**.

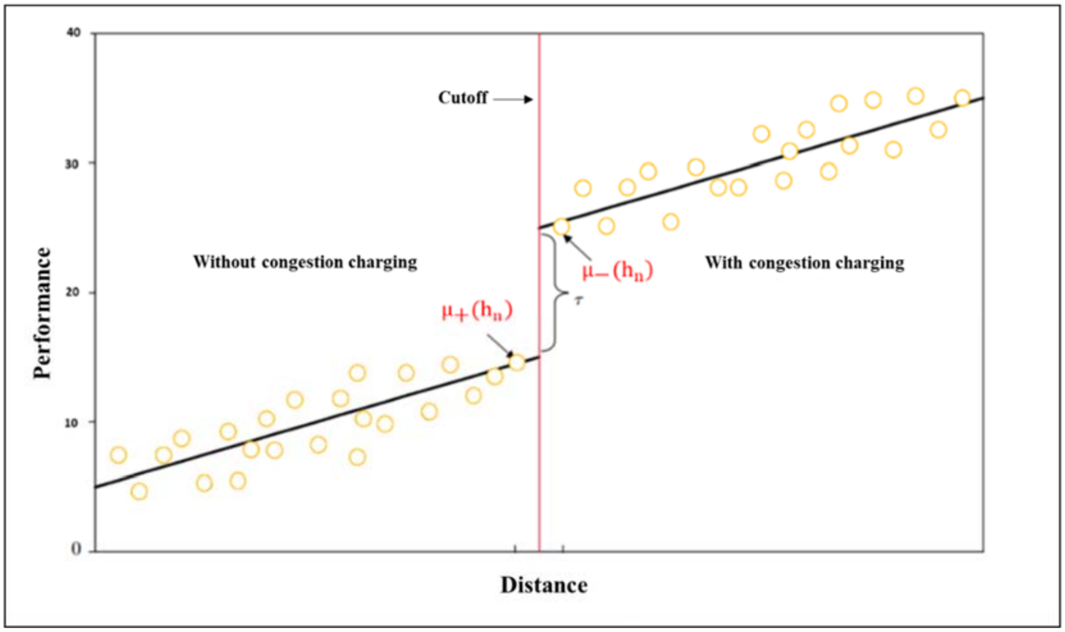


Figure 2. Illustration of regression discontinuity approach

2.2. Assumptions

There are three key assumptions for the regression discontinuity method that can ensure the reliability of the estimate of treatment effect:

(1) Running variable X_i must be continuous at the cutoff point X_0;

(2) Running variable X_i should not be related to the selection of cutoff point;

(3) Outcome variable jumps discontinuously at the cutoff point and not be correlated to any potential confounder.

2.3. Implementing regression discontinuity

A graphical diagnosis is adopted to illustrate the (discontinuous) jump of outcome variable at the cutoff point. Also, such diagnosis can depict the estimated regression functions of the treatment and control groups, with respect to the covariates. Theoretically, each observation (a 'dot' in the plot) represents the local sample mean, and the dots are scattered into partitions (known as "non-overlapping bins") of the running variable. Then, the smooth regression curves that pass through all the observations would be constructed for the treatment and control groups. An initial bin size is specified for the establishment of underlying regression function. However, the default bin size is usually too small for generalization. In this study, the bin size and number of bins would be varied, in accordance with the scattering of observations. Therefore, noticeable "cloud" of points can be generated.

Under the appropriate regularity conditions, the treatment effect $\tau(h_0)$ would follow the mean-square error (MSE) expansion. Based on the MSE expansion, the optimal treatment effect $\tau(h_0)$ can be achieved when the bandwidth is specified using the following expression (Calonico et al., 2014),

$$h_{MSE,n,p} = (V_p/2(p+1){B^2}_p)^{1/(2p+1)} n^{-1/(2p+3)} \tag{4}$$

where B_p is the leading asymptotic bias and V_p is the asymptotic variance of $\tau(h_0)$ of the *p-th* order polynomial regression, $p = 1,2,3,4 \cdots n$.

In some applications, the value of B_p may be close to zero. To resolve this problem, a more robust and consistent bandwidth selection approach was established (Calonico et al., 2014, Imbens and Kalyanaraman, 2012).

$$h_{IK,n,p} = (\hat{V}_{IK,P}/2(p+1){B^2}_{IK,P} + \hat{R}_{IK,P})^{1/(2p+3)} n^{-1/(2p+3)} \tag{5}$$

where $\hat{R}_{IK,P}$ is introduced to avoid small denominator (i.e. close to zero)

Through the bandwidth selection approach proposed by Imbens and Kalyanaraman (2012), known as IK hereafter, can give a simple and immediately applicable solution, the selected bandwidth is not necessarily optimal. To overcome such problem, a bias-corrected bandwidth selection procedure proposed by Calonico, Cattaneo and Titiunik (Calonico et al., 2014), known as CCT hereafter, is adopted,

$$h_{CCT,n,p} = (\hat{V}_{CCT,P}/2(p+1){B^2}_{CCT,P} + \hat{R}_{CCT,P})^{1/(2p+3)} n^{-1/(2p+3)} \tag{6}$$

Furthermore, several alternate approaches, e.g. the cross-validation (known as "CV") method, are also proposed to select the appropriate bandwidth for the regression discontinuity method. For instance, the CV model is specified as (Ludwig and Miller, 2007),

$$h_{CV,n,p} = \arg\min_{h>0} \sum_{i=1}^{n} I(X_{-,[\delta]} < X_i < X_{+,[\delta]})(Y_i - \hat{\mu}_P(X_i: h))^2 \quad (7)$$

where $\delta \in (0,1)$, and $X_{-,[\delta]}$and $X_{+,[\delta]}$ denote the δ-*th* quantile of $\{X_i: X_i < X_0\}$ and $\{X_i: X_i \geq X_0\}$, respectively. Hence, the optimal bandwidth can be estimated for the regression discontinuity model, given that all key assumptions are satisfied.

3. Data

Two key datasets: (i) traffic count data (i.e. annual average daily traffic, known as "AADT" and average speed) and (ii) air quality data (i.e. NO_X and CO_2 emissions) are used in this study. For instance, the traffic count data, which is maintained by the UK's Department for Transport (DfT), covers all major roads and some urban minor roads in the territory. Also, the traffic count data can be derived from the manual classified count (MCC) survey in London (TfL, 2009; TfL, 2010).

The air quality data is obtained from the London Atmospheric Emissions Inventory (LAEI). The inventory covers 32 London Boroughs, City of London, and is extended to the area that is bounded by the London Orbital Motorway (M25). For instance, traffic-related emissions of NO_X and CO_2 on the major roads are available (Beevers et al., 2009; GLA., 2001). Then, the traffic count and air quality data are mapped to the road network using the Geographic Information System (GIS) approach.

To evaluate the effects of potential confounders (i.e. Key Assumption 1), continuity of the covariates at the cutoffs is assessed using the regression discontinuity approach. In this study, factors including built environments and socio-demographics that affect the traffic characteristics in the congestion charging zone are considered (Santos et al., 2008; Santos and Shaffer, 2004; Beevers and Carslaw., 2005b; Larson and Sasanuma., 2006; Johansson et al., 2009). For example, land use, population, employment and deprivation data are obtained from the Office for the National Statistics (ONS)'s database. Also, Index of Multiple Deprivation (IMD) data is obtained from the Office of Deputy Prime Minister (Leeser, 2016). IMD is composed of seven deprivation domain indices including income, housing, employment, education, environment, health and crime rate.

The regression discontinuity method estimates the effect of "treatment" based on the difference in the outcomes between the treatment and control groups. In this study, the cutoff is defined using the boundaries of congestion charging zones. Therefore, the roads ("entities") that are within the congestion charging zones are refered to as the treatment sites and those outside the zones as the control sites. In this study, the effects of implementing (Case 1) and abolishing (Case 2) the WCZ scheme are investigated. For Case 1, there are 172 treatment sites and 141 control sites. On the other hand, there are 100 treatment sites and 112 control sites for Case 2. Figure 3 depicts the areas where the treatment and control sites are picked up for the two cases. Running variable X_i is the shortest distance from an entity to the charging zone boundary. As X_i at the cutoff is set at zero, X_i is positive for the treatment site and negative for the control site. Descriptive statistics of the covariates considered in this study are given in **Table 1**.

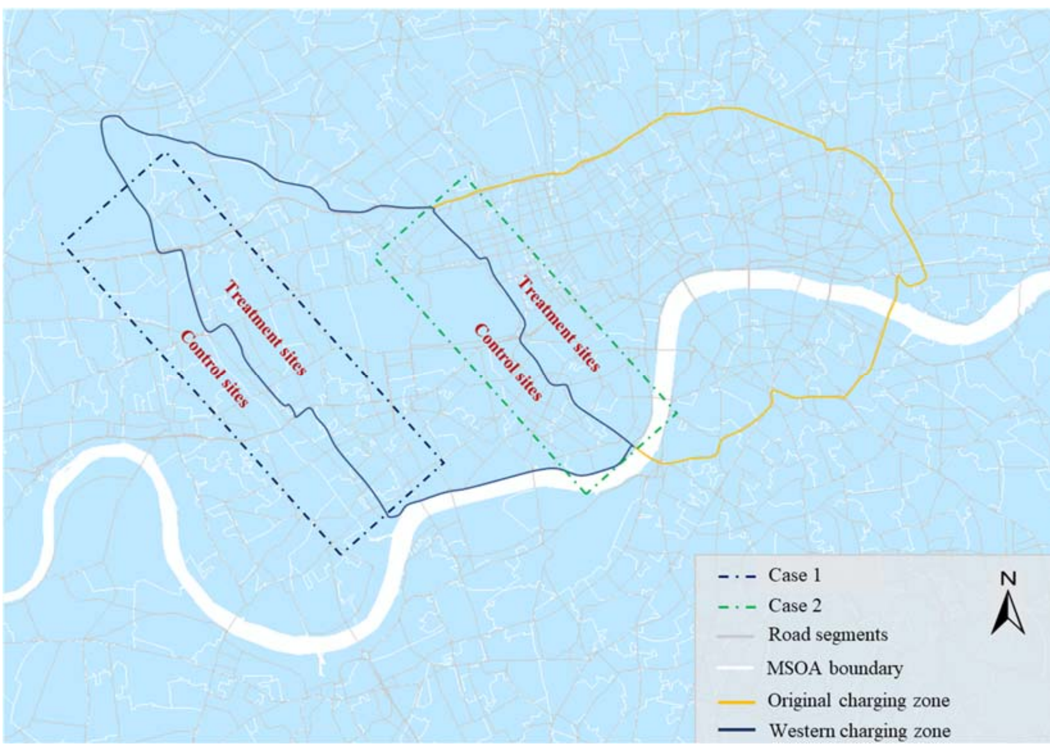


Figure 3. Treatment and control sites for the implementation (Case 1) and abolishment (Case 2) of the WCZ scheme

Table 1. Descriptive statistics of covariates

(a) Case 1

Variable	Description	Mean	S.D.	Max.	Min.
AADT	Annual average daily traffic volume	14940.2	7483.0	54925	4167
IMD	Index of multiple deprivation	4.7	2.1	9	1
Population	Population	1533.0	107.0	1912	1227
Residential	Residential area	23.6	10.1	55	3
Commercial	Business and office area	27.2	40.2	276	0.58
Green	Green area	52.7	152.7	1270	0
Transport	Area covered by public road	36.8	23.9	186	10
Speed	Average vehicular speed (km/h)	23.6	3.5	40	15
CO_2	Vehicle CO_2 emission ($\mu g/m^3$)	320.2	308.3	1886	0
NO_X	Vehicle NOx emission ($\mu g/m^3$)	0.2	0.1	1	0
Petrol car	Number of petrol cars	6154.3	3507.1	21996	543
Diesel car	Number of diesel cars	3056.2	1789.0	10700	103
Petrol LGV	Number of petrol light goods vehicles	66.0	45.2	253	2
Diesel LGV	Number of diesel light goods vehicles	1543.1	1108.0	5901	35

(b) Case 2

Variable	Description	Mean	S.D.	Max.	Min.
AADT	Annual average daily traffic volume	10488.2	4877.2	41745	2784
IMD	Index of multiple deprivation	5.5	1.6	8	2
Population	Population	1484.0	85.4	1680	1204
Residential	Residential area	38.9	21.6	82	5
Commercial	Business and office area	60.5	56.6	282	1
Green	Green area	81.5	246.8	1270	0
Transport	Area covered by public road	76.7	50.0	290	8
CO_2	Vehicle CO_2 emission ($\mu g/m^3$)	165.5	121.0	1085	22.8
NO_X	Vehicle NOx emission ($\mu g/m^3$)	0.3	0.2	1	0
Petrol car	Number of petrol cars	10331.3	2334.0	20787	5656
Diesel car	Number of diesel cars	6609.0	1553.3	15367	3356
Petrol LGV	Number of petrol light goods vehicles	50.7	9.2	88	14
Diesel LGV	Number of diesel light goods vehicles	2691.6	520.0	6797	1205

4. Results

4.1. Continuity test

First of all, continuity of the potential confounders at the cutoff is assessed. As shown in **Table 2(a) and 2(b),** no evidence could be established for significant discontinuity of any confounder. In other word, all the confounders are continuous at the boundaries of the congestion charging zones. Therefore, discontinuity of the outcome should be attributed to the presence and absence of the WCZ scheme. This justifies the use of regression discontinuity approach.

Table 2. Continuity of confounders at the cutoff

(a) Case 1

Covariate	Coef.	Std. error	z	p>|t|	Min.	Max.	Continuity
IMD	-0.60	0.44	-1.36	0.17	-1.47	0.26	Yes
Population	9.78	20.88	0.46	0.64	-31.15	50.72	Yes
Residential	4.22	4.327	0.97	0.32	-4.25	12.70	Yes
Commercial	-18.20	16.52	-1.10	0.27	-50.55	14.20	Yes
Green	3.56	54.49	0.06	0.94	-103.23	110.36	Yes
Transport	4.39	9.31	0.47	0.63	-13.85	22.64	Yes

(b) Case 2

Covariate	Coef.	Std. error	z	p>|t|	Min.	Max.	Continuity
IMD	-0.07	0.44	-0.16	0.87	-0.95	0.81	Yes
Population	-8.97	16.23	-0.55	0.58	-40.79	22.85	Yes
Residential	2.42	4.81	0.50	0.61	-7.00	11.85	Yes
Commercial	4.88	6.60	0.73	0.46	-8.06	17.82	Yes
Green	-36.90	39.39	-0.93	0.35	-114.20	40.28	Yes
Transport	13.13	9.86	1.33	0.18	-6.20	32.46	Yes

4.2. Effects of implementing the WCZ scheme

Then, effects of implementing (Case 1) and abolishing (Case 2) the WCZ scheme on the traffic flow characteristics (i.e. AADT, speed) and traffic-related emissions (i.e. CO_2, NO_X) are assessed using the regression discontinuity approach. **Table 3** and **Figure 4** presents the results of effectiveness evaluation, with which the optimal bandwidth is set out using three different approaches, e.g. CV, CCT and IK. As shown in **Table 3**, effects of implementing and abolishing the WCZ scheme on traffic volume, vehicular speed and vehicle emissions are significant, all at the 5% level, regardless of the bandwidth optimization approach.

Table 3. Effects of implementing and abolishing the WCZ scheme

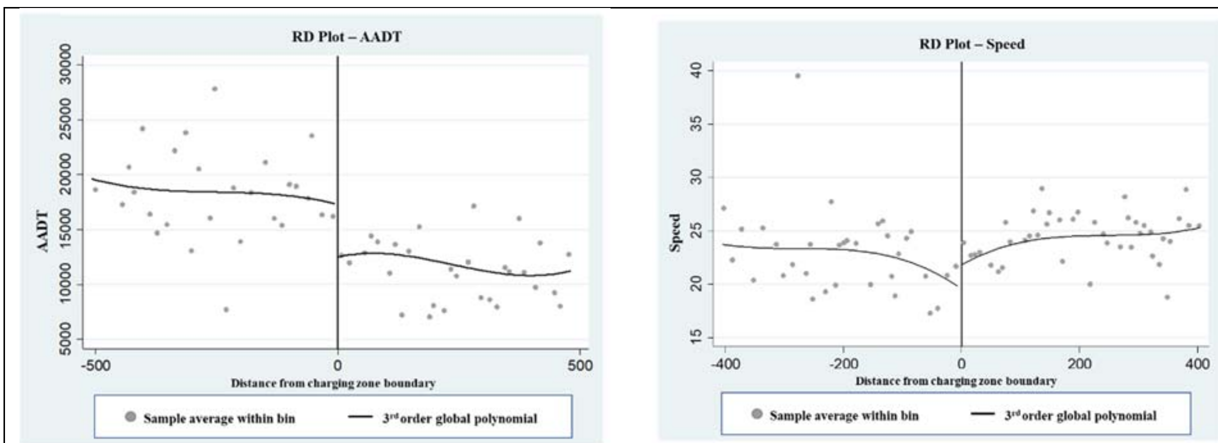
(a) Case 1

Covariate	Method	Coeff.	z	p>|t|	Min.	Max.	Effect
AADT	CV	-4412.21	-4.01	<0.001	-6569.12	-2255.22	-31%
	CCT	-4210.30	-3.83	<0.001	-6367.14	-2054.32	
	IK	-4861.22	-4.10	<0.001	-7178.09	-2535.87	
Speed	CV	2.10	3.05	0.002	0.78	3.59	11%
	CCT	2.80	3.52	<0.001	1.24	4.37	
	IK	1.96	3.01	0.003	0.68	3.24	
CO_2	CV	-134.51	-3.45	0.001	-210.77	-57.87	-33%
	CCT	-138.32	-4.08	<0.001	-205.49	-72.17	
	IK	-133.33	-3.34	0.001	-212.38	-55.35	
NO_X	CV	-86.01	-3.83	<0.001	-131.25	-42.36	-29%
	CCT	-91.32	-3.50	<0.001	-143.49	-40.24	
	IK	-72.23	-2.61	0.009	-126.11	-17.95	
Petrol car	CV	-1624.11	-2.62	0.009	-2840.42	-409.23	-11%
	CCT	-2836.13	-2.51	0.012	-5047.07	-625.06	
	IK	-1462.04	-2.13	0.033	-2808.03	-117.32	
Diesel car	CV	-1049.33	-3.21	0.001	-1689.11	-409.15	-50%
	CCT	-2790.25	-5.26	<0.001	-3830.56	-1750.93	
	IK	-1082.13	-3.21	0.001	-1742.01	-422.02	
Petrol LGV	CV	-23.07	-2.37	0.018	-29.58	-2.78	-23%
	CCT	-46.23	-6.39	<0.001	-60.22	-31.91	
	IK	-22.08	-3.25	0.001	-36.02	-8.92	
Diesel LGV	CV	-637.45	-4.47	<0.001	-917.21	-358.09	-29%
	CCT	-954.13	-5.29	<0.001	-1308.21	-600.04	
	IK	-848.22	-5.30	<0.001	-1161.11	-534.39	

(b) Case 2

Covariate	Method	Coeff.	z	p>|t|	Min.	Max.	Effect

AADT	CV	-3011.32	-3.40	0.001	-4748.51	-1275.34	26%
	CCT	-4960.12	-2.68	0.007	-10314.01	-1607.05	
	IK	-2737.96	-2.91	0.004	-4581.83	-893.36	
CO_2	CV	-70.00	-3.86	<0.001	-106.44	-34.73	21%
	CCT	-164.03	-7.98	<0.001	-205.30	-124.30	
	IK	-69.98	-3.71	<0.001	-106.75	-32.89	
NO_X	CV	-75.04	-2.50	0.012	-137.96	-16.69	24%
	CCT	-87.33	-1.22	0.022	-228.41	-53.09	
	IK	-77.26	-2.48	0.013	-138.63	-16.30	
Petrol car	CV	-1379.12	-2.30	0.022	-2556.52	-201.99	20%
	CCT	-1791.24	-1.32	0.037	-4454.60	871.31	
	IK	-2139.08	-2.77	0.006	-3651.01	-626.92	
Diesel car	CV	-936.67	-2.89	0.004	-1571.42	-300.45	17%
	CCT	-1299.04	-3.02	0.003	-2142.25	-455.92	
	IK	-866.92	-2.41	0.016	-1571.71	-160.81	
Petrol LGV	CV	-16.01	-6.05	<0.001	-17.14	-8.75	13%
	CCT	-15.08	-6.31	<0.001	-21.25	-11.46	
	IK	-14.10	-6.94	<0.001	-18.78	-10.51	
Diesel LGV	CV	-606.23	-3.81	<0.001	-918.08	-294.52	17%
	CCT	-594.35	-3.40	0.001	-936.57	-251.60	
	IK	-626.24	-3.73	<0.001	-955.59	-297.54	



(a) (b)

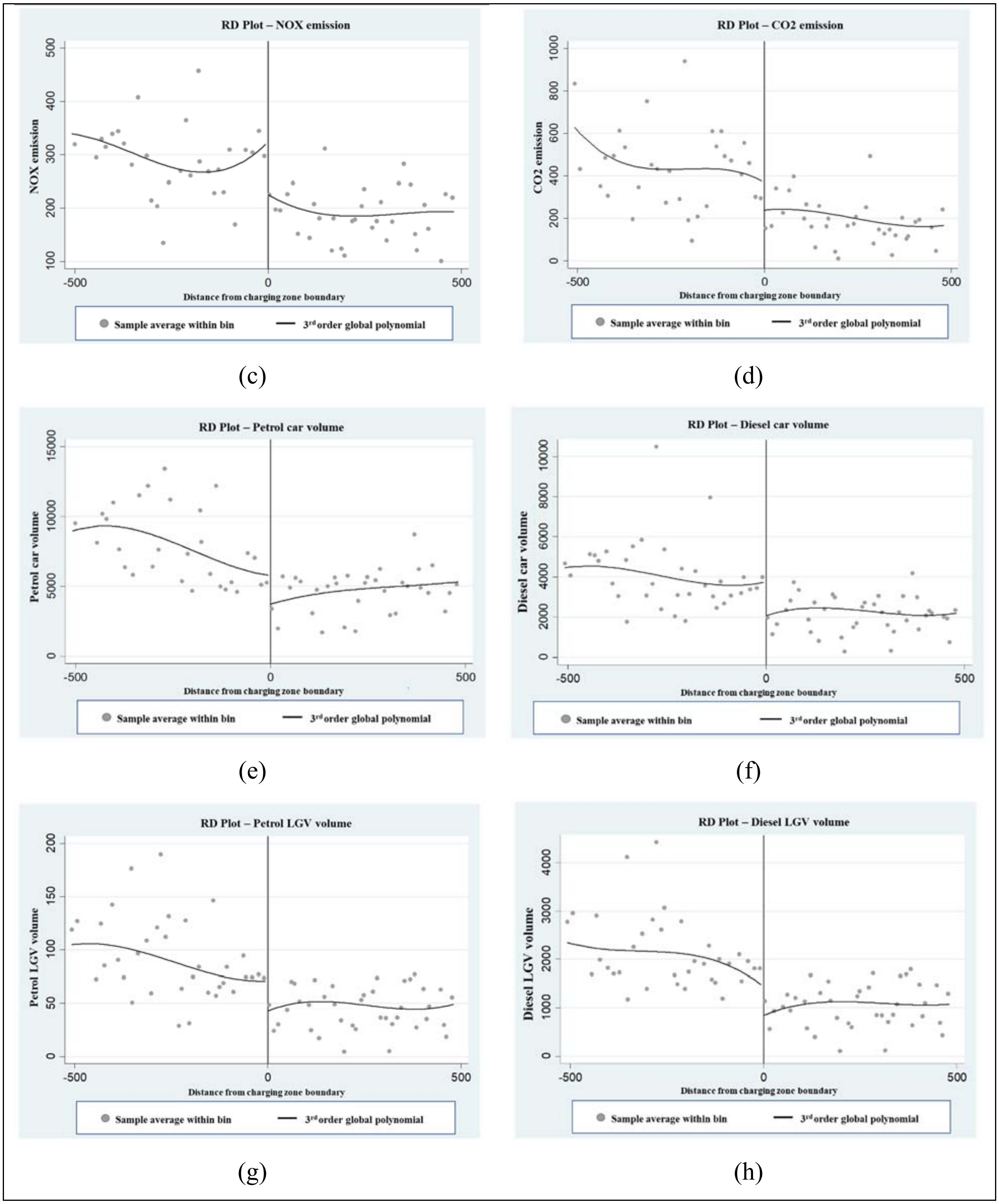


Figure 4. Effects of implementing the WCZ scheme

As shown in Table 3(a), the overall traffic volume is reduced by 31% after implementing the WCZ scheme. This is consistent to that of previous studies (Santos et al., 2008; Santos and Shaffer, 2004;

TfL, 2006; Beevers and Carslaw., 2005a, b; Johansson et al., 2009). Since the congestion charge is waived for some vehicle classes, analysis of the effect on traffic volume is stratified into four: (i) petrol car, (ii) diesel car, (iii) petrol light goods vehicle (LGV) and (iv) diesel LGV. Results indicate that the reduction in the volume of diesel car (50%) is the most obvious amongst the vehicle types considered (11% for petrol car, 23% for petrol LGV, and 29% for diesel LGV respectively). This could be attributed to the implementation of the Low Emission Zone (LEZ) scheme in Greater London (as illustrated in **Figure 5**). The LEZ is in force for 24 hours, 7 days a week, and that of WCZ scheme is between 7.00 am and 6.30 pm on weekdays only. Furthermore, effect of congestion charging on the vehicular speed is also assessed. Results indicate that the average vehicle speed is increased by 11% after implementing the WCZ. This is consistent to the finding of previous study (Beevers and Carslaw, 2005a).

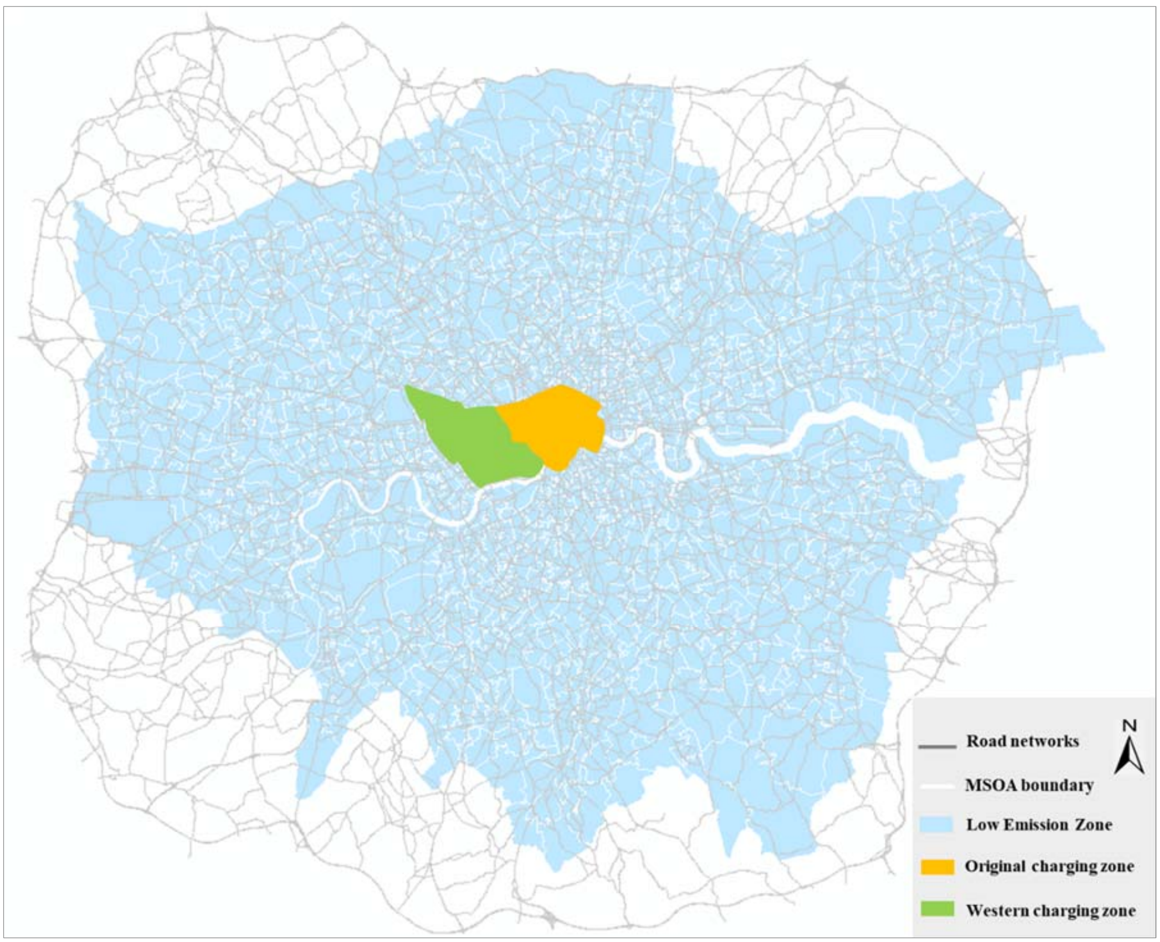


Figure 5. Illustration of the Low Emission Zone in London

Table 3 also illustrates the effects of congestion charging on the traffic-related emissions. Results indicate that both the NO_X (-29%) and CO_2 (-33%) emissions are reduced after implementing the WCZ. This is not surprising as NO_X and CO_2 emissions are positively correlated to AADT, as shown in **Table 4(a)**. As also shown in **Figure 6,** the emission levels are particularly high in the neighboring areas outside the WCZ.

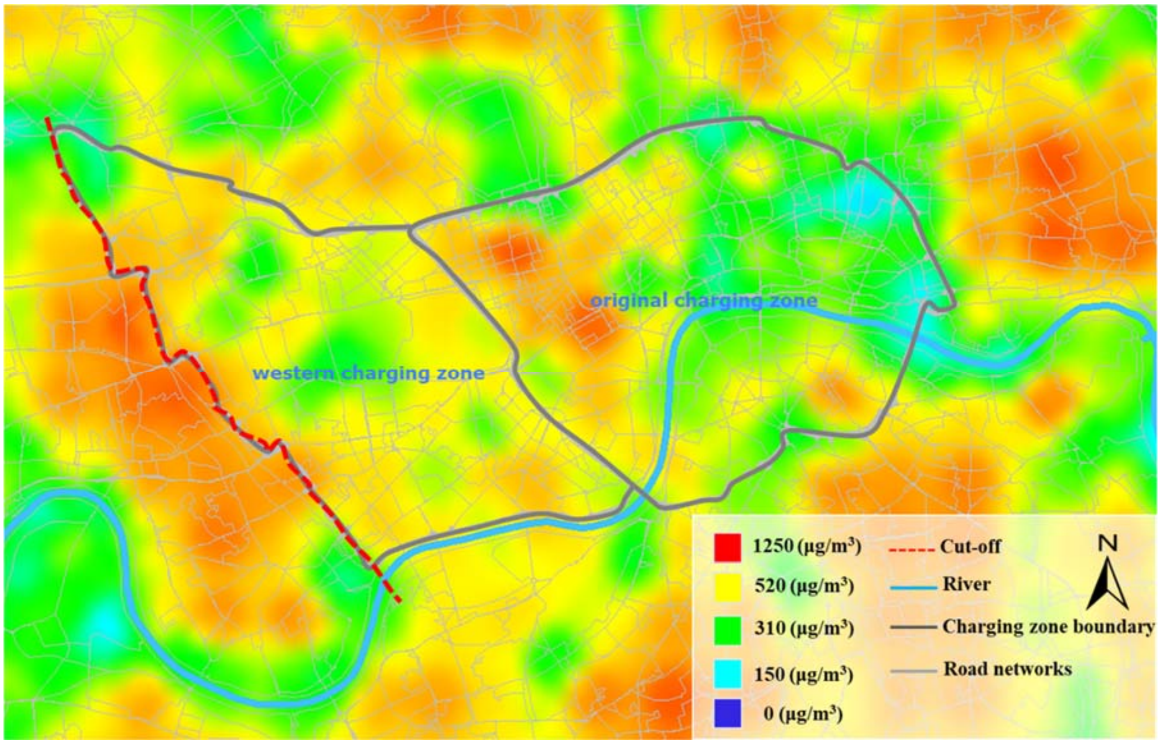
Table 4. Results of regression model for AADT

(a) Case 1

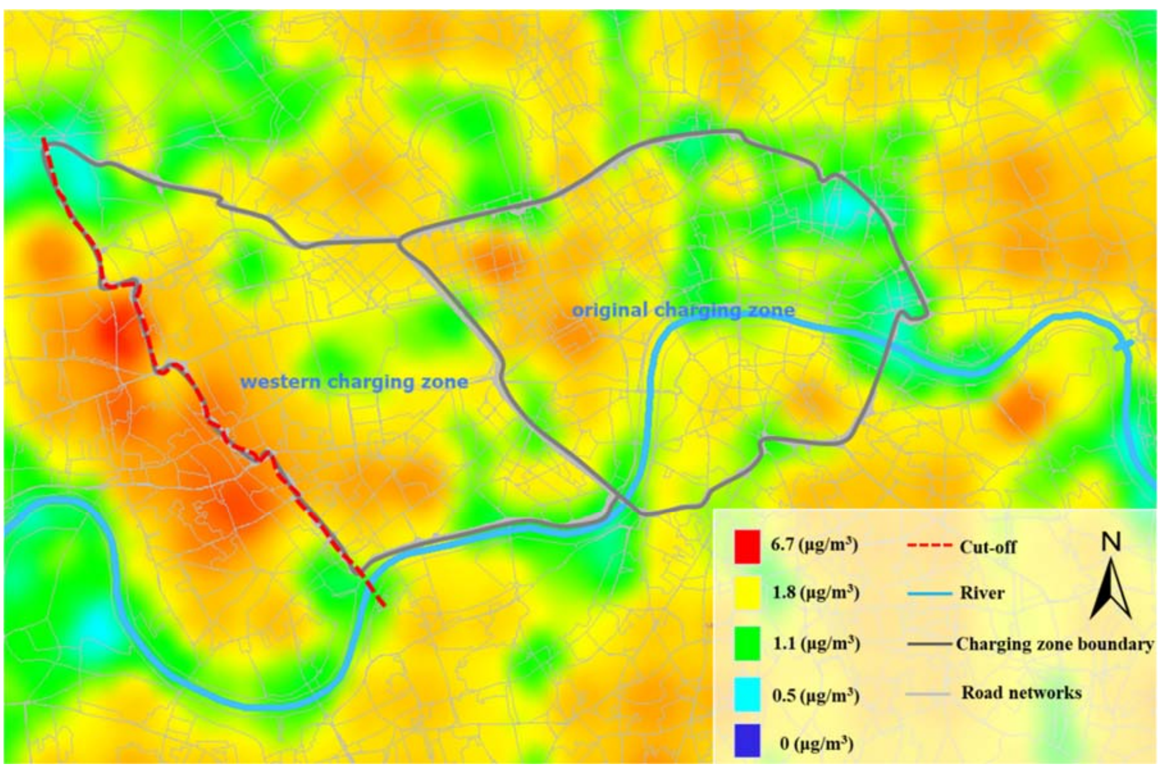
Variable	**Coef.**	**Std. error**	**Z**	**p>|t|**
Constant	8554.20	697.07	12.27	<0.001
NO_X (μg/m3)	8.84	2.40	3.68	<0.001
CO_2 (μg/m3)	12.64	0.84	15.07	<0.001

(b) Case 2

Variable	**Coef.**	**Std. error**	**Z**	**p>|t|**
Constant	5269.2	644.4	8.18	<0.001
NO_X (μg/m3)	10.9	2.18	5.03	<0.001
CO_2 (μg/m3)	12.5	2.61	4.83	<0.001


original charging zone
western charging zone
1250 (μg/m³)
520 (μg/m³)
310 (μg/m³)
150 (μg/m³)
0 (μg/m³)
Cut-off
River
Charging zone boundary
Road networks
N

(a) CO_2


original charging zone
western charging zone
6.7 (μg/m³)
1.8 (μg/m³)
1.1 (μg/m³)
0.5 (μg/m³)
0 (μg/m³)
Cut-off
River
Charging zone boundary
Road networks
N

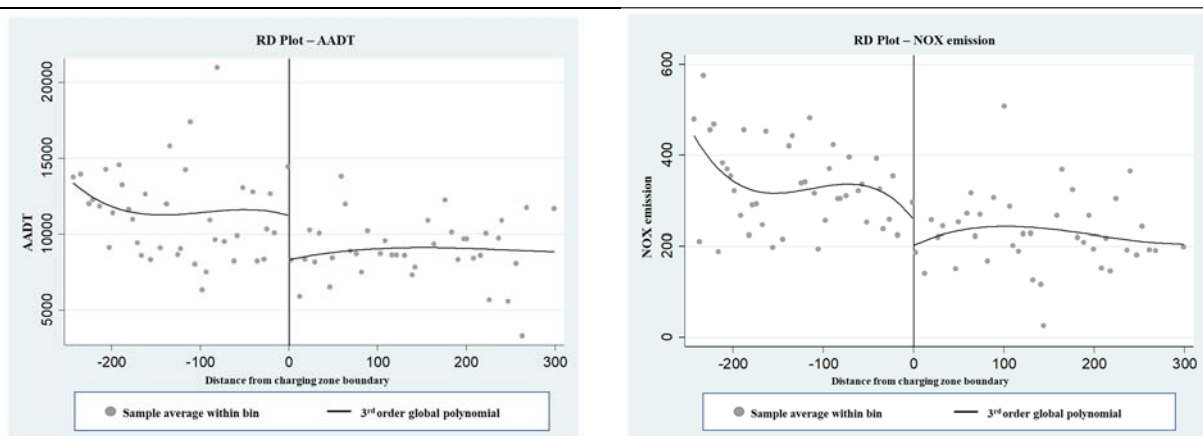
(b) NO_X

Figure 6. Traffic-related emissions after implementing the WCZ scheme

4.3. Effects of Abolishing the WCZ scheme

Effects of abolishing the WCZ scheme on the traffic flow characteristics and vehicle emission are also estimated. Again, effects of removing the congestion charging scheme on both the overall and disaggregated traffic volume by vehicle type are investigated. As shown in **Table 3(b)**, overall traffic volume in the concerned area is increased by 26% after abolishing the WCZ scheme. Increase in the volume of petrol car (20%) is the greatest amongst other vehicle types (17% for diesel car, 17% for diesel LGV, and 13% for petrol LGV respectively). Similarly, it could be attributed to the presence of the LEZ. Similarly, this can be revealed by the "jump" of the overall and disaggregated traffic volumes by vehicle type at the cutoff as shown in **Figure 7**.

Table 3(b) also illustrates the effects of abolishing the WCZ scheme on vehicle emissions. Results indicate that the traffic-related emissions of NO_X (24%) and CO_2 (21%) are increased significantly after abolishing the WCZ scheme, both at the 5% level. Similarly, this can be justified by the remarkable correlation between AADT and traffic-related emissions of NO_x and CO_2 as shown in **Table 4(b)**. **Figure 8** depicts the CO_2 and NO_X concentrations at the locations that are close to the cut-off.



(a) (b)

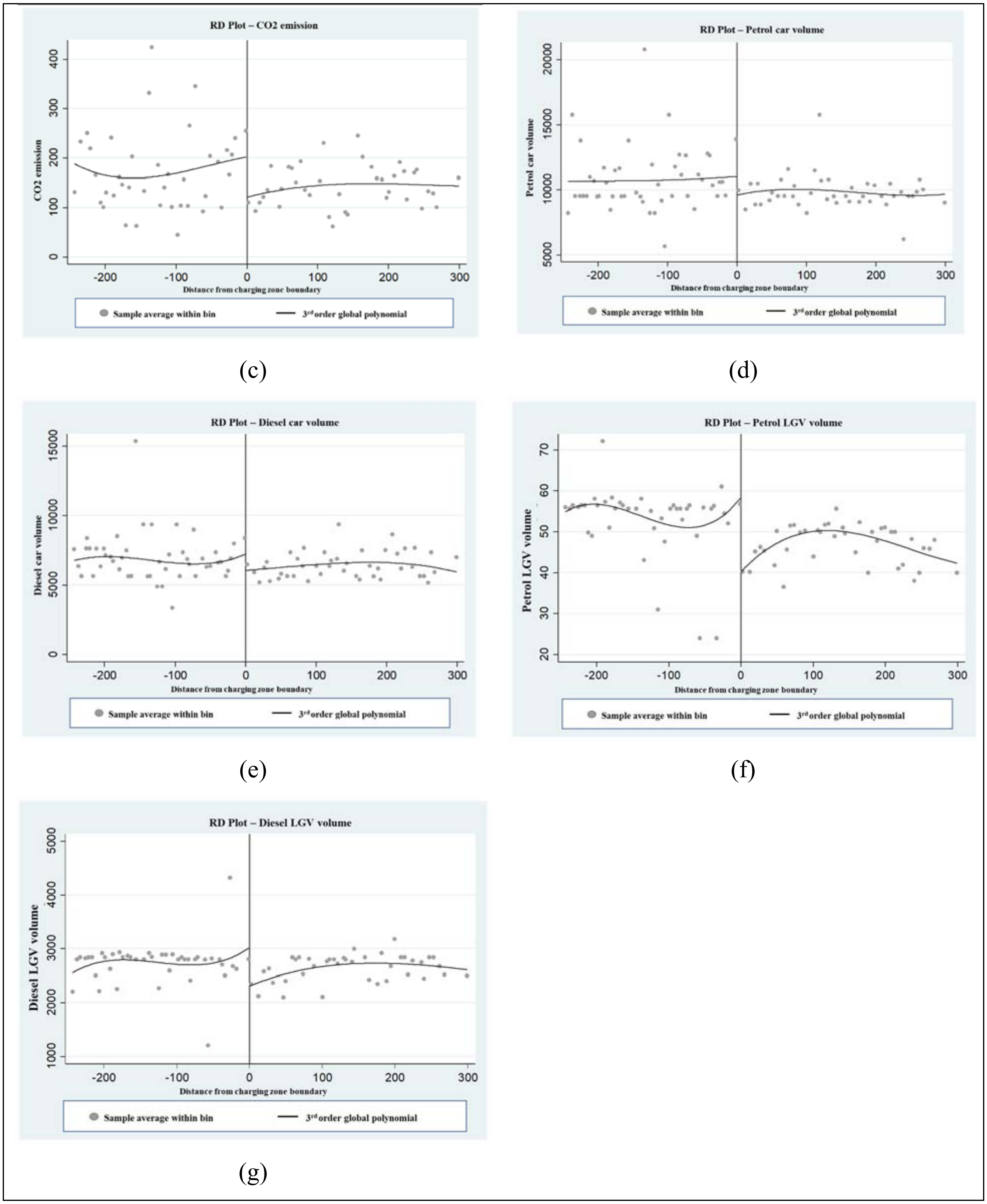
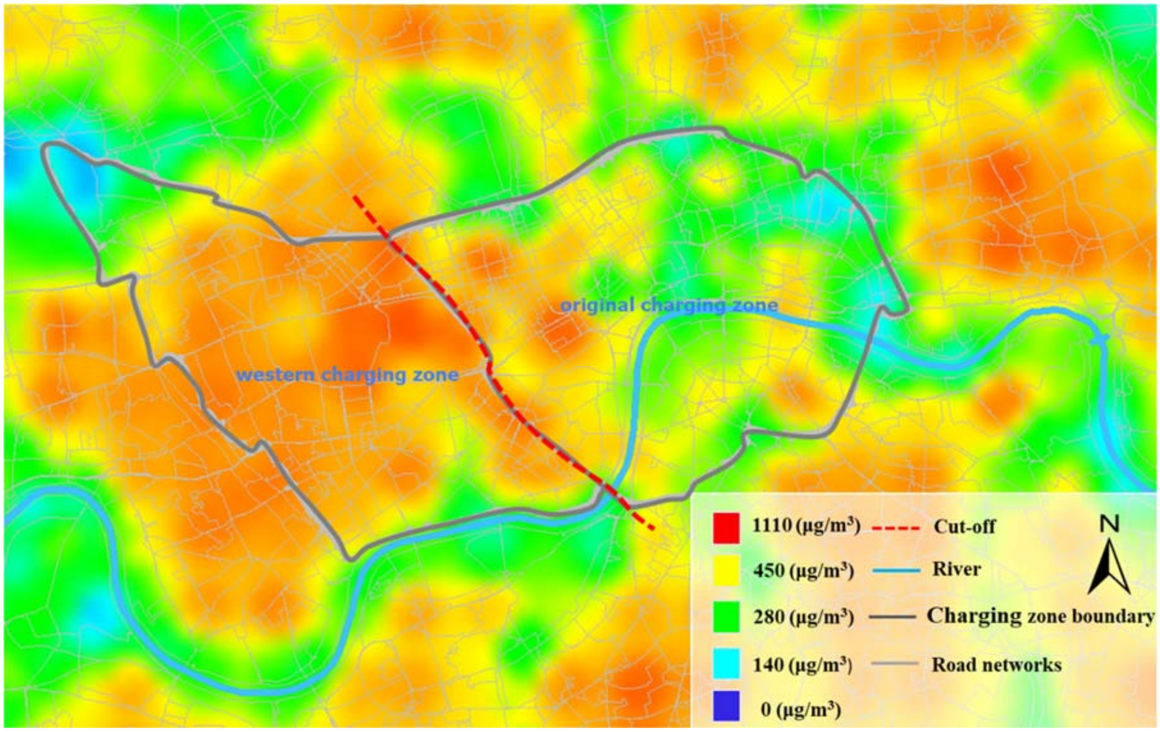
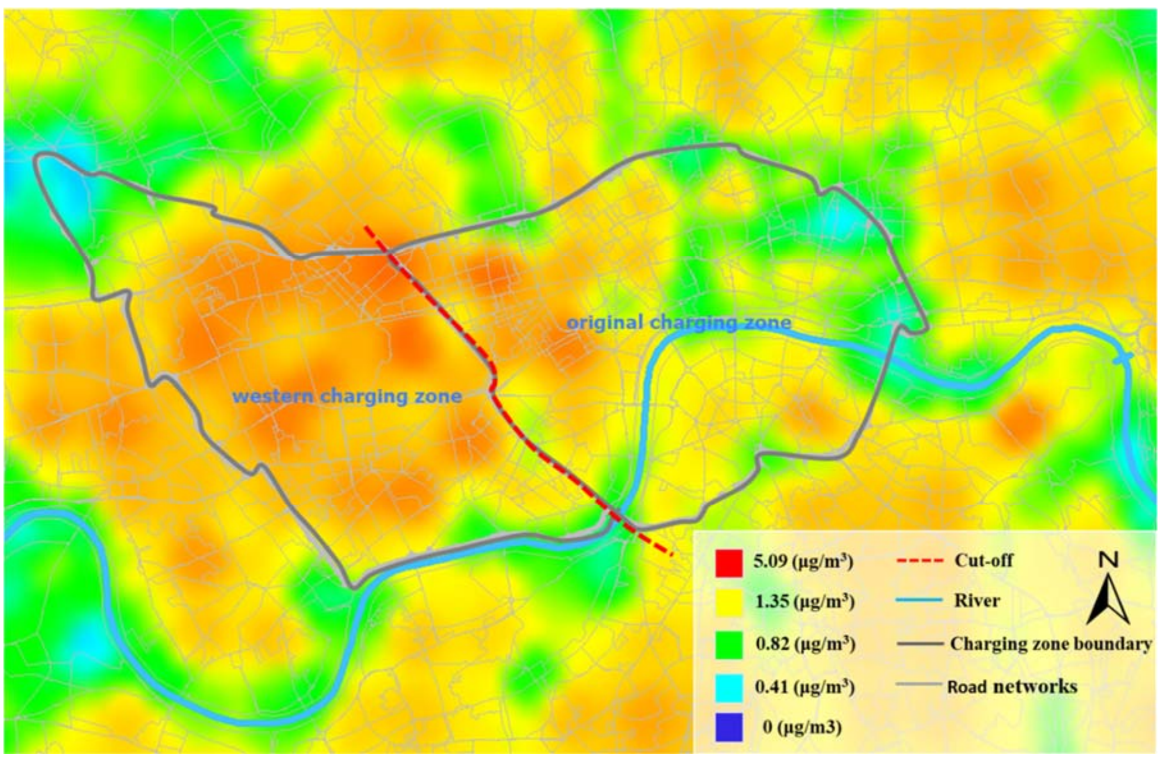


Figure 7. Effects of abolishing the WCZ scheme



(a) CO_2



(b) NO_X

Figure 8. Traffic-related emissions after abolishing the WCZ scheme

5. Discussions and Conclusions

Many engineering measures and transport management strategies, including the congestion charging scheme, are adopted to alleviate the traffic congestion problem and improve the air quality in London. Despite that studies have revealed the benefits of implementing the congestion charging scheme, it is rare that the impacts of abolishing a congestion charging scheme are evaluated. This study focuses on the case of the calling off of the WCZ scheme in London, with regard to the changes in the overall and disaggregated traffic volumes and traffic-related emissions, using the regression discontinuity approach, with which the effects of potential confounders are controlled.

There are favorable effects for the implementation of WCZ scheme. The overall traffic volume is reduced by 31% after the implementation. Reduction in the number of diesel cars entering the concerned area is the most obvious amongst all vehicle types. It could be attributed to the presence of LEZ. In addition, the traffic-related NO_X and CO_2 emissions are reduced by 29% and 33% respectively after the implementation. Moreover, the average speed is increased by 11%.

Not only the favorable effect of the implementation, but also the adverse impacts of abolishing the WCZ are assessed. Results indicate that there are moderate increases in the overall and disaggregated traffic volumes and CO_2 emission after the abolishment. This implies the possible residual effects of the WCZ scheme.

Nevertheless, this study is limited to the short-term effect of the abolishment of the WCZ scheme because of the unavailability of time-series data. It is worth exploring the long-term effects on the travel behavior and air quality of the abolishment when comprehensive traffic characteristics and air quality data are available. Furthermore, the proposed regression discontinuity approach may be limited to the effect of the observations that are around the cutoff. In the future study, effect of possible spatial heterogeneity on the variability of the treatment effect could be estimated.

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