The Cost of Traffic: Evidence from the London Congestion Charge*

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Traffic congestion is a pervasive and urgent concern for major cities around the world. In this paper, I evaluate the effectiveness of the London Congestion Charge Zone (CCZ) in alleviating congestion and subsequently utilize this sharp change in traffic conditions to measure the willingness to pay to avoid traffic. Relying on rich data on traffic flows and home prices, I compare roads and properties in close proximity but on different sides of the CCZ to mitigate neighbourhood unobservables across the boundary. My results show that homebuyers pay up to 4% more to enjoy a 10% reduction in traffic in the zone. (*JEL*: R31, R41, Q51)

1 Introduction

Traffic congestion is an urban disamenity from the agglomeration of economic activities. Attracted by productivity gains and amenities in cities, firms and individuals congregate in urban areas. Stiff competition for space, together with the proliferation of auto-mobiles, attribute to the expansion of cities and encourage more people to drive. The surge in automobiles on roads inevitably lead to traffic congestion, an ubiquitous problem many cities

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around the world faces. According to the 2015 Urban Mobility report, across 471 urban areas in US, congestion causes Americans to spend 6.9 billion hours more on the road and waste 3.1 billion gallons of fuel, leading to a net loss of $160 billion (Schrank *et al.*, 2015). This amounts to an average annual congestion cost of $960 per commuter, an outlay that has increased more than twofold since 1980s. These traffic delays have affected London as well. Average on-road commuting speed in the 1990s was slower than that at the beginning of twentieth century before car travel became prevalent (Newbery, 1990). By 2002, travel speed for motor vehicles during morning peak hours fell by almost 30% compared to that in 1974, from 14.2 to 10.0 miles per hour, and drivers spent, on average, 27.6% of their on-road time stationary (Department of Environment & the Regions, 1998).

Other than the time and fuel wasted being stuck in the gridlock, traffic is also a major source of air pollution. According to figures from Environmental Protection Agency, automobiles contribute more to 50% of the nitrogen oxide, 30% of the volatile organic compounds and 20% of the PM10 in US[1]. These emissions have detrimental effects on health outcomes, increasing infant mortality, reducing birth weight and inducing premature births (Currie & Walker, 2011; Knittel *et al.*, 2016). Heavier traffic can also cause more traffic accidents (Li *et al.*, 2012; Green *et al.*, 2016). In broader sense, bottlenecks can also impede economic growth (Boarnet, 1997; Fernald, 1999; Graham, 2007), increase unemployment (Hymel, 2009) and reduce wages (De Borger, 2009). It is evident that traffic is undesirable and can affect the attractiveness of neighbourhoods, influencing household location decisions.

In response to these concerns, various policies[2] have been introduced to alleviate congestion. One effective way is to explicitly tax road users (Pigou, 1924; Vickrey, 1963). Imposing a Congestion Charge (CC) that equates the marginal private and social cost of transport ensures that drivers incorporate congestion externalities into their private cost of travel. On 17th of February 2003, London successfully[3] introduced this system to control traffic into the city center. A flat £5 daily charge was enforced on private vehicles driving into the cordoned Congestion Charge Zone (CCZ) from 7:00am to 6:30pm on weekdays. The effects were immediate. Six months into implementation, the volume of cars into Central London fell by 27% and average travel speed was 20% higher than before (TfL, 2003a). The CC is subsequently extended to the Western Extension Zone (WEZ) in 2007 to curtail traffic in Central West London.

[1] For more information, refer to `https://www.epa.gov/air-pollution-transportation/smog-soot-and-local-air-pollution`

[2] Some examples include driving restrictions and fuel taxes to reduce driving demand and road constructions to increase road supply.

[3] Other cities that managed to introduce the CC include Singapore, Dubai, Milan, Stockholm, Gothenburg and Durham.

This paper measures the marginal willingness to pay (MWTP) for better traffic conditions using the housing market. The idea is that traffic varies across space and differences in home values should reflect the price paid to avoid traffic, holding all other factors constant. To recover the MWTP, previous literature[4] control for observable differences by estimating the hedonic property function. While the concept is forthright, attempts to estimate the casual effect of traffic on home prices have been fraught with difficulties. First, traffic is not randomly distributed across space and the heaviest traffic is usually found in the city center where economic activities (e.g shopping belts, Central Business District) are congregated. Unobserved neighbourhood differences between these properties with different traffic conditions are likely to confound the estimates. Further, more affluent households who incur costlier time delays have strong incentives to sort into the city center to reduce the need to commute. The concern is whether the WTP to avoid traffic could be confounded with the WTP for better neighbourhoods. As a result, failure to control for differences in neighbourhood characteristics could underestimate the value of less traffic.

Bearing these challenges in mind, this paper exploits the substantial but localised changes in traffic induced by the CC to measure the cost of traffic. The advantage of this strategy is that I can compare properties close to one another but on opposite sides of the CCZ/WEZ to mitigate unobserved differences neighbourhood amenities. Estimation is based on a quasi-experimental difference-in-difference approach that compare price changes for properties inside the zone before and after the implementation of the CC with price changes of properties outside the zone. Put differently, I am exploiting the variation in the traffic conditions over time induced by the charge to recover the cost of traffic.

For the estimates to be valid, the mean differences in unobservables (e.g neighbourhood amenities, housing characteristics) between transactions across the CC boundary should not be correlated with the implementation of the charge. I adopt several strategies to ensure that my analysis satisfy this condition. First, I partial out any time-invariant housing and neighbourhood characteristics (infrastructure, location etc.) by including postcode fixed effects. This is equivalent to comparing repeated sales of similar units or units in the same postcode. Second, I progressively restrict the analysis to transactions that close to the charge zone (up to 1 kilometres) to attenuate unobserved neighbourhood differences between sales on either side of the boundary. This is only possible because first, there are more than half

[4] The hedonic approach has been used extensively in the literature to value non-market amenities since it is formalized by Rosen (1974). Some examples include school quality (Black, 1999; Bayer *et al.*, 2007; Gibbons *et al.*, 2013), air quality (Chay *et al.*, 2005), health hazards (Gayer *et al.*, 2000; Davis, 2004; Currie *et al.*, 2015), crime (Thaler, 1978; Gibbons, 2004) and transportation accessibility (Gibbons & Machin, 2005).

a million of residential sales clustered around Central London and second, the CC generated sharp changes in traffic conditions across the boundary. By doing so, I am comparing properties across the boundary but in the same area, sharing common amenities (e.g school quality, parks, crime rate) and neighbourhood demographics (e.g unemployment rate) but with contrasting traffic conditions. Third, I control for an extensive set of property and location characteristics surrounding each sale to reduce the risk of omitted variable from confounding my estimates.

The headline finding is that homeowners moving into the cordoned charge zone pay more than those buying homes near but outside the zone to enjoy better traffic. Home buyers pay, on average, 4.27% (£18,230)[5] more in the CCZ and 2.23% (£18,828) more in the WEZ after the charge is implemented while traffic flow is on 9.48% lower in the CCZ and 3.49% lower in the WEZ. These results are robust across a range of alternative specifications and falsification tests to control for unobserved neighbourhood characteristics and correlated effects that could confound the estimates. This MWTP to avoid traffic appears to differ across groups and is much higher for home buyers who tend to drive more and incur higher cost of delay. Multiplying the capitalization effects with the total number of dwellings, the charge generated a windfall of £1.33 billion and £3.60 billion for homeowners in the CCZ and WEZ respectively. This figure provides useful metric of the localised benefits associated with the charge.

The remainder of this paper is structured as follows. Section 2 provides an overview on the Congestion Charge in London. Section 3 describes the existing literature on this subject. Section 4 outlines the data and Section 5 illustrates the identification strategy. Findings are then discussed in Section 6 and Section 7 concludes.

2 Road Pricing in London

The initial Congestion Charge Zone (CCZ[6]) covered a total of 21 square kilometres (slightly more than 1% of the Greater London Area) and encompassed the financial centre (Bank), parliament and government offices (Palace of Westminster), major shopping belts (Oxford Circus) and tourist attractions (Trafalgar Square, Westminster Abbey, Big Ben, St

[5]These estimates are obtained from the preferred specification in Column (5) and (10) of Table 5 where I restrict the analysis to transactions 1 kilometre left and right of the charged boundary.

[6]The initial Congestion Charge Zone will be abbreviated as the CCZ while the Western Extension Zone will be abbreviated as WEZ from this point onwards

Paul Cathedral etc). Figure 1 depicts the CCZ, the area shaded in orange and enclosed by the red dashed line. The boundary was drawn to isolate the most congested areas in Central London and does not appear to be constrained by any physical features (rail lines, green spaces and rivers etc). It was bordered by major Inner Ring Roads such as Edgeware, Vauxhall Bridge, Pentonville, Park Lane, Marylebone, Tower Bridge and Victoria to divert traffic displaced by the charge. Commuters travelling on these roads are not required to pay unless they turn into the zone. To protect residents and businesses outside the zone, off-street parking enforcement is improved to deter anyone from parking outside and walking into the cordoned zone to avoid paying the charge. The CCZ crosses the River Thames to the South and covers parts of the Lambeth and Southwark boroughs. Although this is an area not typically considered as Central London, it was incorporated for the ease of implementation and operation (Richards, 2006).

On the 17th of February 2003, a flat fee[7] of £5.00 was levied on commuters driving into the zone between 7:00am to 6:30pm from Monday to Friday, excluding public holidays. Residents living in the zone and some living outside but in discount zones are entitled to a 90% waiver[8] to the CC for their first registered vehicle. These discount zones are shaded in grey for the CCZ and in purple-striped for the WEZ as shown in Figure 1. Residents residing in these areas are entitled to the discount because they are required to bypass the CCZ or WEZ when driving home. This policy was an outcome of extensive consultations with various stakeholders. Other than reducing congestion, another aim of the CC is to generate revenues to improve the public transport system by increasing the frequencies and routes of buses and tube. Reduced travel time and enhanced reliability could encourage commuters to switch from private to public transport when commuting into the zone.

The tax levied was substantially increased to £8.00 on the 4th July 2005 to further reduce traffic and raise revenues. On the 19th of February 2007, charging was extended to Central West London (known as the Western Extension Zone - WEZ) because of congestion in that area. Operating hours of the CC were reduced by half an hour from 7:00am to 6:00pm. The westward extension is circumvented by Harrow Road, Scrubs Lane, West Cross

[7]The rationale for levying a flat fee, other than the difficulty in imposing time varying fees to reduce congestion during peak hours, is that vehicular volume on roads seem fairly uniform across the day.

[8]Other groups excluded from the charge include public transport(taxis and buses), motorcycles, bicycles, environmentally friendly vehicles (battery powered or hybrid cars), vehicles driven by disabled individuals (blue badge holders), vehicles with 9 seaters or more and emergency service vehicles.

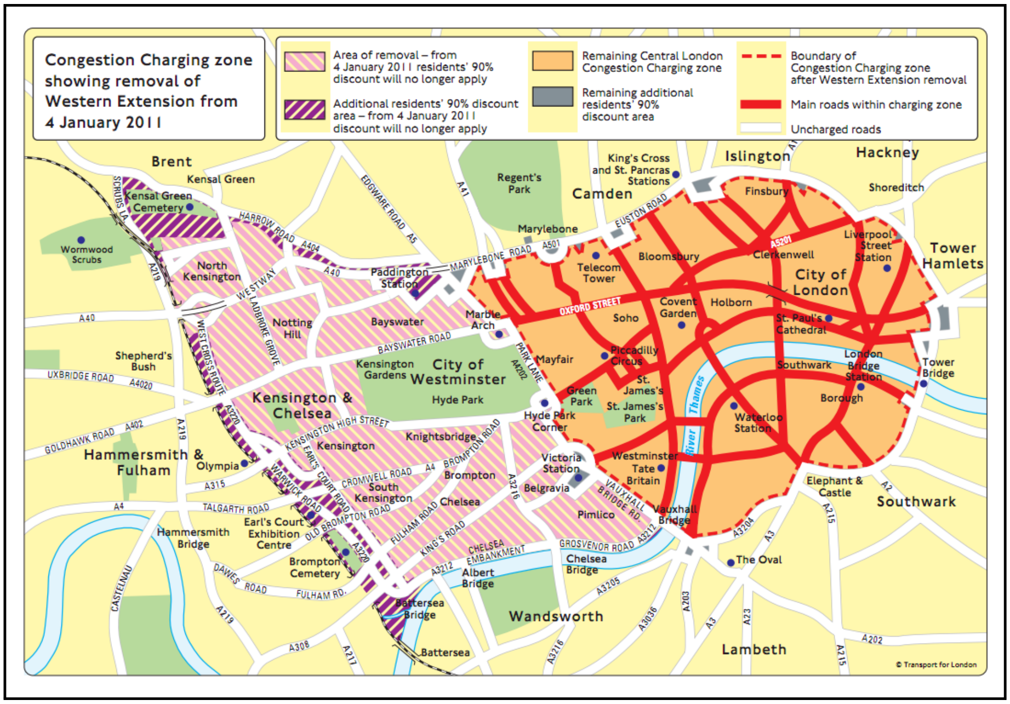


Figure 1: Map of the Original Congestion Charge Zone (CCZ) & Western Extension Zone (WEZ) Source: Transport for London (TfL)

Route, the Earls Court One-Way system, Chelsea Embankment and the River Thames [9] to the South. Refer to the area in pink-striped in Figure 1. However, under tremendous pressure from residents and businesses in West London, on the 24th of December 2010, the WEZ was scrapped. Between 2011 to 2015, the charge in the original CCZ underwent another two hikes. The CC was raised from £8 to £10 on the 4th January 2011 and from £10 to £11.50 on 16th June 2014. Overall, the CC experienced an average 10.83% growth per annum since introduction and this might have a compelling effect on commuters relying on private transport.

Initial impact assessment by Transport for London (TfL) showed significant improvement in traffic conditions after the charge is enforced in 2003. These results are very consistent with those reported in this study. All day travel speeds were almost 20% higher (from 14.3km to 16.7km per hour) and minutes of delay fell by 30% compared to uncongested traffic conditions (TfL, 2003a). This was largely due to a 27% overall drop in the number of private auto-mobiles into Central London. A change in composition of inbound traffic

[9] Unlike the Original CCZ, the WEZ is bounded by physical features. There is a concern whether the the neighbourhoods South of River Thames are different from those in the North such that it might not be a suitable control group. Hence, I exclude transactions south of River Thames in my robustness test (refer to Table6). This has an immaterial effect on my estimates.

into the zone was observed: the volume of bicycles, buses and taxis went up by 28%, 21% and 22% respectively. Surveys conducted echoed similar findings with the majority of the drivers switching to public transport and others travelling during off-charging hours (TfL, 2005). Though the number of commuters using rail did not increase, the number of bus passengers during morning peak periods were 38% higher(TfL, 2004). There was no apparent displacement of traffic into neighbouring uncharged roads and weekends as traffic conditions were fairly similar compared to those during pre-charged periods. As for air quality, the CC led to a 12% reduction in both NO and PM_{10} in the cordoned area (TfL, 2004). Overall, residents living in the charged zone are benefiting from the charge.

3 Literature Review

To estimate the marginal willingness to pay (MWTP) to avoid traffic, a hedonic property value approach is widely adopted in the existing literature. An association between traffic externalities, measured by traffic volume (Hughes & Sirmans, 1992) or noise (Palmquist, 1992; Andersson *et al.*, 2010), and housing prices are established using regression adjusted for differences in observable housing and neighbourhood characteristics. For a review of the literature, refer to Nelson (2008). A meta-analysis of previous literature indicates that the doubling road traffic volume could reduce home values by 0.5%-3.0%, while every decibel increase in traffic noise corresponds to a 0.3%-0.6% reduction fall in transaction prices. Estimates, however, appear to vary across studies that adopt different specifications and perverse relationships are sometimes reported. These results suggest that cross-sectional estimates are biased due to unobserved differences in neighbourhood and housing quality between sales that are correlated with traffic conditions.

To recover the MWTP for non-market amenities using the housing market, many studies address the issue of omitted confounders by focusing on "natural experiments" [10]. Chay *et al.* (2005) rely on the implementation of the Clean Air Act in the 1970s to identify exogenous variation in air quality and examine its impact on housing prices. Davis (2004) take advantage of a sharp rise in paediatric leukaemia cases from a secluded county in Nevada to measure the health risk using home values. Gibbons & Machin (2005) appraises the price for better public transport accessibility by examining the impact of a new metro line on the housing market. Black (1999) and Gibbons *et al.* (2013) quantify the value of good schools

[10] For the advantages associated with quasi-experimental approaches of hedonic methods for environmental valuation refer to Kuminoff *et al.* (2010).

by comparing transaction prices of homes close together but on different school districts. In similar fashion, this study relies on the implementation of the CC that induces sharp variation in traffic conditions inside and outside the zone to recover the MWTP to pay to avoid congestion.

The important question is whether the Congestion Charge can reduce traffic jams and improve the environment. Beevers & Carslaw (2005) show that air quality inside the cordoned area improved after the charge is implemented. The levels of CO_2, NO and $PM10$ fell by 19.5%, 12% and 11.9%. Roads in the zone are also reported to be much safer after the CC is implemented. Li *et al.* (2012) show that car casualties fell by 5.2% although there are more fatalities associated with motorcycles (1.8%) and bicycles (13.5%). This could be driven by the switch to two wheelers to avoid the charge. Larger effects are observed in Green *et al.* (2016). The CC coincides with a 32%-36% fall in accidents and 25%-35% decline in serious injuries and fatalities relative to the pre-treatment periods. No evident displacement of collisions to neighbouring areas outside the cordoned area are documented.

There have been several previous attempts to quantify the benefits associated with the charge using the housing market. Most of these studies have surprisingly documented insignificant or negative effects. The closest to this study is unpublished research conducted by Zhang & Shing (2006). They examine the effect of the CCZ in 2003 on a sample of residential sales in London from 2000 Q1 to 2006 Q1 and show that home prices are 8.5% lower in the zone after the charge is implemented. Using a similar approach, Percoco (2014) investigate the effect of the Milan EcoPass on housing prices. Examining average property values at 192 Micro-zones between 2006 and 2009, he reports that prices fell by 1.2% to 1.8% after the tax is introduced. The contradictory relationship documented in these studies could stem from omitted confounders[11] due to the lack of controls, the incorporating of transactions fairly far from the charge boundary and the adoption of coarse spatial fixed effects. Agarwal *et al.* (2015) improve the estimation by removing time-invariant neighbourhood unobservables with postcode fixed effects. They examine the effects of an increase in the Singapore Electronic Road Pricing (approximately £0.50) on retail, office and residential prices. While retail property values are adversely affected by the hike, residential property values remain unchanged. This is anticipated considering that an immaterial hike in the charge is unlikely to significantly improve traffic conditions to influence housing values[12].

[11] In fact, a similar relationship is documented in weaker specifications in this study (refer to Columns 2 and 3 of Table 4).

[12] This point is reflected in my results in Table 3. Most of the CC increments, except for the initial hike in 2005, do not have a perceptible effect on traffic and housing values.

In contrast, this research improves on the existing literature on several fronts. This is the first paper to provide credible estimation of the effect of the CC on traffic. This is an important "first stage" that explains the mechanism for house price changes associated with the CC. Existing literature, due to the absence of quality traffic flow data, has not addressed that. Second, by relying on the CC as a natural experiment to tackle the issue of omitted con-founders, it is a significant improvement to the existing literature that rely on cross-sectional hedonic regressions. Third, this study employs a more representative dataset with more than half a million housing transactions in the vicinity of the CCZ/WEZ. More than 15% of the transactions from almost 8,000 different postcodes take place in the charged zone. This further allows the restriction of property sales physically close to the charge boundary to mitigate unobserved differences in neighbourhood amenities between properties inside and outside the zone.

4 Data

Average annual daily traffic flow (AADF)[13] collected at each count point (CP) from 2000 to 2014 is retrieved from Department of Transport (DfT). These count points are located along roads and traffic is manually counted at these points to provide junction-to-junction traffic flow. There are a total of 2,774 CPs in London, most of them clustered around Central London. Housing transactions from the 1st quarter of 2000 to the 4th quarter of 2015 are collected from Land Registry database. Property characteristics include sale price, property type (detached, semi-detached, terraced, flat or maisonette), tenure (leasehold or freehold) and whether the property is new or second-hand. Land Registry covers all the transactions made in United Kingdom. Given that terrace and flat housing constitute bulk of the transactions in Central London (close to 95%), other property types are removed from the analysis to reduce heterogeneity in the sample that could raise endogeneity concerns. All the transactions are geo-coded using the address postcode. For a subset of transactions, more property information, such as floor area, number of bathrooms and bedrooms and age, are merged from Nationwide transaction database for balancing and robustness tests.

Information on the boundaries of the CCZ and WEZ and the areas entitled to 90% resident discount are from the shape-files provided by Transport of London (TfL). Using

[13] Each site is counted by a trained enumerator on a *neutral day* in that year for a twelve hour period. A *neutral day* is a weekday between March and October, excluding all public holidays and school holidays. The idea is that traffic on these days are reflective of an "average" day across the year. There are a total of 10,000 manual count points across UK.

Geographic Information Systems (GIS) mapping, together with the official dates of implementation/announcement of the CC from TfL, I assign postcodes and roads into treatment and control groups and compute euclidean distance from the CC boundary. Further information on the locations of tube stations and bus stops are retrieved from TfL Open data source. I measure public transport accessibility based on the distance of each property from the nearest public transport node using GIS.

Demographics at Output Area[14] (OA) level are collected from Census 2001 and 2011 to measure the quality of neighbourhoods. This include the percentage of (1) minority residents and (2) uneducated residents, (3) unemployment rate and the percentage of (4) lone parent households. I assign the demographics from Census 2001 for any transactions before 2006 and demographics from Census 2011 for transactions made after 2006.

Shape files detailing the location of heritage buildings and parks are provided by MAGIC [15]. Using GIS, distances of each postcode from the nearest Grade 1 park - top 10% of all U.K parks with international and historical significance - is measured. For heritage buildings, a 200 meter is drawn for each postcode and the counts of Grade 1 heritage buildings are computed. Designation is done by Historic England and is determined by the age, historical and architecture significance of the building. Only the top 2.5% of the buildings are classified as Grade 1. Maps for Thames River is obtained from Digimap. A buffer of 200 meters is drawn from Thames River and postcodes inside this area are assumed to have a river view.

5 Identification Strategy and Methodology

Traditionally, cross sectional hedonic regressions examining the effects of traffic externalities adopt the following specification:

$$Y_{ijt} = \gamma \mathbf{T_{it}} + X_i'\phi + V_{jt}'\omega + \varepsilon_{ijt}, \qquad \varepsilon_{ijt} = \alpha_i + \theta_{jt} + \epsilon_{ijt} \tag{1}$$

where Y_{ijt} is the logarithm of price for property i in neighbourhood j sold at time t. This exercise relies on the variation of traffic ($\mathbf{T_{it}}$) across space, which is usually measured by traffic volume or noise, and examine how it affects property values. This effect is captured

[14] The smallest geographical area if which Census data is collected. There are a total of 175,434 OAs across England and Wales (25,053 OAs in London) with around 110 to 140 households per OA.

[15] For more information, refer to http://magic.defra.gov.uk/.

by γ. To minimise salient differences between transactions, researchers usually control for some observable property specific characteristics X_i' (e.g number of bedrooms, property size, garage) and neighbourhood characteristics V_{jt}' (e.g crime, unemployment rates). For consistent estimation, the least square estimator of γ requires $E[\varepsilon_{ijt}, T_{it}] = 0$.

In reality, however, this assumption is likely to be violated. Decomposing ε_{ijt}, there are at least two sources that could bias γ. This is because $\mathbf{T_{it}}$ is not randomly distributed across space and the heaviest traffic are usually near the city center with peculiar property and neighbourhood characteristics (e.g business districts, shopping belts). α_i encapsulate these unobserved time-invariant property and neighbourhood characteristics. For example, properties in the city center with more traffic could be better furnished, located in more affluent neighbourhoods, well-connected with transportation nodes, and nearer to shopping belts and tourist attractions.

To address this, the straightforward solution is to include property fixed effects (α_i). This is equivalent to comparing changes in prices with changes in traffic conditions for each property i over time. However, this is unlikely to improve estimation because there could be insufficient repeated sales over treatment period, reducing the representativeness of the study. Second, it is improbable for to observe significant variation in traffic over time unless some areas experience neighbourhood shocks. These unobserved time variant changes are denoted by θ_{jt}. For example, an increase in traffic into neighbourhood j could be due economic developments (e.g retail and commercial projects) that creates employment and attracts more traffic. Given that these projects are likely to increase the attractiveness of a neighbourhood, the WTP to avoid traffic could be underestimated.

In reality, researchers are often compelled to compare houses in different neighbourhoods to capture sufficient variation in traffic conditions across areas. This, in turn, exacerbates the risk of θ_{jt} from biasing the estimates. Moreover, individuals have heterogeneous preferences to avoid traffic and this could induce sorting across different neighbourhoods. Richer households, who incur higher cost of delays, could relocate themselves into areas with less traffic. If other homeowners prefer to stay near these "good" neighbours, WTP for less traffic could correlate with the WTP for better neighbourhoods. When these neighbourhood differences are unobserved or imprecisely measured, γ will be biased.

To address these identification challenges, I rely on the sharp and localised variation of traffic induced by the congestion charge. Employing a difference-in-difference framework, I replace $\mathbf{T_{it}}$[16] with $\mathbf{CC_{it}}$, a binary variable that takes the value of one if property i is located in the CCZ/WEZ and is sold after the CC is implemented in t and zero otherwise. Equation 1 becomes

$$Y_{ijkqt} = \alpha_k + \gamma\mathbf{CC_{it}} + X_i'\phi + (W_k' * \sigma_t)\pi + (V_j' * \sigma_t)\omega + (Qtr_q' * \sigma_t) + \varepsilon_{ijkqt} \quad \varepsilon_{ijkqt} = \theta_j + \epsilon_{ijkqt}, \quad (2)$$

where γ captures the effect of the CC on house prices. In short, this equation compare home prices changes in the charge zone with that outside. If the CC reduces bottleneck in the cordoned area, and that new home buyers value this amenity, I expect γ to be >0. I examine 5 different CC events that are likely to improve traffic conditions: (1) the initial implementation of the CC in 2003 ($CCZ2003\_05$); (2) the CC increase in 2005 from £5 to £8 ($CCZ2005\_11$); (3) implementation of the WEZ in 2007 (WEZ); (4) the CC increase in 2011 from £8 to £10 ($CCZ2011\_14$); (5) removal of the WEZ in 2011 ($RemWEZ$).

α_k represent postcode fixed effects that partial out time-invariant building characteristics to mimic "repeated sales" analysis. The assumption is that properties in the same postcode are fairly similar, such that α_i can be sufficiently captured by α_k. This is not an unreasonable assumption as most of the houses in Central London are multi-family housing and properties sharing the same postcode are usually in the same building or very close to one another. The reason for using postcode[17] rather than property fixed effects (α_i) is that there are insufficient repeated transactions of the same property i before and after $\mathbf{CC_{it}}$.

Next, I control for observable property and neighbourhood characteristics between properties to limit omitted variable bias. This include X_i', which is a set of housing characteristics denoting whether property i is a new build, a terrace house and whether the tenure is leasehold. W_k' represents a vector of time-invariant location characteristics that denotes the level of amenities in postcode k. This include: (1) counts of buildings with heritage value within 200 metres of k; (2) distance of k from the nearest 'Grade 1 Park'; (3) Thames River view (if k is within 200 metres from Thames River) and (4) distance of k from the Central Business District (CBD) denoted by the centroid of the CCZ and its quadratic term to allow for a non-linear relationship[18]. V_j' is a vector of time-invariant controls that captures the demo-

[16] One question is why not use the charge as an instrumental variable for traffic. The main reason for not doing so is the violation of the exclusionary restrictions, given that the charge could affect home prices through other means, such as the 90% waiver of the congestion charge for homeowners living in the zone.

[17] There are on average only 17 housing units sharing one postcode across United Kingdom. I lose almost 70% of the data from including address fixed effects as singletons - no repeated observations in a particular address - are automatically dropped off.

[18] Results remain fairly consistent even after adding higher order polynomials (up to 4) or after removing them and imposing a linear relationship.

graphics at neighbourhood j. This include the percentage of (1) lone parent households,(2) residents of minority race and (3) without education qualifications, and (4) unemployment rate at neighbourhood j. Both W_k' and V_j' are time-invariant and are interacted with year dummies (σ_t).

$Qtr_q' * \sigma_t$ represent year-quarter fixed effects. ε_{ijkqt} is the error term clustered at 300 cross-boundary wedges to allow for spatial correlation of errors across these wedges [19]. To visualize how these wedges are created, refer to Figure 8 in Data Appendix. To summarize, the strategy is to compare the change in housing prices in the CCZ/WEZ with the change in housing prices in areas outside but near to the CC boundary after the charge is implemented. Refer to Table 8 in Data Appendix for more details.

Relying on the charge is unlikely to minimize θ_j if the zone is endogenously drawn to reduce traffic at areas with the busiest roads. This is clearly the case for the London Congestion Charge as the zone overlaps the CBD and major shopping belts. To minimise θ_j, I progressively restrict the analysis to properties physically close to the CC boundary (up to 1 kilometre) to ensure that properties are in comparable if not similar neighbourhoods. To visualize, refer to Figure 2. This is only possible as the charge induces sharp reduction in the zone, and possibly displacing traffic outside with drivers circumventing the area to avoid charge. If unobserved characteristics vary smoothly across space, Conditional Independence Assumption (CIA) is likely to hold as the distance between treated and untreated locations fall (Duranton *et al.*, 2011).

To verify that the house price changes associated with $\mathbf{CC_{it}}$ is indeed due to a reduction in traffic in the cordoned area, I estimate the following equation:

$$T_{pt} = \alpha_p + \zeta \mathbf{CC_{pt}} + (W_p' * \sigma_t)\omega + \sigma_t + \varepsilon_{pt} \quad (3)$$

where T_{pt} is the natural logarithm of the average daily traffic flow for four wheelers or more at count point p in year t. Key variable of interest is $\mathbf{CC_{pt}}$, which is a binary variable taking the value of one if count point p is located in the CCZ/WEZ after the CC event in time

[19] The reason why I have to manually create this wedges is because there are no geographical boundaries that cross the charged zone. One concern is whether these arbitrarily created wedges are too small, which could lead to an underestimation of the standard errors. Thus, I start reducing these wedges from 300 to 100 at 50 wedge intervals and recompute my standard errors for $CCZ2003\_05$ and WEZ. I also cluster the standard errors at ward level. Anything beyond this level has too little clusters. Refer to Table 12 in data appendix for more information. As observed, the standard errors remain fairly stable across the levels of clustering, mitigating the concern of the underestimation of standard errors with the increase in clusters.

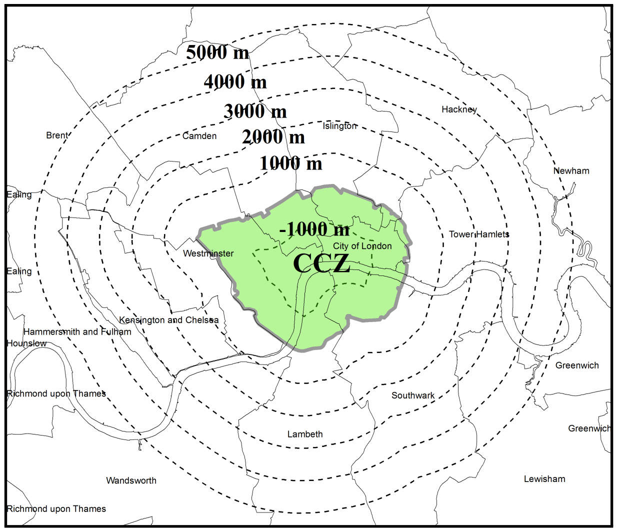


Figure 2: The CCZ (shaded) and 1 kilometre buffers from the CC boundary

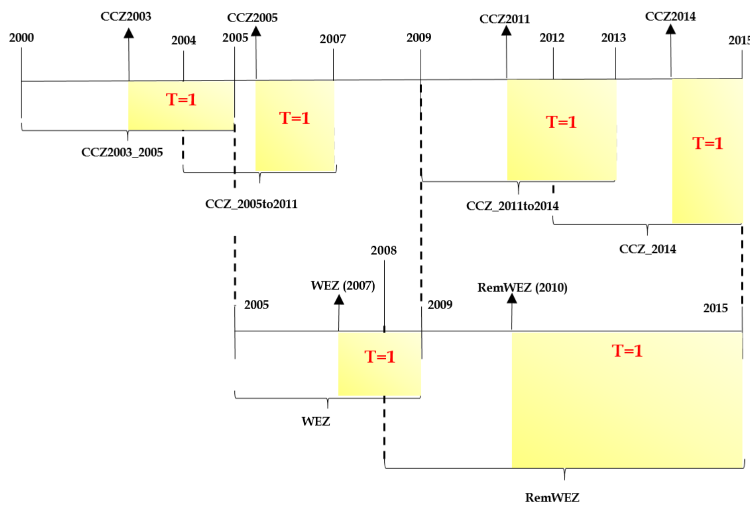


Figure 3: Sample window for the different regressions (T=1 denotes Treatment Period)

t and zero otherwise. ζ captures the impact of the CC event on traffic flow. If the CC is effective in reducing traffic in the cordoned area, I will expect ζ to be <0. W_p' control for the distance of count point p from the CBD and its squared term. This is interacted with year dummies (σ_t) to partial out the temporal variation in traffic due to proximity to the city center. ε_{pt} is the error term. Standard errors are clustered at ward level to allow for the spatial correlation in traffic between proximate roads across the CC boundary. Like before, I constraint the sample to roads just in and out the boundary in 1 kilometres interval to show relative change in traffic conditions across the different bandwidths. This further allow us to observe whether the CC actually pushes traffic out the cordoned area. Presumably, if there is traffic displacement, ζ should increase in size when I examine roads just in and out the charged zone.

6 Empirical Results

In this section, I estimate the effects of the Congestion Charge. First, I describe the dataset with summary statistics and provide some justification to my identification strategy. Next, I examine the impact of the charge on traffic. Subsequently, I estimate the effect of the charge on home prices in the cordoned area relative to those outside but nearby. Finally, I compute welfare estimates associated with the charge.

6.1 Descriptive Statistics

Basic summary statistics computed for a sample of housing transactions/roads within 5 kilometres of the CCZ/WEZ boundary from 2000 to 2015 are detailed in Table 1. I further split the sample into those within and those outside the zone. In total, there are 557,631 transactions from 39,174 different postcodes. This means that, on average, there are around 14 repeated sales for each postcode (=557,631/39,174). Approximately 15% of the sample (84,509 transactions from 7,941 postcodes) took place within the cordoned area (for both the CCZ and WEZ) after the implementation of the CC[20]. Majority of the sales in the estimation sample are flats (79%) or terraces (17%). Comparing across the boundary, properties in the zone are more likely to be leasehold, multi-storey flats that are located near parks and heritage buildings. These time-invariant differences will be eliminated with postcode fixed effects.

One of the key identification assumption for the difference-in-difference approach is parallel trends. In other words, houses in the cordoned area should experience similar price trends as those outside in the absence of the charge. Although there is no way to test this, given that we do not observe house prices in the CCZ/WEZ in the absence of the charge, I show that at least price trends before the charge is enforced are similar between properties inside and outside the zone. Pretreatment year-quarterly property price indices are computed for the CCZ (from 1995 Q1 (Base=100) to 2002 Q4) and for the WEZ (from 2001 Q1 (Base=100) to 2006 Q4) in Figure 4. These indices are created with the following procedure.

[20] The sample in the CCZ/WEZ is largely unchanged when I streamline the sample from 5km to 3km because 3km almost cover the entire CCZ/WEZ.

Table 1: Descriptive Statistics for Estimation Sample from 2000 to 2015

	Outside CCZ/WEZ		**Inside CCZ/WEZ**		**Combined**	
	Mean	SD	Mean	SD	Mean	SD
Log Sale Price	12.50	0.72	12.89	0.90	12.57	0.77
CCZ/WEZ Treatment	0.00	0.00	0.53	0.50	0.10	0.30
New build	0.12	0.32	0.12	0.32	0.12	0.32
Flat/Masionette	0.73	0.44	0.87	0.33	0.76	0.43
Terraced house	0.21	0.41	0.12	0.32	0.19	0.40
Leasehold	0.74	0.44	0.88	0.32	0.76	0.42
Distance to Nearest Grade 1 Park	2430.32	1305.64	850.88	565.88	2126.12	1351.29
Counts of heritage buildings within 200m	0.05	0.40	0.44	1.16	0.13	0.64
Thames River View	0.09	0.28	0.05	0.22	0.08	0.27
		5km	4km	3km	2km	1km
Total Number of Sales		557631	443858	326307	214217	123081
Postcodes		39174	32959	26026	18965	11594
Sales in CCZ/WEZ after the CC is introduced		84509	84509	80580	67549	50536
Postcodes		7941	7941	7816	7507	6315

Note: Table 1 summarizes the descriptive statistics for all the housing transactions within 5 kilometres from the CCZ/WEZ boundary and the number of sales and postcodes as the sample is reduced to 1 kilometre from the CCZ/WEZ boundary.

First, I adopt a specification similar to equation 2 except that key treatment variable, $\mathbf{CC_{it}}$, is excluded. I simply regress home prices against a vector of controls, postcode fixed effects, quarterly year dummies and quarterly year dummies interacted with a cordoned area dummy that takes the value of one if the property sold is inside the CCZ or WEZ. The aim is to partial out all other factors that could affect market trend estimates. I then plot the coefficients from quarterly year dummies (for areas outside the CCZ/WEZ) and quarterly year dummies interacted with cordoned area dummy (for areas inside the CCZ/WEZ). Dashed line represents price trends for properties in the cordoned area (the CCZ & WEZ) while full line represents properties outside but within 5 kilometres of the CC boundary. Overall, pre-treatment price trends are very similar for properties inside and outside the CCZ and the WEZ, ameliorating concerns of a violation of the parallel trend assumption.

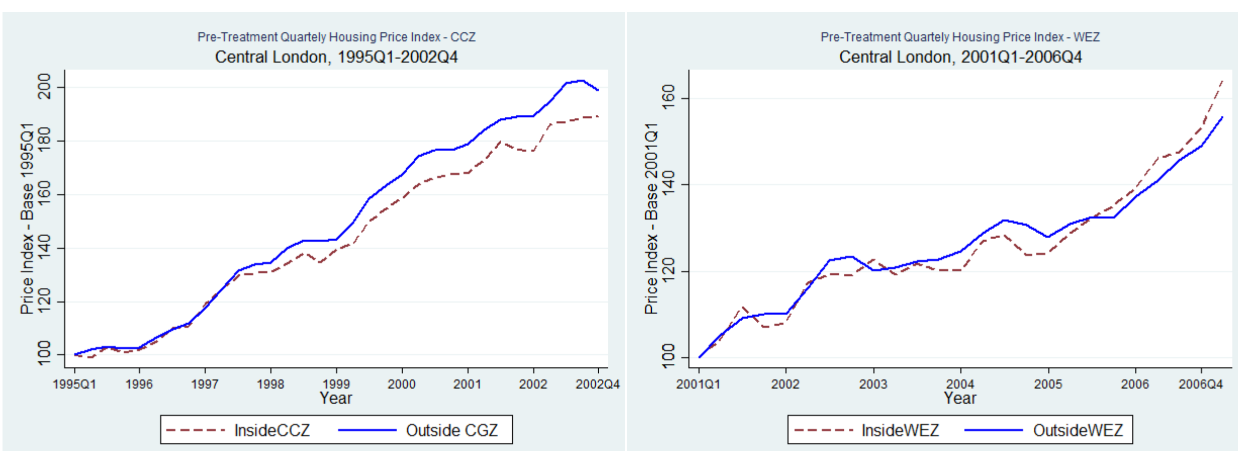
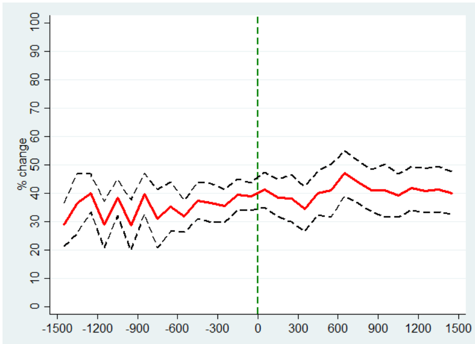


Figure 4: Pre-Treatment Repeated Sales Property Price Index: CCZ (Left) WEZ (Right)

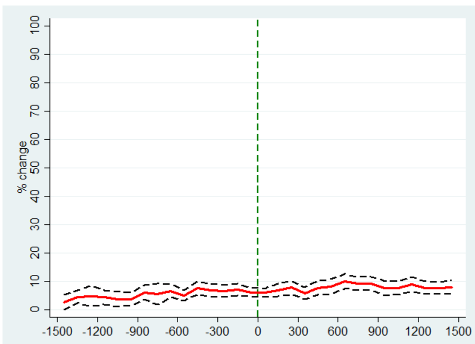
Another concern is the sorting of better households across the CC boundary after the charge is implemented. This sorting of more affluent households into better school zones is observed in the US (Bayer *et al.*, 2007). If "better" neighbours are to move into the zone after the CC is introduced, the concern is whether the WTP for traffic may be confounded with the WTP for better neighbourhoods. To investigate, I examine the change in various demographics across the boundary before and after the charge is implemented in Figure 5. This include percentage change (% Δ) of (1) residents who are ethnic minorities, (2) unemployment rate, (3) residents with no education, (4) lone-parent households, (5) households with cars and (6) residents driving to work. These figures are constructed by taking the first long difference of census Output Area[21] characteristics in 2001 (before) and 2011 (after), before regressing these changes on the interaction of the CCZ dummy with distance to boundary fixed effects. Each point in the figure, which is the coefficient of the respective distance dummies (in 100 meters bandwidth), denotes the conditional average of the change in neighbourhood characteristics at a given distance from the boundary. Negative distances, to the left of the green line, indicate neighbourhoods in the CCZ. As shown, there are no sharp changes in demographics, driving habits and car ownership in and around the CC, suggesting that there are no sorting of better residents across the boundary after the charge is enforced.

Another assumption when I specify postcode fixed effects is that there are no changes in quality/characteristics for units sold in the same postcode after the charge is implemented. This could be violated if units sold post-implementation differ in quality. For instance, if higher income households move into the charged zone after the CC is implemented, it is possible that better units (e.g penthouses) in a postcode are sold after the charge is enforced. To address this concern, I conduct a battery of balancing tests on various hedonic characteristics. Results are summarized in Table 2. The specification is similar to that in Equation (2) but the dependent variable is replaced with various housing characteristics, including flat dummy, leasehold dummy, floor area, availability of central heating and garage, number of bedrooms and bath, and the age of unit. Columns 1 to 2 comprises of a larger sample of land registry transactions while column 3 to 8 comprises of a sub sample of residential sales from Nationwide sales database that has a richer set of hedonic characteristics. The analysis incorporates transactions within 3 kilometres of the CC boundary. There are no significant changes in the composition of transactions within a postcode before and after the introduction of the CC, mitigating the risk that estimates are driven by the change in

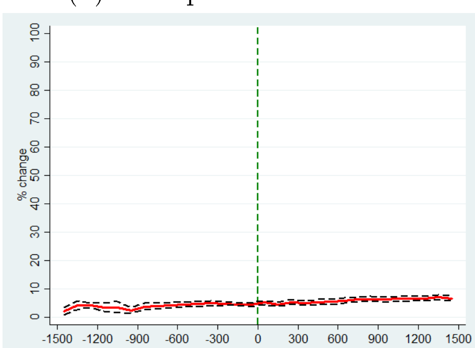
[21] Output Area is the lowest geographical level at which census estimates are provided in UK. There are a total of 175,434 Output Areas in England and Wales.



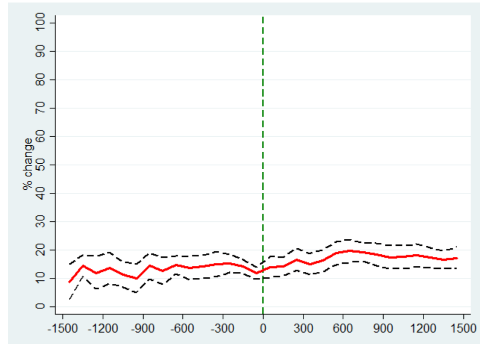
(a) Minority ethnicity



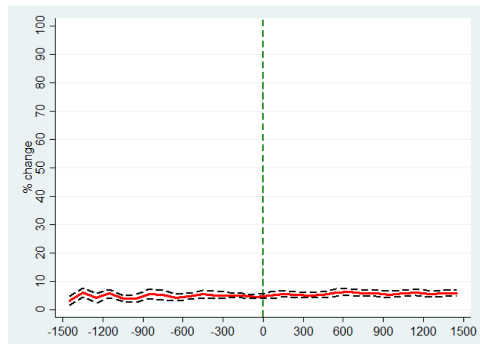
(b) Lone parent households



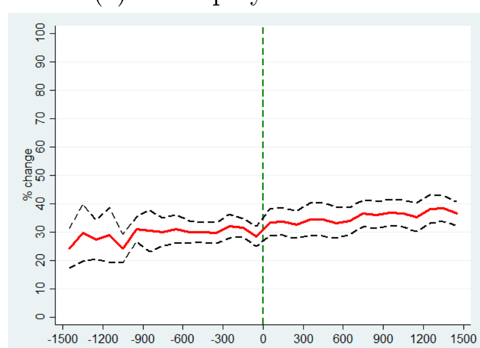
(c) Driving to work



(d) Uneducated



(e) Unemployment Rate



(f) Car ownership

Figure 5: Census demographics around the Congestion Charge Boundary. The red line represents the conditional average change of various demographics at a given distance from the CC boundary and the dashed line represents the 95% confidence interval. It is constructed by regressing the % Δ in demographics at Census Output Area with boundary fixed effect and 100 meters distance bandwidths and coefficients of each distance dummies are plotted. Distance is negative when it is in the charged zone (Left of Green Line). There are a total of 1,727 output areas within 1.5 kilometres in and out of the CCZ.

quality of housing units[22].

[22] I also estimated equation 2 with these hedonic characteristics as controls for the sample of transactions from Nationwide Database. The results are very similar to that reported in Table 5. However, due to the small sample size (less than 1,000 observations), I do not report the findings

Table 2: Balancing Test for Housing Characteristics for a subsample of transactions within 3km from the CC boundary

	(1) Flat	(2) Leasehold	(3) Floor Area	(4) Bathrooms	(5) Bedrooms	(6) Central Heat	(7) Garage	(8) Age
CCZ	-0.00498	-0.00361	-2.349	0.0338	0.00295	-0.0122	-0.113	-3.041
	(0.00352)	(0.00348)	(3.699)	(0.125)	(0.0709)	(0.0933)	(0.212)	(6.795)
N	110719	110719	5288	5288	5288	5288	5288	5288
WEZ	0.00188	0.00686	-5.041	-0.102	0.0288	-0.238	-0.381	-1.628
	(0.00533)	(0.00461)	(11.22)	(0.116)	(0.193)	(0.251)	(0.349)	(4.779)
N	62952	62952	3283	3283	3283	3283	3283	3283

Note: Each coefficient is from a different regression. All regressions include post code and year quarter fixed effects. Dependent variable is the respective housing characteristics labelled below the columns. Flat (1) is a binary variable indicating whether property sold is a flat. Leasehold (2) is a binary variable representing whether unit sold is leasehold. Floor area (3) is the size of unit in square meters. Bathrooms (4) and Bedrooms (5) is the count of Baths and Bedrooms in the unit. Central heating (6) and Garage (7) is a binary variable that denotes if unit has such facilities. Age (8) is the number of years since the unit is built. Columns 1-2 comprises of transactions from Land Registry while 3-8 comprises of transactions from Nationwide Database. Robust standard errors clustered at 300 cross-boundaries wedges are reported in parenthesis.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

6.2 Congestion Charge and Traffic Flow

Next, I evaluate the effectiveness of the CC in reducing traffic. Table 3 reports the estimates and standard errors for $\mathbf{CC_{pt}}$ from equation 3 for 5 different CC events. Moving from column (1) to (5), I progressively restrict the sample of roads from 5 kilometres to 1 kilometre left and right of the CC boundary. After the introduction of the CC in 2003 (CCZ2003_05), I observe that traffic flow for roads in the zone experience a 9.83%[23] decline when compared to roads within 5 kilometres from the boundary. Treatment estimates remain fairly stable when I streamline the sample to more comparable roads in proximity to the zone. Within 4 kilometres, effect increases to 10.37% and within 3 kilometres, effect is 10.04%. The effects fall to 9.41% when I constrain the sample to roads within 2 kilometres from the charged boundary and impact remains quite stable at 9.48% when only roads within 1 kilometre are examined. In absolute terms, I am looking at between 1,883 and 2,351 less automobiles[24] inside the zone everyday.

Similar reductions in traffic are observed when the charge is increased from £5 to £8

in this paper although it is available upon request.

[23] As it is a log-linear model, capitalization effects are computed by taking the exponential of the point estimates before subtracting by one. For instance, $Exp(0.0938) - 1 \approx 9.83\%$. The same conversion is applied for housing prices.

[24] This is obtained by multiplying the point estimates with the average pre-treatment traffic volume.

in 2005 ($CCZ2005\_11$). Traffic flow is, on average, by 3.70% to 6.16% (550 to 1,056 fewer vehicles) lower when compared to roads outside the zone. As for the implementation of the WEZ (WEZ), traffic is 5.57% lower for roads within 5 kilometres from the charged boundary. Within 4 kilometres, the effect is 5.90% and is 5.46% when I constrain the analysis to roads 3 kilometres from the boundary. When I examine roads within 2 kilometres from the charged zone, the impact falls to 3.31%. These effects remain stable at 3.49% for roads 1 kilometre inside and outside the zone. In absolute terms, I am observing 653 to 1,174 less vehicles on roads in the WEZ every day. Estimates from the removal of the WEZ ($RemWEZ$), although positive, are too imprecise to be statistically significant. This is consistent with the reports from TfL[25] Similarly, the increase of charge in 2011 ($CCZ2011\_14$) has an immaterial effect on traffic. Overall, I do not observe traffic displacement across the boundary after the charge is introduced. If the charge forces drivers to detour the cordoned area, I should observe a surge in traffic for roads close to but outside the CCZ/WEZ, which will result in larger effects when I restrict the sample to roads near to the boundary. This is clearly not observed in my estimates[26].

To ensure that earlier estimates are not spurious, I conduct a battery of placebo and robustness tests for a sample of CPs 3 kilometres in and out of the CC boundary. This range is chosen because it covers all the roads inside the CC. Results are summarized in Panels A to C in Table 9 in Data Appendix. First, I repeat the analyses with announcement dates of the CCZ and WEZ to examine if there are any effects that predate the implementation. If anything, there seems to be more traffic for roads in the WEZ before the charge implementation, suggesting possible displacement of traffic from the CCZ. These effects, however, are rather weak and do not hold across specifications. Another concern is whether the estimates are capturing any trends in traffic flow due to the CBD given that it overlaps with the CCZ/WEZ. To partial out these effects, I shrink and expand the CCZ/WEZ by 1 kilometre. Findings are detailed in Panel B and C. Most of the estimates are indistinguishable from zero, suggesting that earlier findings are not spuriously driven.

[25] Retrieved from `https://tfl.gov.uk/info-for/media/press-releases/2011/June/tfl-announces-initial-results-following-removal-of-the-western-extension-of-the-congestion-charging-zone`

[26] The absence of displacement of traffic across the CCZ/WEZ also mitigate the concern that I might be overestimating the localised benefits of the CC in my welfare estimates (See Section 6.4).

Table 3: The Effects of the CCZ/WEZ on Traffic

	(1) 5km	(2) 4km	(3) 3km	(4) 2km	(5) 1km
CCZ2003_05	-0.0938[b]	-0.0987[b]	-0.0957[b]	-0.0899[b]	-0.0906[b]
	(0.0377)	(0.0387)	(0.0389)	(0.0386)	(0.0404)
Obs	3916	3466	2802	2280	1424
R2	0.98	0.98	0.98	0.98	0.98
No.of CPs	675	596	481	392	243
CCZ2005_11	-0.0591[b]	-0.0598[b]	-0.0587[b]	-0.0565[b]	-0.0363[c]
	(0.0250)	(0.0251)	(0.0250)	(0.0239)	(0.0205)
Obs	4066	3596	2941	2379	1430
R2	0.98	0.98	0.98	0.98	0.98
No.of CPs	833	748	632	494	291
CCZ2011_14	0.0054	0.0031	0.0042	0.0063	0.0041
	(0.0147)	(0.0150)	(0.0153)	(0.0154)	(0.0170)
Obs	4050	3612	2982	2376	1429
R2	0.99	0.99	0.99	0.99	0.99
No.of CPs	816	731	615	477	286
WEZ	-0.0542[a]	-0.0573[a]	-0.0532[a]	-0.0326[c]	-0.0343[c]
	(0.0154)	(0.0155)	(0.0162)	(0.0175)	(0.0198)
Obs	1767	1456	1152	738	466
R2	0.99	0.99	0.99	1.00	1.00
No.of CPs	491	407	322	206	128
RemWEZ	0.0644	0.0624	0.0791[c]	0.0657	0.0429
	(0.0434)	(0.0444)	(0.0441)	(0.0439)	(0.0513)
Obs	2160	1760	1403	887	583
R2	0.99	0.99	0.99	0.99	0.99
No.of CPs	435	355	283	179	118

Note: Each coefficient is from a different regression. All regressions include count point (road) and year fixed effects. Other controls include distance to the CBD, denoted by the centroid of the CCZ, and its quadratic term. Sample for the different events includes traffic count from year *t-2* to year *t+2* where t = the year treatment is implemented. Refer to figure 3 for more information. Dependent variable is the logarithm of traffic count for 4 wheels or more drive. Robust standard errors clustered at ward level reported in the parenthesis.

6.3 Congestion Charge and Housing Prices

6.3.1 Baseline Estimates

Table 4 summarizes the results from estimating equation 2 for the four CC events that significantly improve traffic conditions - the initial implementation of the CCZ ($CCZ2003\_05$) and WEZ (WEZ) in 2003 and 2007 respectively, the subsequent hike in 2005 ($CCZ2005\_11$) and the removal of the WEZ in 2011 ($RemWEZ$) [27]. Only the coefficients and standard errors for the key treatment estimates $\mathbf{CC_{it}}$ are reported. The sample includes all transactions within 5 kilometres of the CCZ/WEZ boundary. Additional covariates are included in the estimation sequentially moving from left to right of the table. Column (1) has no control variables other than year quarter dummies and postcode fixed effects. In Column (2), a vector of housing characteristics is included. In Column (3), I control for the distance of each postcode from the CBD interacted with year dummies where the CBD is denoted by the centroid of the CCZ. Next, I include a set of demographics-by-year controls that captures how the attractiveness of the neighbourhood can affect home prices in column (4). Finally, a vector of amenities-by-year controls are included in column (5). For details on the co-variates refer to Table 8 in Data Appendix. Standard errors are clustered at 300 cross-boundary wedges to allow for spatial correlation of price changes in proximate postcodes across the CC boundary.

In columns (1) and (2), I observe significant associations between all the CC events and housing prices for the most parsimonious specifications. Positive housing price effects are documented for the CC hikes in 2005 and for the implementation and removal of the WEZ. Conversely, negative responses are reported for the initial implementation of the CCZ in 2003 ($CCZ2003\_05$). These results are qualitatively similar to those reported in Zhang & Shing (2006) and Percoco (2014) but are much smaller after I partial out time-invariant characteristics with postcode fixed effects. These findings, however, should not be taken as causal estimates: as soon as I control for distance to CBD-by-year, the effect associated with $CCZ2003\_05$ becomes positive while the effect for $CCZ2005\_11$ is no longer significant. This result merits more attention. One explanation is home prices closer to the CBD could be falling when the CC is introduced in 2003 and failure to capture these effects attribute to negative effects in earlier specifications. Next, I control for the changes in the WTP for neighbourhood demographics over time. I observe that households now pay more for properties in the cordoned charge zone after $CCZ2003\_05$, WEZ and $RemWEZ$ are introduced.

[27] The effects of the CC increases in 2011 ($CCZ2011\_14$) and 2014 ($CCZ2014$) are reported in Table 10 in Appendix.

These findings remain robust even after I control for the changes in the WTP for location amenities in Column (5). Preliminary findings suggest that home buyers are paying more for properties to enjoy better traffic conditions in the zone after the charge is implemented.

Table 4: The Effects of the CCZ/WEZ on Housing Prices: Baseline

	(1)	(2)	(3)	(4)	(5)
CCZ2003_05	-0.0135	-0.0189[b]	0.0163	0.0257[b]	0.0270[b]
	(0.0088)	(0.0085)	(0.0128)	(0.0128)	(0.0127)
Obs	193663	193663	193663	193663	193663
R2	0.72	0.77	0.77	0.77	0.77
No.of Postcodes	21803	21803	21803	21803	21803
CCZ2005_11	0.0188[c]	0.0175[c]	0.0135	0.0120	0.0073
	(0.0105)	(0.0102)	(0.0133)	(0.0131)	(0.0130)
Obs	98630	98630	98630	98630	98630
R2	0.72	0.80	0.80	0.80	0.80
No.of Postcodes	16404	16404	16404	16404	16404
WEZ	0.0760[a]	0.0762[a]	0.0660[a]	0.0595[a]	0.0459[a]
	(0.0111)	(0.0099)	(0.0102)	(0.0102)	(0.0108)
Obs	102708	102708	102708	102708	102708
R2	0.74	0.80	0.81	0.81	0.81
No.of Postcodes	16235	16235	16235	16235	16235
RemWEZ	0.0457[a]	0.0360[a]	0.0325[a]	0.0322[a]	0.0267[b]
	(0.0109)	(0.0102)	(0.0104)	(0.0102)	(0.0106)
Obs	130166	130166	130166	130166	130166
R2	0.75	0.82	0.82	0.82	0.82
No.of Postcodes	17878	17878	17878	17878	17878
Postal Code FE	✓	✓	✓	✓	✓
Year Quarter Dummies	✓	✓	✓	✓	✓
Housing characteristics		✓	✓	✓	✓
Distance to CBD -by-year			✓	✓	✓
Demographics-by-year				✓	✓
Amenities-by-year					✓

Note: Each coefficient is from a different regression. Dependent variable is the natural logarithm of transacted prices. All regressions are estimated with post code and year quarter fixed effects for transactions within **5 kilometres** from CCZ/WEZ boundary. In column (2), housing characteristics, including 1. a dummy denoting whether the property is leasehold, 2. whether it is new build and 3. whether it is terrace housing, are controlled for. In column (3), the distance of each property from the CBD and its quadratic term are accounted for. In column (4), demographics, including the percentage of residents 1. with no education qualification, 2. of minority race, 3. unemployed and 4. percentage of lone parent households, are accounted for. In column (5), amenities include whether the property has a 1. Thames river view, 2. the counts of heritage buildings within the 200 metres from the property and 3. the distance of the property from the nearest Grade 1 park. For the sample window of each of the CC event, refer to figure 3 for more information. Robust standard errors clustered at 300 cross-boundaries wedges reported in the parenthesis.[c] $p<0.10$, [b] $p<0.05$, [a] $p<0.01$

6.3.2 Estimates Restricted To Proximate Transactions

Next, I begin restricting the sample of transactions physically close to the CC boundary to further mitigate unobserved heterogeneity in neighbourhood amenities between sales in and out the charged zone. Results are summarized in Table 5. The specification adopted is similar to that of Column (4) in Table 4. Moving from Column (1) to (5) (from left to right of the table), I progressively reduce the sample in 1 kilometre intervals from 5 to 1 kilometre inside and outside the charge zone.

Consistent with results earlier, I document that the implementation of the CC ($CCZ2003\_05$) leads to significant house price appreciation. When compared to residential sales within 5 kilometres from the boundary, house prices in the cordoned zone are 2.74% higher. Effects are fairly stable at 2.65% relative to houses within 4 kilometres and effects are around 3.25% within 3 kilometres. Restricting the analysis to housing units just 2 kilometres in and out the CC boundary further increases price responses to 3.83%. Finally, looking at sales 1 kilometre or less from the CC boundary, which reduces the sample by almost 80%, I document that property values are 4.27% higher than before. In monetary terms, this amounts to between £11,575 and £18,230. [28] All the estimates are significant at least at 10% level. Estimates for the hike in 2005 ($CCZ2005\_11$), although positive[29], do not appear to be precisely estimated to be statistically significant. The slightly lower WTP could be driven by expectations as new homebuyers might not expect the hike in the charge to improve traffic conditions.

House price increments are also observed for the WEZ (WEZ). Capitalization effects are around 4.70% when compared to untreated units within 5 kilometres of the boundary. Within 4 kilometres, effects fall to around 4.21% and within 3 kilometres, effects further decrease to around 3.50%. Restricting to housing units just 2 kilometres from the boundary reduces price response to 3.46%. Comparing units not more than 1 kilometre in and out the CC boundary, which cuts the sample size by about 75%, further depresses price change to 2.23%. All of the estimates are significant at least at 10% level. In monetary terms, homeowners are paying between £18,828 and £40,937 to enjoy better traffic in the WEZ. Positive house price effects documented for the removal of WEZ ($RemWEZ$) disappear as

[28] This is computed by multiplying the estimates on the pre-treatment average home prices adjusted to 2010 price levels in the cordoned area within the distance bandwidth from the CC boundary.

[29] Though these effects appear much smaller for $CCZ2005\_11$, the marginal changes in home prices relative to changes in traffic conditions are quite comparable. Homeowners pay about 0.45% (4.27% $\div$ 9.48%) more for their homes for every 1% reduction in traffic after $CCZ2003\_05$ while homeowners pay about 0.35% (1.28% $\div$ 3.70%) more for their homes for the same improvement in traffic after $CCZ2005\_11$.

soon as I constraint the analysis to transactions 3 kilometres in and out the zone. This is expected since taking away the WEZ did not lead to a significant rebound in traffic flow in the charged zone.

A few notable observations can be made. First, I document persistent house price increments in the zone even when I restrict the analysis to a sample of residential sales physically close from one another around the boundary, suggesting that unobserved differences in neighbourhood amenities are not driving the results. Second, the magnitude of these effects appear to vary with the relative changes in traffic flow. As observed, house price effects reduce for the WEZ as soon as I constraint to the sample of sales proximate to the boundary. These results corresponds to the relative changes on traffic flow. Conversely, house price effects are fairly stable for the CCZ across the distance bandwidths, which corroborates with the results on traffic flow. Both observations lend support that what I am identifying is the effect of traffic on home prices.

Taking the estimated effects from the preferred specification at 1 kilometre inside and outside the CC boundary (See Column (5) of Table 5)), I find that new homebuyers in the WEZ are paying 0.67% (or £5,395) for every 1% fall in traffic in perpetuity (or £27.37 per vehicle per day) while those in the CCZ are paying 0.45% (or £1,923) for every 1% less traffic (or £9.68 per vehicle per day). [30] The much larger WTP to avoid traffic for homebuyers in the WEZ commands more analysis. Dwelling deeper into the demographics of home owners in both the CCZ and WEZ[31], I observe that residents in the WEZ are more likely to drive and incur much higher costs being stuck in the traffic. First, homeowners living in the WEZ earn (£4,095), on average, much higher wages compared to those living in the CCZ (£3,517). Second, it is more probable for a household in the WEZ (49%) to own a auto-mobile than those living in the CCZ (37%). There is also a higher tendency for those staying in the WEZ (25%) to drive to work if compared to residents in the CCZ (13%). This is probably because homeowners in the CCZ are much closer to their work place. 42% of the residents in the CCZ stay less than 2 kilometres from their workplace, compared to 25% of the residents in the WEZ. This disparity in the WTP is consistent with the idea that individuals have heterogeneous preferences on travel time (Small *et al.*, 2005).

In Panel B of Table 5, I repeat the same specification but with announcement dates.

[30] This is simply computed by scaling the capitalized house price premium with the percentage change in traffic attributable to the charge.

[31] Data is collected from Census 2001 and 2011 and is weighted according to the geographical distribution of transactions analysed in this study.

This addresses the concern[32] whether there are any house price responses to the release of the news for the charge. If homeowners expect the charge to be effective and react upon it, I would expect home prices to increase after announcement. The treatment period is defined as the day the CC event is officially announced by TfL and ends the day before the CC event is implemented. As hikes are announced only a few months before being implemented, there are insufficient pre-treatment property transactions. Hence, announcement effects are computed only for the initial implementation of the CCZ and WEZ (refer to figure 3).

Results suggest that new homebuyers only respond to the announcement of the WEZ, but not to the CCZ. An absence of tangible effects surrounding the CCZ suggests that residents are unsure of the effectiveness of the novel policy initially. This is consistent with the survey conducted by TfL that echoed the uncertainty among respondents on the effectiveness of the CC on reducing traffic and improving accessibility (TfL, 2003b). Conversely, homeowners are optimistic about the impact of the WEZ, possibly, after observing the effectiveness of the CCZ in curbing traffic congestion. The disclosure of the news of WEZ is linked with an increment of housing prices that ranged from 2.50% to 4.07% - equivalent to an absolute increase of between £17,369 and £27,437.

[32] Another concern is whether there are negative house price effects that predate the CC implementation such that any effects documented earlier is merely capturing mean reversion of home prices. As observed, this is not a concern as home prices either appreciated or are unaffected by the announcement of the CC.

Table 5: The Effects of CCZ/WEZ on Residential Property Prices: Proximate Transactions

	Panel A:Implementation					Panel B:Announcement				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	5km	4km	3km	2km	1km	5km	4km	3km	2km	1km
CCZ2003_2005	0.0270[b]	0.0262[c]	0.0320[b]	0.0376[b]	0.0418[b]	-0.0011	-0.0014	0.0017	0.0005	0.0055
	(0.0127)	(0.0135)	(0.0139)	(0.0147)	(0.0182)	(0.0169)	(0.0176)	(0.0178)	(0.0188)	(0.0212)
Obs	193663	153383	110719	70737	40039	118989	94167	68340	43372	24616
R2	0.77	0.77	0.77	0.76	0.74	0.78	0.77	0.77	0.76	0.75
No.of Postcodes	21803	17524	12835	8163	4591	17635	14048	10200	6351	3494
CCZ2005_2011	0.0073	0.0080	0.0062	0.0127	0.0127	-	-	-	-	-
	(0.0130)	(0.0131)	(0.0136)	(0.0145)	(0.0170)	-	-	-	-	-
Obs	98630	75477	52898	34031	19164	-	-	-	-	-
R2	0.80	0.79	0.79	0.79	0.77	-	-	-	-	-
No.of Postcodes	16404	12859	9353	6118	3387	-	-	-	-	-
WEZ	0.0459[a]	0.0421[a]	0.0350[a]	0.0340[a]	0.0221[c]	0.0288[b]	0.0247[c]	0.0277[c]	0.0305[c]	0.0399[b]
	(0.0108)	(0.0112)	(0.0117)	(0.0124)	(0.0132)	(0.0140)	(0.0146)	(0.0151)	(0.0165)	(0.0199)
Obs	102708	82001	62952	44172	26032	57751	46140	35501	25054	14935
R2	0.81	0.80	0.79	0.78	0.76	0.81	0.81	0.80	0.79	0.76
No.of Postcodes	16235	12816	9703	6793	3877	12226	9681	7368	5150	2986
RemWEZ	0.0242[c]	0.0278[b]	0.0240[c]	0.0237[c]	0.0220					
	(0.0133)	(0.0134)	(0.0134)	(0.0136)	(0.0152)	-	-	-	-	-
Obs	130166	104077	80901	56950	34401	-	-	-	-	-
R2	0.82	0.81	0.81	0.80	0.77	-	-	-	-	-
No.of Postcodes	17878	14184	10846	7699	4575	-	-	-	-	-

Note: Each coefficient is from a different regression. Specification is similar to that in column 5 of Table 4. Sample is constrained to sales within 5 kilometres (Column 1) to 1 kilometres (Column 5) from the CCZ/WEZ boundary. Panel A summarizes the findings associated with implementation of CCZ/WEZ and Panel B reports those surrounding the announcement. For announcement, treatment period begins the day the CC event is announced officially by TfL and ends the day the CC event is implemented. Robust standard errors clustered at 300 cross-boundaries wedges reported in the parenthesis.[c] $p<0.10$, [b] $p<0.05$, [a] $p<0.01$

6.3.3 Robustness and Placebo Tests

Table 6 summarizes the findings from a battery of robustness and placebo tests that further addresses the challenges that impede identification to provide more assuring evidence.

CBD Capitalization Effects: One impediment of establishing casual inference, due to the overlapping of the cordoned area with Central Business District (CBD), is that the key estimates could be capturing house price changes due to proximity to the CBD. To allay this concern, I create artificial treatment areas by shrinking and expanding the CCZ and the WEZ by 1 kilometre. I provide an illustration for the CCZ in Figure 6. For the shrank zones, postcodes at 0 to 1 kilometre from the boundary inside the treatment area are denoted as control properties (Shrank Control Area) and postcodes beyond 1 kilometre from the boundary in the cordoned area are denoted as treated properties (Shrank Treatment Area). For the expanded CC zones, postcodes between 0 and 1 kilometre outside the actual CC zone are flagged as treated units (Expanded Treatment Area) while those between 1 and 2 kilometres outside the actual CC zone are denoted as control units (Expanded Control Area). Results in Panel A and B of Table 6 indicate that none of the estimates is significant, confirming that earlier results are not spuriously driven by property price changes due to proximity to the CBD.

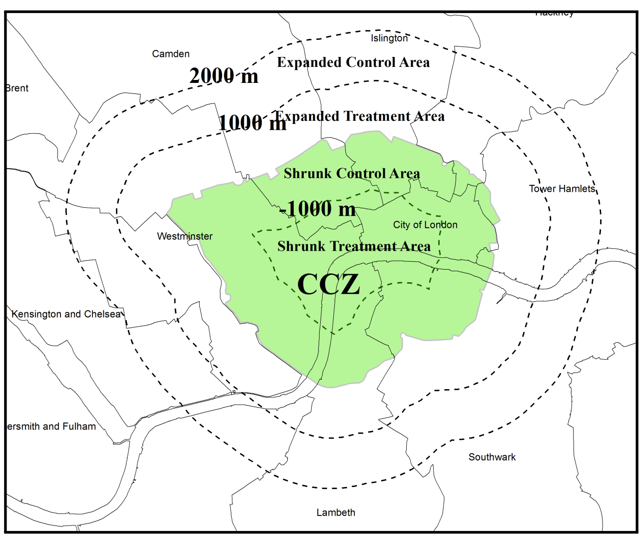


Figure 6: The Shrank and Expanded Placebo CCZ

Insufficient Transactions: Another issue is that there could be inadequate repeated sales within a postcode. If there are insufficient transactions in some postcodes, outliers could bias the estimates. Thus, I drop any postcodes with less than 5 transactions in Column (3).

This reduces the sample by about 14% for the CCZ and 44% for the WEZ. Again, this did not matter as results are not affected.

Physical Barriers: An additional concern is whether the CCZ/WEZ is drawn due to physical constraints (hills, rivers, forest etc.) or major infrastructures (railways, flyovers etc.). If the CC boundary overlaps with these features, even restricting to proximate housing units on different side of these features might not eliminate unobserved differences. While the CCZ crosses the Thames River due to the ease of charge implementation, the south of the WEZ is bounded by Thames River. The concern that properties to the south of the river are different from those in the north is not unfounded as these areas are typically not considered as part of Central London. Thus, I exclude housing transactions located south of the Thames River from the estimation in Panel C of Table 6. Removing these sales has no apparent effect on the estimates.

Public Transport Capitalization Effects: One of the correlated effects associated with the implementation of the CC is the channelling of charge revenues on improving public transport facilities. This could increase the values of homes that are better connected to public transportation nodes. This is especially true for the houses outside the zone as driving into the zone is more expensive. To partial out these effects, I added a vector of controls that include: (1) a binary variable denoting whether property i is within 200 metres of a tube station and (2) the count of bus lines from bus stops within 200 metres of the property. Both are interacted with year dummies as they are time-invariant. As seen in Panel D of Table 6, upon controlling for these covariates, the effects of both the CCZ and WEZ on home prices are less pronounced. This is consistent with the idea that transport capitalization effects could be correlated with the implementation of the CC.

Parallel Trends: One of the identification assumption is that both the properties in and out the CCZ/WEZ experience similar price trends in the absence of the charge. I relax this assumption by estimating a model with wedge-specific trends. By interacting each of the wedge dummy with a year trend, this allows properties in each of this small wedges to vary linearly and differently across the 50 cross boundary wedges[33]. Results in Panel E of Table 6 show that relaxing this assumption did not matter much although the estimates are slightly smaller.

Spurious time effects: Next, I address the concern whether capitalization effects of the CCZ and WEZ could be documented in pre-treatment periods. To do so I generate rolling 1-year pre-treatment placebo windows for every quarter from 1996Q1 onwards till 2002Q1

[33] Increasing the number of wedges have an immaterial effect on the results.

Table 6: The Effects of CCZ/WEZ on Residential Property Prices: Robustness Test

	(1) Shrank	(2) Expanded	(3) Pcd>=5	(4) North	(5) Transport	(6) Wedge*Yr
CCZ2003_05	-0.0028	0.0109	0.0425[a]	0.0411[b]	0.0252[c]	0.0319[b]
	(0.0340)	(0.0137)	(0.0160)	(0.0174)	(0.0138)	(0.0140)
Obs	19204	51814	95529	80599	110719	110719
R2	0.72	0.77	0.74	0.75	1.00	0.77
No.of Postcodes	2177	6020	7488	9584	12835	12835
CCZ2005_11	-0.0001	-0.0135	-0.0043	0.0058	0.0068	0.0064
	(0.0307)	(0.0131)	(0.0146)	(0.0161)	(0.0130)	(0.0136)
Obs	10511	24344	37759	34205	52898	52898
R2	0.75	0.79	0.74	0.78	1.00	0.79
No.of Postcodes	1779	4482	3800	6242	9353	9353
WEZ	0.0515	0.0140	0.0287[b]	0.0305[b]	0.0345[a]	0.0325[a]
	(0.0360)	(0.0114)	(0.0138)	(0.0123)	(0.0127)	(0.0117)
Obs	16679	30536	35259	45265	62952	62952
R2	0.73	0.77	0.74	0.78	1.00	0.79
No.of Postcodes	2702	4477	3725	7227	9703	9703
RemWEZ	0.0212	-0.0015	0.0142	0.0121	0.0202	0.0173
	(0.0349)	(0.0128)	(0.0126)	(0.0121)	(0.0145)	(0.0116)
Obs	19446	37575	67591	58976	80901	80901
R2	0.75	0.79	0.77	0.80	1.00	0.81
No.of Postcodes	2905	4809	6189	8158	10846	10846

Note: In Column (1) & (2), the original CCZ/WEZ is shrank and expanded by 1 kilometre respectively. In Column (3), I remove any postcodes with less than 5 repeated transactions. In Column (4), I remove any transactions located south of Thames River. In Column (5), distance to tube station-by-year and number of buslines-by-year are included. In Column (6), 50 cross boundary wedge fixed effects interacted with year trends are included. All regressions in Column (2) to (6) include transactions within 3 kilometres from the treatment boundary. Robust standard errors clustered at 300 cross-boundaries wedges reported in the parenthesis.[c] $p<0.10$, [b] $p<0.05$, [a] $p<0.01$

for the CCZ and till 2006Q1 for the WEZ. Placebo treatment period is between t_{false} and $t_{false} + 1year$ and the placebo window is from $t_{false} - 1year$ to $t_{false} + 1year$ where t_{false} represents every quarter 1 year before the implementation of the CCZ and WEZ. For instance, for 1996Q1, the pre-treatment period is from 1995Q1 to 1995Q4 and the treatment period is from 1996Q1 to 1996Q4. The new key regressor - $CCZ * t_{false}$ and $WEZ * t_{false}$ - is the interaction of a binary variable of whether the property i in the CCZ or WEZ is sold during the false treatment period. This falsification test incorporates transactions within 1 kilometre from the CCZ or WEZ boundary.

Placebo estimates are summarized in Figure 7. Each dot represents estimate from a different placebo regression and the tails denote the 95% confidence interval. The blue dash line denotes the implementation effects from column (5) of table 5. As observed, for the CCZ, all of the placebo estimates are not statistically different from zero and are much smaller than the implementation effects except for 1998Q1. Similar can be observed for the WEZ. Other than 1999Q2 and several quarters right before the WEZ implementation[34], most of the placebo estimates are smaller than the implementation effects. Even so, most of these larger estimates are too imprecise to be statistically significant. If anything, home prices in the WEZ dipped before 2000 but these trends should not confound the WEZ capitalization effects. Taken together, results from Figure 7 increase the confidence that treatment effects documented earlier are casual and not spurious.

Congestion Charge Savings: Another concern is that new residents are paying more for their houses post implementation because of the 90% discount for the CC. To address this, I examine capitalization effects for properties outside the CCZ/WEZ but are entitled to the 90% waiver of the charge (See areas are shaded in purple-striped (grey) for the WEZ (CCZ) in Figure 1). In particular, I run the following specification:

$$Y_{ijkqt} = \alpha_k + \gamma \mathbf{CC_{it}} + \theta \mathbf{Dis_{it}} + X_i'\phi + (W_j' * \sigma_t)\omega + (Qtr_q' * \sigma_t) + \varepsilon_{ijkqt}, \tag{4}$$

where Dis_{it} that denotes houses in the discount zone that were sold after the implementation of the CC. I will expect θ to be indistinguishable from zero if new homeowners do not pay for the 90% waiver. As there are only 936 transactions outside CCZ that are eligible for the CC savings, the focus will be on the discount zone of the WEZ that has a larger sample of 15,976 transactions. Panel A of Table 7 presents the estimates. Home prices in the discount zone are not materially affected after the CC is enforced, suggesting that new home buyers are not paying more to enjoy the 90% waiver of the CC. However, the traffic conditions in the discount zone might be affected by the charge. To verify, I re-estimated equation 4 with traffic volume as the dependent variable (See results in Table11 in Data Appendix). Although there are some evidence indicating that traffic conditions in the discount zone might have worsen, it is fairly weak and disappears when I extend the sample of roads beyond 3 kilometres. Overall, results suggest that earlier house price changes associated with the WEZ are not spuriously driven by the 90% discount to the charge.

[34] This is consistent with earlier results surrounding the announcement effects of the WEZ on home prices. See column 6-10 in Table 5.

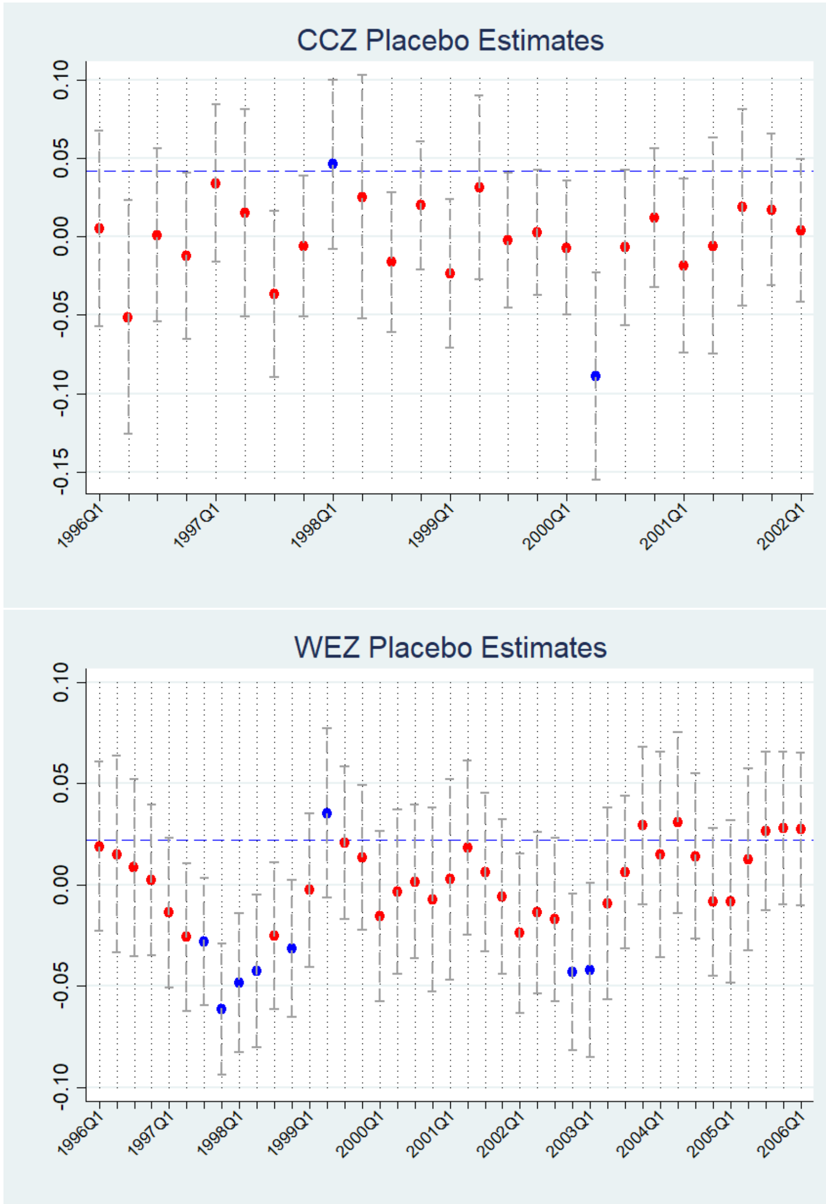


Figure 7: The CCZ (Top)& WEZ (Bottom) Placebo Estimates during pre-treatment period. Each point represents a different regression where the treatment period is 1-year rolling window from the corresponding quarter and the pre-treatment period is 1 year before the quarter. The tails represent 95% confidence interval and blue denotes that the estimate is significant at least at 10%, red otherwise.

6.4 Welfare Estimates

Next, I employ earlier estimates to compute the localised economic benefits associated with the charge. To simplify things, I make the following assumptions: (1) the preferences

Table 7: Residential Property Prices in the Congestion Charge Discount Zone

	(1) 5km	(2) 4km	(3) 3km	(4) 2km	(5) 1km
Discount(θ)	0.0175	0.0122	0.0076	0.0091	0.0075
	(0.0177)	(0.0181)	(0.0184)	(0.0190)	(0.0197)
WEZ(γ)	0.0452[a]	0.0413[a]	0.0345[a]	0.0342[a]	0.0232[c]
	(0.0109)	(0.0113)	(0.0118)	(0.0125)	(0.0134)
Obs	105833	85073	65999	47215	29062
R2	0.80	0.80	0.79	0.78	0.75
No.of Postcodes	16636	13209	10090	7179	4260
Discount(θ)	0.0037	0.0004	-0.0083	-0.0135	-0.0113
	(0.0193)	(0.0198)	(0.0199)	(0.0202)	(0.0202)
RemWEZ(γ)	0.0261[b]	0.0248[b]	0.0150	0.0111	0.0096
	(0.0107)	(0.0113)	(0.0120)	(0.0131)	(0.0157)
Obs	130439	104195	80977	57022	34473
R2	0.82	0.81	0.81	0.80	0.77
No.of Postcodes	17920	14212	10862	7714	4590

Note: *Discount* is a binary variable equals to one for properties (or count points) outside the WEZ but inside the CC discount zone after the WEZ is introduced. Dependent variable is the natural logarithm of the transacted property prices. Specification is similar to that of Column (5) in Table 4 other than the inclusion of *Discount*. Robust standard errors clustered at 300 cross-boundary wedges are reported in parenthesis.[c] $p<0.10$, [b] $p<0.05$, [a] $p<0.01$

for traffic are identical across individuals living in the same cordoned area but could differ between the CCZ and WEZ and (2) the relationship between traffic and house price is linear. The implementation of the charge, on average, induces home prices to increase by £14,524 and £31,686[35] in the CCZ and WEZ respectively per home. Based on the Census estimates on the number of dwellings, which indicates that there are around 91,848 and 113,535 houses in the CCZ and WEZ in 2011 respectively, this implies that the CCZ and WEZ have generated benefits of around £1.33 billion and £3.60 billion respectively for homeowners inside the zone. This figure is meaningful as it presents monetary measure of the local benefits associated with the charge.

Although these effects seem large at first sight, it is not as it measures the WTP for improvement in traffic conditions in perpetuity given the long-lived nature of real estate.

[35] This is computed by simply taking the average of the capitalization effects across the different distance bandwidths.

But are they tenable? To answer this, I compare the benefits to the present value of the annual expenditure to implement the charge. I did some adjustments to the operating costs of running the London Congestion Charge provided by Leape (2006). Estimating the first year cost to be around £163 million and the subsequent annual operating cost equal to £140 million (£23 million is the set up cost), the present value net cost of implementing the charge for the next 30 years is around £16.83 billion. This is computed by assuming an inflation rate of 3% and growth rate of 11% - also the annual growth rate of the CC. The net house price gains, which measures the benefits for home owners in the zone, is around 10% of the net cost. This is just about right considering the array[36] of benefits enjoyed by others that are not quantified in this study.

7 Conclusion

This paper exploits the sharp but localised changes in traffic conditions induced by the London Congestion Charge (LCC) in the Congestion Charge Zone (CCZ) and the Western Extension Zone (WEZ) to estimate the cost of traffic using the housing market. Using a credible natural experiment, this study is an improvement from traditional hedonic approaches that are blighted by omitted variable bias and sorting. Comparing properties just inside and outside the Congestion Charge (CC) boundary in Central London to reduce unobserved neighbourhood differences, I show that new homeowners pay, on average, 4.27% - or £18,230 - more for homes in the CCZ and 2.23% - or £18,829 - for homes in the WEZ after the charges are implemented. Corroborating with these results, traffic flow is 9.48% - or 2,150 auto-mobiles- lower in the CCZ and 3.49% - or 689 auto-mobiles - lower in the WEZ after the tolls are up. These estimates are robust across a variety of specifications and placebo tests that relax identification assumptions. My results verify that home-owners value less traffic and illustrate that households are more willing to pay for this amenity than previously estimated.

Welfare estimates indicate that the tolls generated substantial local wealth gains of around £1.33 billion and £3.55 billion for home-owners in the CCZ and the WEZ respectively. These gains represent local benefits associated with the charge. My findings suggest that the subsidy - a 90% waiver of the charge - given to homeowners living in the CCZ/WEZ should be reduced since they already benefit from the local reductions in traffic that are capitalized

[36] Other benefits that are not localised include the time savings for those living outside the zone and the overall improvement in air quality with less traffic.

in their home values. Channelling these additional revenues to enhance the reliability and quality of public transit could further improve the efficacy of the charge and provide a more equitable redistribution of benefits to home-owners living outside.

Overall, this study provides credible evidence on the effectiveness of the CC in curtailing incoming traffic by forcing drivers to internalize the cost of negative traffic externalities imposed on others. Given that congestion is fast becoming a salient issue for many cities around the world, this problem has drawn considerable interests from policy makers and economists. Yet, solutions such as constructing more roads (Duranton & Turner, 2011) and implementing fuel taxes (Anas & Lindsey, 2011) are notoriously ineffectual in reducing traffic jams. Nevertheless, this paper's findings suggest that congestion tolls could lead us one step closer to abate bottlenecks.

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Data Appendix

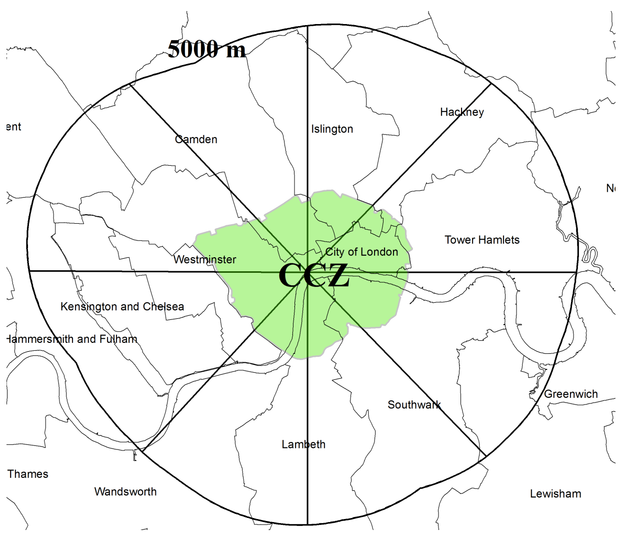

Figure 8: Cross Boundary Wedges for Clustering of Standard Errors

Table 8: List of Variables

Variable	Source	Description
Panel A: Main Specification Variables		
Dependent Variable		
Housing Price (Y_{ijkqt}))	Land Registry	Log of property price of transaction i at postcode k, neighbourhood j at quarter q of year t
Traffic Flow ($Traffic_{pt}$)	Department Of Transport	Log of traffic flow from vehicles with 4 or more wheels in CP p at year t
Housing Characteristics(X'_{it})		
New Sales	Land Registry	Dummy denoting whether transaction i is new build
Terrace	Land Registry	Dummy denoting whether the property type for transaction i is terrace
Leasehold	Land Registry	Dummy denoting whether the tenure for transaction i is leasehold
Location Characteristics (W'_j)		
Distance to CBD	-	Elucidian distance of postcode j from centroid of CCZ
Neighborhood Controls(W'_j)		
Minority race residents	Census 2001 & 2011	% of Asian/African/Middle Eastern and other minority race residents in OA
Unemployment rate	Census 2001 & 2011	% of unemployed working adults in OA
Uneducated residents	Census 2001 & 2011	% of residents in OA with no education qualifications
Lone parent households	Census 2001 & 2011	% of single-parent households in OA
Amenities (W'_j)		
Distance to nearest Grade 1 Park	Magic	Elucidian distance of nearest Grade 1 Park from postcode j in km
Counts of Heritage Buildings	Magic	Number of Heritage buildings within 200m from postcode j
Thames River View	Digimap	Binary variable = 1 if postcode j within 200m from Thames River, 0 otherwise

Table 9: The Effects of the CCZ/WEZ on Traffic Count:Robustness Tests

	Panel A: Announcement				
	(1)	(2)	(3)	(4)	(5)
	5km	4km	3km	2km	1km
PlaceboCCZ2003	0.0189	0.0203	0.0226	0.0212	-0.0130
	(0.0227)	(0.0243)	(0.0247)	(0.0238)	(0.0160)
N	1908	1695	1373	1118	702
R^2	0.992	0.992	0.993	0.992	0.993
PlaceboWEZ	0.0455*	0.0453*	0.0391	0.0539	0.0892**
	(0.0236)	(0.0237)	(0.0288)	(0.0376)	(0.0361)
N	2677	2361	1905	1549	963
R^2	0.985	0.983	0.982	0.981	0.979
	Panel B: Shrank CCZ/WEZ				
	CCZ2003_05	CCZ2005_11	CCZ2011_14	WEZ	RemWEZ
Treatment	0.0504	0.117	-0.0109	-0.0119	-0.0209
	(0.0481)	(0.0672)	(0.0106)	(0.0350)	(0.0708)
N	1043	1082	1063	177	234
R^2	0.975	0.964	0.986	0.996	0.985
	Panel C: Expanded CCZ/WEZ				
Treatment	0.0807*	0.00146	0.0197	-0.00541	0.0230
	(0.0482)	(0.0185)	(0.0142)	(0.0314)	(0.0310)
N	1237	1301	1319	561	653
R^2	0.983	0.993	0.989	0.995	0.992

Note: In Panel A, announcement dates are used to define treatment period. In Panel B (C), I shrink (expand) the treatment area accordingly to mitigate concerns that the treatment effects could be due to CBD. Otherwise, the specification is similar to Table 3. Robust standard errors clustered at ward level reported in the parenthesis.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 10: The Effects of the CCZ hikes in 2011 and 2014 on Housing Prices

	(1)	(2)	(3)	(4)	(5)
CCZ2011_14	0.00772	0.00491	0.0222	0.0202	-0.0111
	(0.0119)	(0.0117)	(0.0201)	(0.0202)	(0.0120)
N	90293	90293	90293	90293	90293
R^2	0.726	0.800	0.801	0.801	0.801
CCZ_2014	-0.0321*	-0.0327*	-0.0302	-0.0248	-0.0234
	(0.0170)	(0.0171)	(0.0214)	(0.0213)	(0.0215)
N	76572	76572	76572	76572	76572
R^2	0.750	0.809	0.809	0.809	0.810
Postal Code FE	✓	✓	✓	✓	✓
Year Quarter Dummies	✓	✓	✓	✓	✓
Housing characteristics		✓	✓	✓	✓
Distance to CBD -by-year			✓	✓	✓
Demographics-by-year				✓	✓
Amenities-by-year					✓
	Panel B: Proximate Transactions				
	(1)	(2)	(3)	(4)	(5)
	5km	4km	3km	2km	1km
CCZ2011_14	0.00883	0.0104	0.00793	0.0100	0.00259
	(0.0201)	(0.0213)	(0.0221)	(0.0227)	(0.0252)
N	90293	71455	51576	34343	18965
R^2	0.801	0.796	0.794	0.794	0.779
CCZ_2014	-0.0234	-0.0162	-0.0133	-0.0175	-0.0213
	(0.0215)	(0.0218)	(0.0228)	(0.0247)	(0.0326)
N	76572	57263	39424	24994	14322
R^2	0.810	0.802	0.804	0.801	0.780

Note: Each coefficient is from different regression. Dependent variable is the natural logarithm of transacted prices. For the sample window of each of the CC event, refer to figure 3 for more information. Panel A summarizes the estimates from baseline specification similar to Table 4. Panel B presents the estimates surrounding a streamlined sample of transactions proximate to the CC boundary similar to Table 5. Robust standard errors clustered at 300 cross-boundaries wedges reported in the parenthesis.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 11: Traffic in the Congestion Charge Discount Zone

	(1) 5km	(2) 4km	(3) 3km	(4) 2km	(5) 1km
			1. WEZ		
Discount	0.0117	0.00458	0.00626	0.0427*	0.0592**
	(0.0150)	(0.0150)	(0.0170)	(0.0253)	(0.0223)
N	1767	1456	1152	738	466
R^2	0.992	0.992	0.992	0.995	0.996
			2. RemWEZ		
Discount	0.0358	0.0372	0.0539*	0.0286	-0.0170
	(0.0249)	(0.0264)	(0.0273)	(0.0331)	(0.0499)
N	2160	1760	1403	887	583
R^2	0.988	0.989	0.990	0.990	0.989

Note: *Discount* is a binary variable equals to one for properties (or count points) outside the WEZ but inside the CC discount zone after the WEZ is introduced. Dependent variable is the natural logarithm of traffic at CP. Specification is similar to that in Table 3 other than the inclusion of *Discount*. Robust standard errors clustered at ward are reported in parenthesis.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 12: Standard errors at different levels of clustering

	(1) 300	(2) 250	(3) 200	(4) 150	(5) 100	(6) Ward
CCZ2003_05	0.0320**	0.0320**	0.0320**	0.0320**	0.0320**	0.0320**
	(0.0139)	(0.0129)	(0.0139)	(0.0128)	(0.0119)	(0.0151)
N	110719	110719	110719	110719	110719	110719
R^2	0.766	0.766	0.766	0.766	0.766	0.766
WEZ	0.0350***	0.0350***	0.0350***	0.0350***	0.0350***	0.0350***
	(0.0117)	(0.0118)	(0.0116)	(0.0119)	(0.0125)	(0.0113)
N	62952	62952	62952	62952	62952	62952
R^2	0.790	0.790	0.790	0.790	0.790	0.790

Note: Each coefficient is from different regression that incorporates transactions within 3 kilometres from the CCZ/WEZ boundary. Specification is similar to that of column (3) in Table 5. This explains why the estimated coefficients are similar. Robust standard errors, reported in the parenthesis, are clustered at the levels denoted in the heading of the different columns.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.