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Effects of the London Congestion Charge on Air Quality: A Regression Discontinuity Approach

by Marco Percoco

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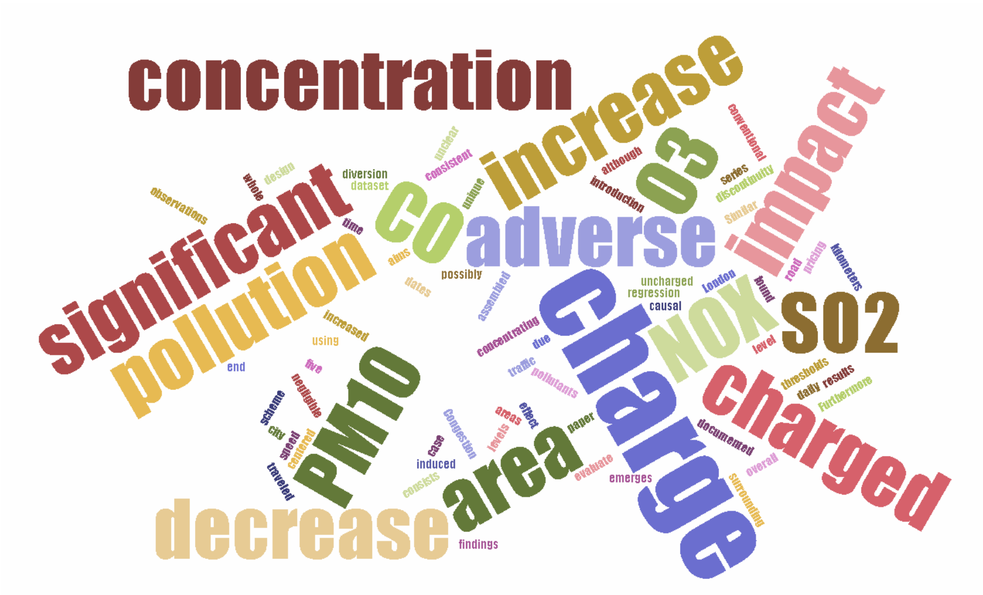

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Effects of the London Congestion Charge on Air Quality: A Regression Discontinuity Approach

by Marco Percoco

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ABSTRACT

This paper aims to evaluate the causal effect of the London Congestion Charge on the level of pollution. To this end, we have assembled a unique dataset. This consists of daily observations, concentrating on five pollutants: PM10, O3, CO, NOX, SO2.

By using a regression discontinuity design in time series; with thresholds centered on the dates of the introduction of the charge, a negligible and adverse impact of the charge is documented. It emerges that the road pricing scheme has induced a decrease in the concentration O3 in the whole city, a significant decrease in the concentration of PM10 and NOX, in the charged area and an increase in surrounding areas.

Similar results, although not significant at conventional levels, are found in the case of CO and SO2. These findings are consistent with an overall increase in traveled kilometers, due to traffic diversion from the charged to the uncharged area. Furthermore, there is an unclear, possibly adverse, impact of increased speed on pollution.

Keywords: LONDON CONGESTION CHARGE, POLLUTION, REGRESSION DISCONTINUITY DESIGN

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Effects of the London Congestion Charge on Air Quality: A Regression Discontinuity Approach

by Marco Percoco[*]

1. Introduction

Curbing congestion and pollution is a central issue in modern urban policy making. In 2013, congestion cost $8.5 billion and 82 hours per driver in London. These figures are expected to rise by 63% in 2030 (Gordon and Pickard, 2014). Similar costs are faced by most of the world cities. Furthermore, there is a large consensus and empirical study on the negative effects of exposure to high levels of pollution on human health. According to Cohen *et al.* (2004), urban pollution causes up to 6.4 million premature deaths every year. Given this empirical evidence, policy makers are implementing measures at local level to decrease the concentration of some pollutants; in particular, through transport policy actions (OECD, 2010; Greater London Authority, 2006).

To cope with the external costs of transport, several cities have introduced – or are considering to introduce – road pricing schemes, as in the case of: London (Banister, 2003), Milan (Rotaris *et al.*, 2010), Hong Kong (Ison and Rye, 2005), Singapore (Santos, 2005), Stockholm (Eliasson *et al.*, 2009) and several Norwegian cities (Leromonachou *et al.*, 2006).

In the case of London, pollution and congestion were considered to be the reasons that led to the then Mayor of London, Ken Livingstone, overseeing the implementation of the London Congestion Charge (henceforth denoted as LCC). The LCC, introduced in 2003 and then modified to extend the treated area, is probably the most known and studied example (Banister, 2003; Givoni, 2012; Ison and Rye, 2005; Prud'homme and Bocarejo, 2005; Quddus *et al.*, 2007; Santos and Bhakar, 2006; Santos and Fraser, 2004; Santos and Shaffer, 2004). However, literature has not reached a consensus on the socio-economic convenience of such measures, since infrastructure and administrative costs seem to exceed the benefits in terms of a reduction in external costs (Mackie, 2005; Prud'homme and Bocarejo, 2005; Raux, 2005).

The aim of this paper is to estimate the causal effect of the LCC on air quality in London.

It should be noted that the affects of the LCC on atmospheric pollution is not clear a priori and it highly depends on the behavioural

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response of road users. On one hand, road pricing should reduce traffic volumes, given demand elasticity to changes in transport cost and this should result in an overall improvement in pollution concentration. On the other hand, the reduction in the number of cars reduces congestion, by increasing travel speed and this, in its turn, will result in an increase in fuel consumption and in a deterioration of air quality. Kelly *et al.* (2011) have estimated a reduction in traffic and road congestion by 30% in the areas of application of the LCC. Therefore, the net consequences of the LCC on air pollution cannot be unequivocally determined a priori and need to be empirically estimated.

In early works, Atkinson *et al.* (2009) found limited evidence to demonstrate the impact of the LCC on air pollution. As the authors clearly state, their approach is based on descriptive statistics, making it difficult to consider their estimates of the charge's causal effect. In fact, Givoni (2012) has argued in favor of a more robust statistical analysis of the effects of road pricing experiences. This is because figures used in ex post evaluations are, in general, unreliable and biased by other phenomena (confounding factors) not considered in the analysis. To deal with this identification issue, we adopt an econometric framework consisting of the estimation of a parameter measuring a break in the trend of time series of concentration of pollutants. In particular, following Percoco's early work (2013; 2014a) on the case of Milan, we adopt a Regression Discontinuity Design (RDD) to estimate a local average treatment effect of the introduction of the congestion charge. This approach allows for a counterfactual identification of the effect of the policy. As a result, it provides reliable estimates of the impact of the LCC in a short timeframe around the date of the scheme's introduction.

To estimate the effect of road pricing, we study the impact of the introduction of the LCC in February 2003 on the concentration of pollution. To this end, we make use of a unique dataset of daily concentrations of: PM10, O3, CO, NOX, SO2 over the period January-March 2003, for several monitoring stations in London. Results indicate a negligible or adverse impact of road pricing, most likely because of spatial displacement of traffic from the charged area to neighboring areas, possibly with an increase in traveled kilometers.

2. The London Congestion Charge

London's fight against pollution has its origins in the second half of the XIX century; although it was only after the Great Smog of 1952 that the first policies were introduced, aiming to improve air quality. This event was disastrous for Londoners: a huge blanket of smog covered the entire city for four days and, by some estimates, caused the deaths of 4,000 people (Mayor of London, 2002). Since then, air quality has much improved; although it remains one of the European cities with the highest levels of pollution. Road transport is a major cause of the high concentration of pollutants, accounting for about 40% of emissions of nitrogen oxides and more than 60% of particulates (Greater London Authority, 2006; Kelly *et al.*, 2011).

In an attempt to reduce traffic flow, the LCC was introduced on February 17th, 2003. The objective was to reduce congestion in the central area of London, covering an area of 22 sq. km, or 1.4% of the territory of Greater London. LCC consists of a daily payment to obtain permission to move freely in the area. The policy's enforcement is achieved through the use of cameras and the automatic recognition of cars' license plates. The charge is in operation from Monday to Friday, from 7:00 AM to 6:00 PM. Initially, the scheme provided for a daily fee of £5. Subsequently, this increased to the current rate of £10. Exemptions are provided for the means of public utility, such as: buses, vehicles of law enforcement and for all vehicles powered by alternative sources of fuel. Finally, for the vehicles of the residents in the area, the price is discounted by 90%.

The original area covered was largely contained by the Inner London Ring Road. Hence major areas, such as; the West End, the City of London and the financial district, fell under this new policy. A later extension (the so-called Western Expansion), beginning on February 2007 and ending on December 2010, increased the size of the area covered to parts of West London. Additionally, it shortened the charging hours by 30 minutes to 6:00 PM. This extension nearly doubled the area covered by the LCC. This is because it included the areas of Kensington and Chelsea, covering approximately 41.5 sq. km. or 2.6% of the metropolitan area of London. Figure 1 shows the area of the LCC and of the Western Expansion. Over time, pricing of the charge has also increased. The original £5 charge was increased in July 2005 to £8 per day and, since January 4th, 2011, it has had a base daily rate of £10.

The stated objective of implementing the congestion charge was a 15% reduction in traffic in the central areas of London, with a simultaneous maintenance of traffic levels in the surrounding affected area. Transport for London (2006) reports that in the first years of the scheme's operation, the number of cars entering the central area of London significantly decreased by 21% – with respect to the pre-treatment period, although with no significant changes in travel time. However, when considering the effect of the policy at the level of congestion, the results are less positive. In regards to congestion considered as excess delay, above conditions not congestion; in the first years of the policy's operation, there was a substantial reduction in the level of congestion in the order of 30%. However, since 2006; despite the previously mentioned reduction in the number of vehicles, the congestion level has increased, compared to the levels prior to the policy. Overall, the LCC has had, at least in the early years of operation, the anticipated effect on the level of congestion and traffic in the affected area. It quite rapidly changed the habits and choices of the people concerned. Later, however, the effects of the policy have been mitigated. This can be justified by car users' adaptation of habits to the new policy; the interference of other schemes; or other exogenous factors. Figure 2 shows the timeline of the adoption of the LCC and variations in the setup.

The aim of the congestion charge was largely two-fold (TfL, 2004a). Firstly, to reduce congestion and secondly, to use the funds raised to improve transport infrastructure. In so far as private consumption of motor transport can be seen to impose negative externalities, e.g., increased congestion, noise, pollution etc., LCC can be thought of as a form of Pigouvian taxation. It can better equate the marginal private and social costs of transport; that is, to make individual agents incorporate external costs of their consumption into their private costs.

However, it should be noted that the marginal cost of congestion was not used as a basis for the charge. Instead, to find the optimal pricing scheme, simulations and models of household behavior were used to predict changes in traffic. Nonetheless, Santos and Shaffer (2004) state that the £5 per day charge is a reasonable approximation of the marginal congestion costs for an agent driving through the congestion charge zone.

The revenues raised are not insignificant. In 2009/10, the congestion charge revenue was £312.6 million, making up 8.7% of TfL group revenue. Since its establishment, the contribution to group revenue has remained relatively stable; in 2003/04 revenue was £186.7 million, making up 8% of group revenue. Due to direct and other expenditures, net income from congestion charging in 09/10 was £158.1 million. This is still a significant sum, considering that these funds are used to operate and improve TfL (TfL 2004a, 2010). A notable change came with the new Mayor of London; Boris Johnson. On November 27th, 2008, in keeping with his election manifesto, Johnson announced the planned abandoning of the Western Extension. Following subsequent consultation processes and legal reviews, this was later officially implemented. On January 4th, 2011, increased pricing for the remaining zone was applied; although the congestion charge was lifted from Christmas Eve 2010 to January 3rd, 2011 to coincide with the holiday period. The policy shift was met with both support and criticism. The TfL had stated that the LCC policy had had a "broadly neutral impact on the Central London economy", with perceived benefits in the form of: improved public transport, better air quality, and fewer collisions and accidents (TfL, 2008). Furthermore, the TfL's estimates suggested that this decision would lead to a £55-70 million loss of annual revenue, a large sum by any measure (TfL, 2008).

Although there is an abundance of analysis on the effect of the LCC on several aspects of the city, a causal analysis of its impact on environmental quality has not yet been conducted. The use of simple descriptive statistics may, in fact, pose severe bias in the evaluation of the policy, since it assigns to the LCC. Furthermore, the effect of other variables (confounding factors) can contribute to this 2003, for several monitoring stations in London. Results indicate a negligible or adverse impact of road pricing, most likely because of spatial displacement of traffic from the charged area to neighboring areas, possibly with an increase in traveled kilometers.

3. Methodology and data

Our empirical approach is based on fairly recent literature using the Regression Discontinuity Design (henceforth denoted as RDD) to examine the impact of policies related to transport and air quality (Chen and Whalley, 2011; Davis, 2008; Percoco, 2013).

RDD is a non-experimental approach that uses ex post to evaluate a program's impact on a situation in which units are considered treated or not, according to a certain threshold in a reference variable (forcing variable). In our case, the date in which the LCC was implemented is used as a threshold that introduces an exogenous variation in the access of polluting vehicles in the city. Thus, the expected outcome is a reduction in the level of pollutants. It should be stated that RDD identifies the impact of LCC under mild assumptions; hence, it excludes the bias imposed by confounding factors.

Let y_0 and y_1 denote the counterfactual outcomes before and after the treatment T (the introduction of the LCC), let x be the forcing variable (in our case, the time) and consider the following assumptions (Angrist and Pischke, 2009):

A1. $E(y_g \mid T, x) = E(y_g \mid x)$, g=0,1

A2. $E(y_g \mid x)$, g = 0,1 is continuous at $x = x_0$

A3. $P(T=1 \mid x) \equiv F(x)$ is discontinuous at $x = x_0$, i.e. the propensity score of the treatment has a discrete jump at $x = x_0$.

Following Imbens and Lemieux (2008) the goal is to estimate the parameter ρ on treatment of this form (for the moment we do not specify the model across locations):

$$y_{t,T} = \theta + \rho LCC_t + f(\tilde{x}_{t,T}) + \eta_t \quad (1)$$

where $y_{t,T}$ in our case is the concentration of a given pollutant in day t whose treatment status is T (i.e. before or after the introduction of the LCC), θ is a constant, $\tilde{x}_{t,T}$ is the forcing variable properly normalized (a time trend centered at the date of the introduction of the LCC, i.e. 17 February 2003). Consequently, ρ expresses the impact of the treatment at $x_{t,T} = x_0$. The $f(\tilde{x}_{t,T})$ term is a p-th order parametric polynomial to account for non linearity of the relationship between the time trend and pollution and thus to control that the eventual break in $x_{i,T} = x_0$ is not due to unaccounted non-linearity. Lastly η_t is an error term. LCC is our treatment variable taking the value of 1 after the introduction of the congestion charge and zero before.

Seasonal and climatic factors are crucial in explaining the level of pollutants in the air. To deal with these problems in the reference model (1), seasonality is accounted for with day of the week, month and year dummies.

To make (1) operational for the analysis of the impact of the LCC and to account for the heterogeneity of monitoring stations (Auffhammer *et al.*, 2009; 2011), we have estimated an equation in the form:

$$y_{it} = a_i + \rho LCC_t + \gamma LCC_t \cdot Treated_i + f(\tilde{x_t}) + \varepsilon_i \qquad (2)$$

where a_i is a full set of station-specific fixed effects and $Treated_i$ takes the value of 1 if station i is located in the charged area and zero otherwise. It should be stated that station- specific fixed effects are of particular relevance in (2) to identify the policy parameter γ as $Treated_i$ is time-invariant. In all the specifications we make use of a 5th order trend polynomial and control for weather conditions and standard errors were clustered by month in order to account for possible spatial correlation. Seven days of temporal lags of the dependent variable are also used to account for the temporal persistence of pollutants, especially in the case of particulate matter. Finally, model (2) is estimated in logarithms, so that parameter estimates can be interpreted as percentage changes.

In equation (2), parameter γ identifies the effect of the policy in the charged area (the Average Treatment on the Treated), whereas ρ indicates the average effect of the introduction of the London Congestion Charge across stations, regardless of the their location.

The data used in the analysis were made available by the LAQN (London Air Quality Network). They comprise daily observations of pollution from several monitoring stations in London, over period January-March 2003. These detectors are not homogeneous with regard to pollutants and weather conditions monitored, as well as for the location of the detector, with respect to the road surface. Not all variables are available for all stations. Of a total of 194, 28-72 (depending on the pollutant) monitoring stations were selected on the basis of availability of information for at least one of the variables of interest and within 10 kilometers arc distance from the city center. The dataset contains information on the concentration of five pollutants: PM10, O3, CO, NOX, SO2. Of those pollutants, only SO2 is less related to transportation. The concentrations of all the others are widely considered to be indicators of transport-related pollution (although not exclusively). Furthermore, information on: temperature, wind speed, rain and humidity is also available. [1] Table 1 shows a mean concentrations before and after the introduction of the LCC. Interestingly, the results show a sizeable increase in the emission levels for almost all of the pollutants considered, also within the area where the congestion charge was implemented.

Before proceeding with the parametric analysis described in this section, figure 3 reports a graphical analysis, as in the spirit of Imbens and Lemieux (2008); and Lee and Lemieux (2010). In particular, scatter plots report daily concentrations one year before and one year after the introduction of the LCC for the seven pollutants across the monitoring stations of our sample. Local polynomial regressions are also added to highlight eventual breaks in correspondence of the introduction of the LCC. No significant drop in the concentration of pollution is detectable. Results of the descriptive analysis in table 1 and figure 3 are admittedly puzzling and need to be scrutinized in a more systematic way, through a parametric analysis.

4. Results

In table 2, baseline models for the evaluation of the LCC are reported. They have been all estimated over the period January-March 2003 with a 5th order polynomial trend; weather controls and seven days of temporal lags of the dependent variable. In Panel A, we report results of the difference-in-discontinuity model in (2). A slight but only marginally significant increase in the concentration of PM10 is detected for the whole city and a significant reduction in the treated area is estimated in -0.059%. As for ozone, a reduction of an order of magnitude of 0.394% is found, with no significant spatial differentiation. Interestingly, as for CO, NOX and SO2 a significant increase in the concentration of pollution is detected, with a contemporary reduction in the treated area, although this decrease is significant only in the case of NOX. In Panel B, we consider only monitoring stations out of the treated area but located within 5 kilometers from the boundary of the charged area. Therefore, the estimated model assumes $\gamma = 0$. Results confirm the overall reduction in the concentration of ozone, but also significant increases in PM10, CO, NOX, SO2 with parameters ranging from 0.106% as in the case of PM10 to 0.513% for SO2 (although, only marginally significant).

[1] It should be mentioned that the complete dataset covers the years 2000-2013. However, in this paper, we have restricted the sample to only three months (January-March 2003) to make our regression analysis comply with general practice of RDD consisting in restricting the interval around the threshold. An analysis over longer period was conducted with results qualitatively similar, although less reliable. Results are available upon request.

Finally, in Panel C, we have excluded monitoring stations located in the treated area and in the surrounding area within a 5 kilometers arc distance. Therefore, we have considered only monitoring stations in the outer circle within a 10 kilometers from the treated area. Also in this case results are confirmed: an overall decrease in O3 equal to -0.277% and an increase in PM10, CO, NOX and SO2.

Overall, econometric results show unclear effects of the congestion charge in London. For some pollutants, such as PM10, CO, NOX and SO2, an increase in the concentration was found out of the treated area, with only small reductions in the charged area. This can be due to the diversion of traffic from the city center to external areas, with a subsequent increase in the kilometers traveled and the potential of polluting emissions. This spatial pattern of traffic flow is consistent with the findings of ITO (2010), for which some areas of northern London witnessed an increase in traffic counts by more than 30% over the period 2001-2010. This hypothesis can be further investigated by using data on traffic counts in the London area.

In particular, the Department for Transport makes traffic counts for the period 2000- 2013 available, with annual observations for 2,141 count points. Count points have been geolocalized and hence assigned to three groups: *Treated* (if located in the congestion charge area), *Surrounding* (if located in a borough partially treated by the congestion charge or neighboring the charged area[2]), or in the control group. In column 1 in table 3, descriptive statistics of differences-in-mean is reported. In particular, statistics refer to the change in the mean of traffic counts before the treatment and after the introduction of the charge. It is noted that the pre-treatment mean is computed over the years 2000-2002, whilst the post-treatment mean is calculated over the years 2003-2005. Descriptive statistics show a decrease in the number of vehicles by 128,538 and 207,296 in the treated and controlled areas, although both estimates are not significantly different from zero. Interestingly, count points surrounding the treated area registered an average increase by 111,325 vehicles. This estimate is significant at a 99% statistical level. Together, these statistics imply a diversion of traffic from the treated to the surrounding area. However, a compelling parametric analysis is needed to account for unobserved heterogeneity and time trend. To this end, the following difference-in-difference model can be estimated over the years 2000-2005:

$$traffic_{it} = a_i + \beta trend_t + \gamma post_t + \delta_1 Treated_i \cdot LCC_t + \delta_2 Surrouding_i \cdot LCC_t + \varepsilon_{it} \qquad (3)$$

[2]The following boroughs have been considered to be in the *Surrounding* group: Wandsworth, Lewisham, Greenwich, Newham, Waltham, Haringey, Barnet, Brent, Kensington, Hammersmith.

where the dependent variable is the number of traffic count in year t at count point i, a_i are count point specific fixed effects, trend indicates a temporal trend, post is a dummy variable taking the value of one after 2002 and zero otherwise, $Treated_i$ and $Surrouding_i$ are indicator variables for the treatment and surrounding group to which count point i belongs to. In model (2) in table 3 we consider $\delta_2 = 0$ and it emerges a decrease by 12,358 vehicles in the treated area with respect to the rest of the city, although this coefficient is not significant. In model (3) the full model is reported and it emerges that the introduction of the congestion charge has resulted in an increase in traffic counts by 279,596 vehicles. This figure is statistically significant, whereas no significant (at conventional level) change is found in the treated area.

Estimates in table 3 corroborate the hypothesis advanced in the previous section to justify the finding of a decrease in pollution concentration in the treated area and an increase outside of this area. However, results may still hide some heterogeneity in terms of traffic composition. In table 4, the sample is split into four categories (heavy goods vehicles, light goods vehicles, cars, motorbikes) and the number of bikes is added. Interestingly, the introduction of the LCC has decreased the number of heavy goods vehicles by 13,434 units in the treated area, although this estimate is only marginally significant. Additionally, no significant effect is found in the case of light goods vans; whilst, in model 3, a clear increase in the surrounding area by 242,411 cars is estimated. According to estimates in models 4 and 5, an increase by 34,664 and 30,335 occurred in the case of motorbikes and bikes. Hence, from an environmental perspective, a shift towards uncharged vehicles (and in this case, motorbikes) is not efficient. Another possible transmission channel might make a change in the kilometers traveled; drivers may be willing to avoid the charged area by traveling longer routes around the area. The UK Department of Transport provides statistics on kilometers × vehicles at the level of local authority. Estimates of the effect of the LCC in the treated and surrounding areas are not precise, since some local authorities are only partially treated. In this case, the assignment to the charged; surrounding or to the controlled area, is carried out on the basis of the share of surface treated. In particular, we consider the following local authorities as treated: City of London, Lambeth, Southwark, Tower Hamlets, Hackney, Islington, Camden, City of Westminster. Local authorities in the surrounding area are: Wandsworth, Lewisham, Greenwich, Newham, Waltham, Haringey, Barnet, Brent, Kensington, Hammersmith.

Table 5 reports estimates of the LCC on traveled kilometers by using a difference in means. As in the previous case, the pre-treatment mean is computed over the years 2000- 2002, whilst the post-treatment mean is determined over the years 2003-2005. Interestingly, a decrease by 45,000 kilometers × vehicles was found in the treated area, whereas an increase by 39,000 kilometers × vehicles was found in the surrounding area. Therefore, also in this case, there is evidence of traffic diversion from the treated to the surrounding area which possibly explains the results in table 2.

Another important factor for the interpretation of the results presented in table 2 is the relationship between emissions of a given pollutant and average speed. In fact, the relation- ship between the production of nitrogen oxides and traveling speed is directly proportional to the vehicles with diesel engine (EEA, 2010). Thus, an increase of the vehicle's average speed is due to a greater production of nitrogen oxides. This might be relevant because of the reduction of congestion caused by the introduction of the charge, especially in the early years after the policy was introduced (Greater London Authority, 2006). However, the relationship between pollutants and average speed of vehicles is still not very clear, especially for ozone and particulates, and further studies are needed to shed light on this issue (EEA, 2010).

5. Conclusion

In this paper, the environmental effect of road pricing in London was studied with a RDD approach to estimate the causal impact of the LCC. In particular, the exogenous variation in traffic flows after the introduction of the policies was used to estimate a variation into the concentration of: PM10, O3, CO, NOX, SO2. A negligible effect of the policy was found, along with a spatial displacement effect, since a reduction in the concentration of several pollutants in the treated area and an increase in the surrounding areas was found. In particular, a significant decrease in the concentration of O3 was found across the whole city of an order of magnitude of -0.4% (on average). CO, NOX and SO2 present significant increases by 0.4-0.5% (on average) in the area surrounding the charged area. A reduction in the concentration of PM10 and NOX was also found in the charged area.

This pattern in the estimates is consistent with the hypothesis that the introduction of the congestion charge has diverted traffic in space and shifted drivers from charged to uncharged routes and, eventually, vehicles. Traffic data show that the number of circulating vehicles in the area surrounding the treated area by 279,596 vehicles; 242,441 of which were cars. A substantial increase in the number of motorbikes and of bikes has also been detected in the city center. In terms of kilometers traveled, a decrease by 45,000 kilometers × vehicles was estimated in the treated area, along with an increase by 39,000 kilometers × vehicles in the surrounding area.

Overall, in terms of pollution concentration of the whole city, our results suggest that the congestion charge has had a limited or even adverse impact, possibly because of the spatial diversion of traffic. This result calls for careful consideration of the spatial extent and of the cross elasticity of traffic flows when implementing road pricing schemes.

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Table 1: Descriptive statistics

	Whole sample		*Treated area*	
	(1) Before	(2) After	(3) Before	(4) After
PM10	21.49	40.24	22.26	40.95
	(9.874)	(16.48)	(7.914)	(15.94)
O3	29.32	34.94	22.74	29.16
	(15.16)	(19.86)	(12.37)	(18.10)
CO	0.387	0.390	0.468	0.495
	(0.268)	(0.250)	(0.188)	(0.240)
NOX	74.82	88.11	76.30	99.03
	(57.06)	(59.68)	(46.67)	(64.21)
SO2	7.033	9.670	4.553	7.211
	(5.372)	(8.209)	(3.406)	(5.418)

Table 2: The effect of the London Congestion Charge on air quality

Panel A: Whole sample					
	(1) PM10	(2) O3	(3) CO	(4) NOX	(5) SO2
LCC	0.0669*	-0.394***	0.463***	0.423***	0.472***
	(0.0337)	(0.0773)	(0.0875)	(0.0633)	(0.117)
LCC x Treated	-0.0592***	0.00397	-0.0219	-0.0451***	-0.0186
	(0.0172)	(0.0145)	(0.0344)	(0.0129)	(0.0406)
Observations	4,149	1,827	1,691	5,126	2,139
R-squared	0.620	0.329	0.306	0.397	0.366
Number of st.	59	27	28	72	35
Panel B: Excluding treated area, within 5 km					
LCC	0.106**	–0.491**	0.424***	0.416***	0.513*
	(0.0344)	(0.0690)	(0.0296)	(0.0314)	(0.187)
Observations	1,016	340	487	1,242	604
R-squared	0.622	0.380	0.377	0.402	0.418
Number of st.	14	4	6	16	9
Panel C: Excluding treated area, more than 5 km					
LCC	0.0768*	–0.277**	0.646**	0.484***	0.540***
	(0.0336)	(0.101)	(0.218)	(0.0985)	(0.134)
Observations	2,896	1,183	1,029	3,672	1,262
R-squared	0.623	0.313	0.311	0.397	0.365
Number of st.	39	15	14	48	18

Notes: All specifications include a 5th order polynomial time trend, controls for wind speed, humidity, temperature, rainfalls and a series of dummies for day of the week, month and year. Standard errors are clustered by month.

Significance levels: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 3: Difference-in-differences in traffic within London
(dependent variable is the number of vehicles; in thousands)

	(1) Descriptive statistics	(2) Least squares	(3) Least squares
Treated	−128.538	−12.358	77.973
	(123.444)	(90.738)	(83.302)
Surrounding	111.325***		279.596***
	(23.332)		(89.434)
Control	−207.296		
	(231.211)		
Obs.		12,846	12,846
R. sq.		0.094	0.094

Notes: Column 1 reports descriptive statistics of changes in total vehicles between the pre-charge period (2000-2002) and the post-charge period (2003-2005). Models (2) and (3) are difference-in-differences models with count point fixed effect, a temporal trend and a *post* dummy taking the value of 1 after 2003 and 0 before. Models are estimated via least squares over the period 2000-2005. Dependent variable is the total number of vehicles. Standard errors in models 2 and 3 are clustered by local authority.

Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table 4: The effect of the London Congestion Charge on traffic composition
(dependent variable is the number of vehicles by type; in thousands)

	(1) Heavy Goods Vehicles	(2) Light Goods vans	(3) Cars	(4) Motor-bikes	(5) Bikes
Treated	−13.434*	7.002	41.967	34.664***	30.335***
	(7.121)	(15.401)	(77.960)	(11.123)	(8.338)
Surrounding	−3.952	31.497	242.441**	3.592	−3.479
	(9.541)	(20.818)	(101.360)	(8.988)	(12.804)
Obs.	12,846	12,846	12,846	12,846	12,846
R. sq.	0.012	0.012	0.013	0.016	0.014

Notes: All models are difference-in-differences models with count point fixed effect, a temporal trend and a *post* dummy taking the value of 1 after 2003 and 0 before. Models are estimated via least squares over the period 2000-2005. Dependent variable is the total number of vehicles by type as reported in column headings. Standard errors are clustered by local authority. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table 5: The effect of the London Congestion Charge on kilometres travelled
*(Million of km*vehicles)*

	Before	After	Implied DID
Treated	3494.333	3353.000	−45,000**
Surrounding	5645.667	5588.667	39,333**
Control	10914.33	10818.000	

Notes: Data at local authority level. Treated local authorities are: City of London, Lambeth, Southwark, Tower Hamlets, Hackney, Islington, Camden, City of Westminster. Local authorities in the surrounding area are: Wandsworth, Lewisham, Greenwich, Newham, Waltham, Haringey, Barnet, Brent, Kensington, Hammersmith. Years before the London Congestion Charge are 2000-2002; years after the policy are 2003-2005.

Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Figure 1: The LCC and the Western Expansion

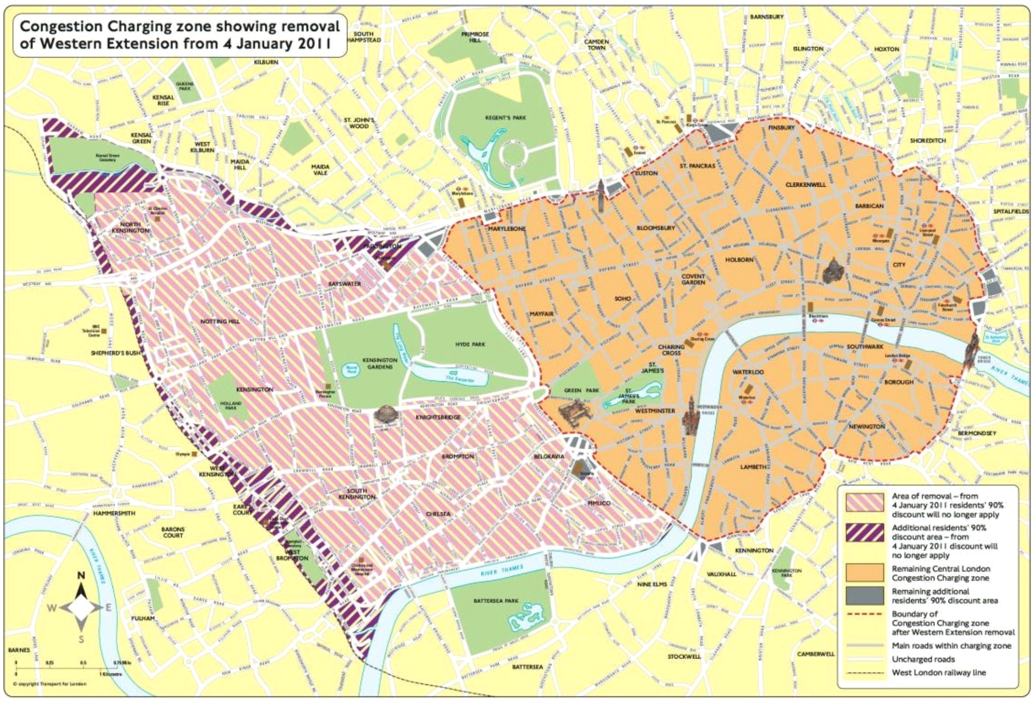


Figure 2: Timeline of the setup and variations of the London Congestion Charge

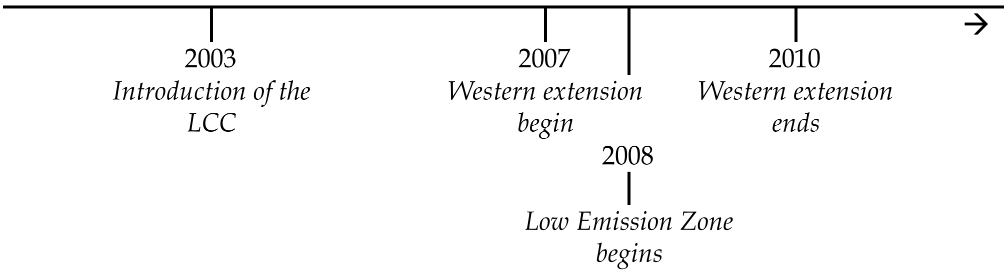
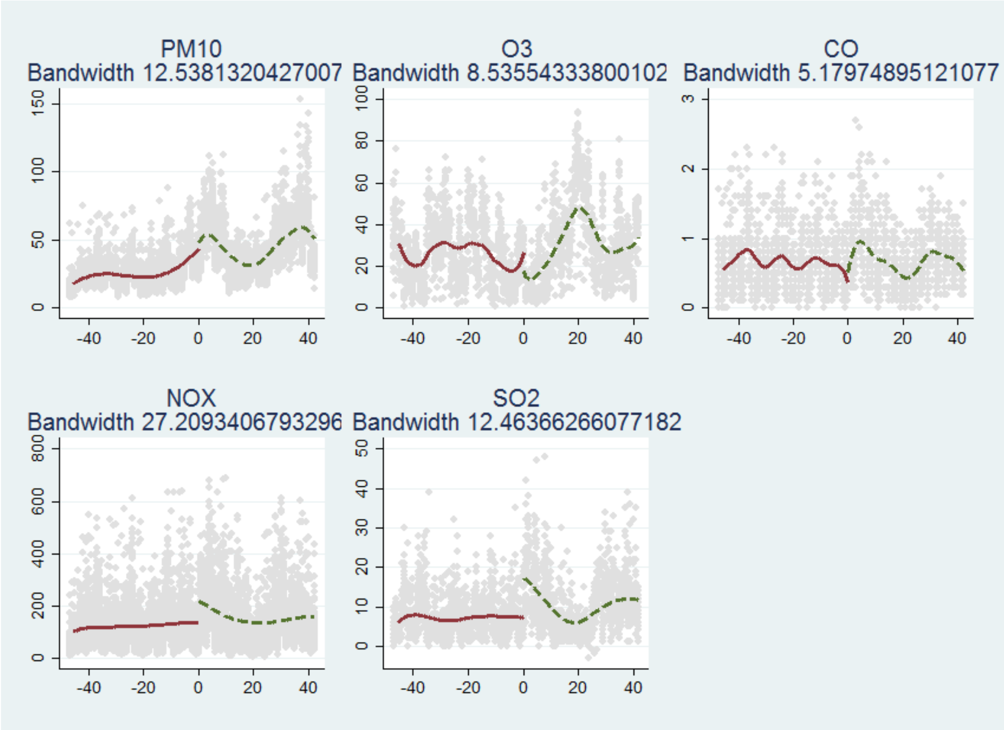


Figure 3: The effect of the introduction of the London Congestion Charge on pollution concentration



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