Do Economic Incentives Promote Physical Activity?  
Evaluating the Impact of the London Congestion Charge on Active Commuting and Health*

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Abstract

We investigate the role of economic incentives for health behaviour by estimating the impacts of the London Congestion Charge, a major transportation policy which increases the cost of car use within the central London area, on travel-related physical activity and health. Individuals living inside the charging zone are eligible for a 90% discount of the charge. Using a geographical information system (GIS), we analyse full-digit post code information to precisely identify the eligibility of the discount for survey participants in the London Travel Demand Survey 2005-2011. We employ a boundary regression-discontinuity design, and find no evidence that the financial incentive promotes active commuting (cycling and walking) or improves general health status around the border of the congestion charging zone. The result rejects the high aspirations expressed in the social epidemiology and public health literature.

Keywords: financial incentive; health behavior; the London Congestion Charge; geographical information system; regression-discontinuity.

JEL Classification Codes: D04, I18, R48.

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1. Introduction

Tax and subsidy have been considered an effective economic tool for reducing smoking, excess alcohol drinking, and consumption of unhealthy foods (Gruber and Koszegi, 2001; Giné et al. 2010; Volpp et al. 2009; Yaniv et al., 2009). However, it is largely unknown whether economic incentives can achieve a sustainable improvement in physical activity. Several recent studies have examined the impact of personal financial incentive in a micro setting, such as sports gym attendance (Charness and Gneezy, 2009; Royer et al. 2012). Nonetheless, the evidence base is particularly scarce when it comes to altering economic incentives at a more aggregate population or community level (Martin et al. 2012).¹

The purpose of the study is to investigate the effects of a large scale economic incentive on health behaviour at a population/community level in a non-experimental setting. Active commuting, i.e. walking and cycling, is a form of physical activity. Since commuting is a part of everyday habitual activity for everyone, it is a key target area for public policy interventions. The topic has obvious relevance to health economic research and it is of considerable policy importance, in light of the ongoing struggle to identify measures that are effective and affordable in tackling the “epidemic” of obesity and physical inactivity (Mokdad et al. 2004).

The London Congestion Charge is one of world’s most prominent transportation policies. The scheme imposes charges (initially £5, currently £10 per day) to most types of cars entering, leaving, and running within the central London area. Although the primary aim of the policy was to reduce congestion, rather than to directly promote physical activity, the increased costs of car use have naturally been seen as a major incentive for active commuting in the area. For example, Pucher et al. (2012) list the London Congestion Charge in first place

¹There are studies on macroeconomic fluctuations (e.g. gasoline price) and obesity (for example, Courtemanche (2011), which could be seen as indirect evidence.
among other policy factors that could promote cycling in the city. Also, Maibach et al. (2009) claim that the congestion charging is a policy option to promote activity levels, showing data indicating that cycling increased substantially in central London after the congestion charge was implemented. Givoni (2012) concludes that almost all papers on the London congestion charge scheme are supportive and did not challenge the premises about its effectiveness in terms of a wide range of outcomes, including but not limited to active commuting (pp.1091).²³

Despite these high aspirations, there has hitherto been little in the way of formal evaluation of the policy to promote physical activity. Arguably the most notable existing assessment, of which findings are often cited in the related literature, is the series of reports by Transportation for London, a local governmental body in charge of London transport.⁴ The reports provide detailed information of transitions of travel modes, and overall provide evidence that the amount of travel-related physical activity increased after the charge was implemented. For instance, travel distance cycled increased by about 30% after the charge was implemented (Transportation for London, 2006). A crucial problem of such assessments from our perspective is that because the congestion charging scheme had been accompanied by other relevant transportation policies, such as improvement of bus network and cycle roads, it is difficult to attribute the favourable change to the economic incentive (Givoni, 2012).

To identify the effects of the economic incentive, we analyse an interesting case of `discount’ of the charge. In the scheme, individuals living inside the central London area (i.e. the charging zone) are eligible for a 90% discount of the charge, whereas those living outside the

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² The studies cited in Givoni (2012) are not necessarily those which address physical activity and health, but include studies mainly on transportation.
³ A related study Noland et al. (2007) show that traffic accident did not increase or decrease in the area after the London Congestion Charge was implemented.
zone have to pay the full amount. This generates a significant difference in the incentive between those living just inside and those just outside the charging zone. The border of the charging zone, and hence eligibility for the 90% discount, is drawn deterministically by law. We exploit this legislation in our estimation of the effects of financial incentive using a boundary discontinuity design (Black, 1999; Dell, 2010).

The eligibility for the 90% discount is determined by post code. We use a geographical information system (GIS) to geo-code the charging zone border and residential locations of survey participants in London Travel Demand Survey 2005-2011. This data include full-digit postal code information. The detailed geographic information enables us to calculate precisely the distance between residential locations and the border of the charging zone, which we define as the ‘treatment’ assigning variable. Using GIS, we also construct geographic segments of the study area, which we use as “spatial fixed effects” in our regression model, which capture time-invariant neighbourhood characteristics across the study area (Goldstein and Udry 2008).

Our fixed-effect boundary discontinuity estimates show no evidence that the financial incentive of the London Congestion Charge increases physical activity levels (as measured by duration of time spent on cycling and walking for travel) around the border of the charging zone (i.e. cut-off point for the eligibility of the 90% discount). Moreover, we do not find any health effects around the border. The result rejects existing anecdotal expectations in the social epidemiologic and public health literature.\(^5\)

The rest of the paper is organised as follows. Section 2 provides an overview of the London Congestion Charge scheme. Section 3 describes our boundary discontinuity design. Section 4

\(^5\) Some environmental and epidemiologic studies address the potential health effects due to a reduction of air pollution in the central London area (for example, Beevers et al. 2005; Tonne et al., 2008). Since we estimate the health effects induced by active travel, we of course do not claim that our findings are directly relevant to those studies.
explains details of the data. Section 5 reports empirical findings. Finally Section 6 concludes the paper.

2. The London Congestion Charge scheme

In this section we briefly describe the history and the implementation of the scheme. For more details, see Leape (2006). The idea of a congestion charge in London began in 1964. The main purpose of this large scale transportation policy was to reduce congestion in the central London area, and also to use the revenue to invest in transport system improvement. The economic rationale of the scheme is based on the need to internalize the cost of congestion. As the cost of car travel within the zone increases by the charge, an optimal level of congestion, which would be lower than what was experienced, should be achieved and would then then lead to efficiency gains in the area.

The central London congestion charge was implemented in February 2003. The border of the charging zone was set to the “London Inner Ring Road”, which is an approximately 20 kilometres route, comprising a number of major roads which surround the central London area including the City of London and the West End (see Figure 1).

[Figure 1 about here]

Historically, the Inner Ring Road was planned in the 1943 County of London Plan, and established after the war. Before the charge was implemented, for about 25% of car traffics entering the border, the zone was just a pathway through. The border was chosen so that these cars could go around the Inner Ring Road without entering the zone (Leape, 2006).

Drivers of chargeable vehicles (private cars excluding motorcycles, vehicles with nine or more seats, and ultra-low emission cars) are charged when they enter, leave, travel or park within the charging zone during the charging time (but driving on the London Inner Ring
Road is not charged) during the charging time. Charging time is from 7:00 to 18:00 (initially 18:30 until January 2007), Monday to Friday excluding public holidays and the Christmas/New Year week. Approximately 200 cameras are set across the area (particularly around the border of the charging zone). The cameras, together with “patrol” cars equipped with CCTV, take photo images of number plate of the car, and send the images to the central system. The system matches the images and the drivers’ information which are provided by the Driver and Vehicle Licensing Agency. The drivers have to pay the charge without being prompted to do so; they do not receive a warning that they have been captured within the charging zone on the day of travel, and are simply expected to take responsibility for arranging their payment (however, if the drive fails to pay, a penalty charge notice is sent after some days). Initially, the amount of charge was £5 per day if they pay before 10 pm on the day of travel. The standard charge rate was increased to £8 in July 2005, and then further increased to £10 in January 2010. The amount of charge increases as the payment delays (maximum £130 per day).

In February 2007, the charging zone was expanded to include western London incorporating the City of Westminster and Kensington & Chelsea area (the “Western Extension”), also presented in Figure 1. The expanded zone included the largely residential area of west London. The extension was abolished in January 2011.

The scheme provides a residents’ discount, in which residents of areas within the charging zone (and some “buffer areas” just outside the zone) are eligible for a 90% discount of the full charge if they register (in 2014, the discounted rate is £20 a month if paid monthly,

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6 In 2014, the standard rate is £10 per day if payment is made by 22:00 on the day of travel. The rate increases to £12 if paid in the next day. If one fails to pay the charge, a penalty charge notice for £130 is sent to the car owner. If the penalty charge is paid within 14 days, the amount of charge is reduced to £65.
whereas the full rate is £200 a month). This creates a significant difference in the cost of driving within the charging zone between those living outside the zone and those living inside. The residents living inside the zone are not charged if their cars remain parked in a registered location during the charge time. However, once they drive their car they face the risk of being charged if they are captured by the cameras (which costs 10% of full daily charge).

All revenues earned from the congestion charging are used to invest in improvements to transportation in the area. About 80% of the revenues are used to expand the local bus network and improve the services, including the number of services and also new payment system (Givoni, 2012). It is also worthwhile noting that there have been intensive investments to promote cycling in the area, including the expansion of the cycle network, construction of cycle superhighways, construction of new cycle parking spaces, and a bike-sharing scheme (Pucher et al., 2012).

Active travel increased after the congestion charge was implemented. While the number of cars entering the central London area during the charge time decreased after the charge was implemented, the number of pedal cycles entering the area increased (Transport for London, 2007). Similarly, the average distance cycled by residents increased by 30% (Transportation for London, 2006). Furthermore, the number of bus passengers (who tend to accrue more physical activity than door-to-door car drivers) increased substantially during the same period. It is however not clear if these increases in physical activity levels can be attributed to the congestion charging, given that some related policies which potentially increased active travel were implemented during the same period.

3. Research Design

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7 Eligibility for the charge is determined by full postal code of residential location. Transport for London operates “zone checker” in their website, which tells residents whether they are eligible for the discount.
The primary goal of this study is to estimate the causal effect of increasing the cost of chargeable sedentary travel mode (i.e. private car use) on the degree of travel-related physical activity.

There are at least two concerns in estimating the causal effects of the financial incentives derived by the London Congestion Charge. The first concern is a typical endogeneity problem. Eligibility for the discount scheme is determined by residential location. Residential location is likely to be correlated with neighbourhood characteristics that independently determine travel modes, such as features of the built environment (e.g. shops, roads, bus stops) and social characteristics. Those factors are not fully covered in our data, leading to omitted variable bias.

The second concern is how to isolate the effect of the congestion charge from that of relevant policies. As reviewed in the last section, the implementation of the policy is accompanied by other policies that are aimed at improving urban transportation, including improvement of the bus network and expansion of cycle routes. Since these accompanying policies can also improve travellers’ physical activity levels, identification strategies of any causal effects that involve before-and-after comparison (e.g. difference-in-differences) are inappropriate.

To address these two main concerns, we exploit the geographic discontinuity of eligibility for the discount scheme, in which car owners living inside the charging zone (and in several ‘buffer areas’ located just outside the zone) are eligible for a 90% discount of the charge. By focusing on individuals living close to the border of the charging zone, who share neighbourhood characteristics, we avoid concerns regarding the omitted variable bias due to unobserved neighbourhood characteristics (our first concern). Also, the benefits of the development of urban transportation infrastructure should be very similar on either side of the border street (if a person who lives at a border street receives a better bus service, then
someone living on the opposite side of the street can enjoy it, too). Therefore, the effects of accompanying transportation policy are not likely to bias our analysis (our second concern).

The eligibility for the 90% discount is assigned deterministically by postal code. Our data contains full six digit post code information. Using a geographical information system, we locate each survey participants within London (as shown in Figure 2).

This enables us to know precisely the eligibility condition for all participants. Also, we divide the map into segments (the size of each segment is 50x50 metres), and assign a segment identifier for each residential location. All analyses are clustered at the segment level (Goldstein and Udry 2008). This is to avoid comparing individuals who live close to the border but are located far from each other.

Since in this research design we focus on individuals who live close to the border of the charging zone, we restrict our samples to those who live 2 kilometres from the border (based on the direct distance between their home and the nearest point on the border). This includes all participants who live inside the charging zone, and only a small part of participants who live outside the zone.

In our analysis, the treatment is the full congestion charge, i.e. individuals who live just outside the charging zone represent the “treatment” group, and those who live just inside the zone are the “control” group. Our basic regression model is given as follows:

$$y_{ist} = \alpha + \tau LC\bar{C}_{ist} + z'_{ist}y + f(Dist_{ist}) + \varphi_s + \varepsilon_{ist}.$$  

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8 The Transport for London website offers a “charging zone checker”, in which residents can check whether they are eligible for the discount by entering their postcode. https://congestioncharging.tfl.gov.uk/.
where $a_{ist}$ is the outcome variable for an individual $i$ in district segment $s$ in period $t$. $LCC_{ist}$ is the treatment indicator, and equals 1 if the individual lives outside the congestion charge zone (i.e. eligible for full charge) and 0 otherwise (eligible for the 90% discount). On 9th February 2007, the charging zone was extended to the western side of central London. Hence, for those who live in the western extension zone, $LCC_{ist}$ is 0 if they were surveyed before 9th February 2007, and it takes 1 after this date. We later analyse the effects of the western extension separately. The vector $z_{ist}$ includes control variables. Year fixed effects are included in all models; and age, gender, and household income are included in selected models. These additional control variables do not show any discontinuous differences around the cut-off\(^9\), and are included in the model to reduce sample variations. The term $f(Dist_{ist})$ gives the flexible function of the distance between the residential location and the border of charging zone. Finally, $\varphi_s$ is the spatial segment fixed effect. This implies that the analysis provides within-segment effects, which are robust to time invariant neighbourhood characteristics.

We estimate the model by local linear regression with triangular kernel (Hahn et al. 2001; Porter 2003). As for the choice of sample bandwidths for estimation, we used an algorism for calculating the bandwidths suggested by Imbens and Kalyanaraman (2012), which minimises bias with smaller loss of precision. Sensitivity checks using different bandwidths are conducted (not reported in the paper). Bootstrap standard errors, adjusted for clustering at segment level, are estimated.

The function $f(Dist_{ist})$ is also modelled by a quartic polynomial function, allowing for different functional forms on either side of the cut-off point by including interaction terms between the polynomial and the treatment dummy. Similarly to the local linear regression

\(^9\) We plot the control variables against the assignment variable, and test whether the variable jumps at the cut-off (Lee and Lemieux 2010). We confirmed that all control variables are smooth at the cut-off.
model estimation, robust standard errors adjusted for clustering at segment level are estimated.

As pointed out in the literature, the estimated treatment effect should be viewed as weighted average treatment effect, where the weight is the probability of living close to the border of the charging zone (for example, Lee and Lemieux, 2010). This raises concerns regarding external validity of the estimated effects. We include all participants who live inside the charging zone in the analysis. However, effects on those who live more than 2 kilometres from the charging zone were not analysed, and this is acknowledged as a clear limitation of our approach.

Since the congestion charge applies on weekdays only, we exclude travel data from weekends and public holidays. Also, the charge only affects potential car users (although it could affect residents’ decisions to own a car), we present estimates using participants who state at least one car was available to use for them on the day of travel, as well as estimates using all participants. Car ownership does not differ significantly on either side of the border of the charging zone.

Similarly to existing studies employing boundary discontinuity designs (Black, 1999; Dell, 2010; Magruder, 2012), our setting is likely to violate a basic assumption of standard regression discontinuity design, namely, participants should not be able to choose precisely where they live around the border (i.e. self-sorting). Although there is no particular reason to assume that sorting happens around the border area only, it is entirely possible that people who do not wish to pay the full congestion charge decide to move into the charging zone, or those who newly move into London will choose to live inside the zone to avoid paying the full charge. If this is the case, the effect of the congestion charge will be overestimated. If we
do find some significant effects at the cut-off, this could undermine the analysis. We come back to this point later in Section 6.

Finally, it is possible that instead of changing travel mode, individuals around the charging zone could change or restrict their living area (e.g. place to shop, workplace, and school). We also explore this possibility.

4. Data

We use London Travel Demand Survey (LTDS) from 2006 to 2011. The survey started in the financial year of 2005/6. Unfortunately, data for 2003 up to the middle of 2005, when the congestion charge was just implemented, are not available. This implies that our analysis addresses the long term effects of the congestion charge rather than the immediate effects. The LTDS is a repeated cross-sectional household survey for residents within the London boroughs and some parts of the area outside Greater London (restricted to those within the M25 motorway).

The sample households are representative of Londoners in terms of household characteristics as well as residential locations within the area. The total sample size is around 5,000 to 8,000 in each survey year (response rate is around 50 to 55%). The survey comprises three sets of questionnaires, which were conducted through household interviews. First, a household questionnaire covers various household characteristics (socioeconomic and demographic), vehicle ownership (e.g. how many and what kind of vehicles), and information of housing tenure (e.g. when the household started to reside in the current place). Second, an individual questionnaire is completed by all household members aged five or above. The questionnaire covers individual level demographic characteristics such as age and gender,

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10 If the household income band is missing, it is imputed using information of householders’ characteristics: i) numbers of full and part-time workers in the household; ii) household size and structure; iii) housing tenure; iv) whether the household has a home computer; v) number of vehicles available to the household; and vi) whether the household has another home.
working/schooling status, details of workplace/school, and travel related characteristics including whether one has a driver’s licence. Third, a trip questionnaire is completed by all household members aged five or above and records information of all trips made during the day prior to the household interview (a single-day travel diary). The information includes main travel mode, trip origin, trip destination, time of departure, time of arrival, and purpose of the trip. Each trip is further divided into travel stages, and the information above is also available at travel stage level.\textsuperscript{11}

The data provides detailed geographic information, including full digit postcode information of the home address, workplace or school, plus trip origin and destination. This enables us to precisely geo-code the locations of household and geographic characteristics of trips (e.g. distance) using GIS.

Although the eligibility of the 90% discount to the congestion charge is precisely identified by the full postal code information, unfortunately the data do not allow us to know whether individuals who are eligible for the discount actually registered to be discounted.

The key outcome variable is the duration of time spent on active travel, i.e. walking and cycling. This is the sum of time spent on all travel stages in which walking or cycling were used during the same day by the individual. If an individual reports that he or she made no trip on the travel day, the variable is recoded as zero. Some participants neither completed the travel diary nor stated that they made no trip on the travel day. These participants are excluded from further analyses. Finally, we construct a variable measuring the duration of active travel in a single trip between residential location and their workplace/school. This

\textsuperscript{11} For an illustrative example, in a trip to workplace, a person walks from home to the nearest bus stop (stage 1), and then takes a bus to the city centre (stage 2), and again walks to the workplace (stage 3). Total time spent on walking in this trip is the sum of duration of stage 1 and stage 3.
variable is measured only for participants who made a trip to workplace/school on the travel day.

The data contain some general health outcome variables. We constructed an indicator variable based on any short-term or long-term illness that was reported.

5. Results

Summary statistics

The main analysis focuses on individuals living within 2 kilometres from the border of the congestion charge zone. This includes all survey participants living inside the charging zone. Table 1 presents summary statistics for three different subsamples: 1) the full sample (including all survey participants); 2) individuals living within the 2 kilometres range but outside the charging zone; 3) individuals living inside the charging zone.

[Table 1 about here]

The total duration of time spent on active travel (walking or cycling) is around 25-30 minutes per day. Inner London residents (i.e. estimation participants) spend more time in active travel than those in the other areas. A similar difference is found for duration of active travel to their workplace and school. This could be because the inner London residents are located some distance away from their workplace or school. The proportion of individuals reporting an illness is around 10% for both sets of participants. A smaller proportion of the inner London residents own a car (54.2%) compared to more general London residents (74.4%). The physical activity level of car owners is only slightly lower than among those who do not own a car. The difference between the estimation sample (inner London residents) and the full sample implies that the travel environment in the inner London area is somewhat distinctive,
and empirical findings from the inner London sample may not be generalised to greater London residents.

**Graphical analysis**

We now analyse our estimation sample. In Figure 3, the total duration of active travel and the probability of reporting an illness are plotted (with separate lowess lines on either side of the cut-off) against the distance between residential location and the border of the charging zone.

[Figure 3 about here]

In the figure, the distance is zero at the border; positive if one lives outside the border; and negative if one lives inside the border. For each outcome variable, we present two types of graphs using the same data - one using raw data, and the other using aggregated data. In the aggregated data, individuals located within a 25 metres’ band (a bin) are grouped together.

For both outcome variables, the plots show no apparent difference at the cut-off border. This holds for different sizes of sample bin. The lowess lines do not show any meaningful jump at the cut-off point.

**Regression analysis**

We now turn to the regression results. Table 2 gives the results for physical activity level.

[Table 2 about here]

Panel A shows the effects on total duration of active travel per day. For all samples and the subsample of car owners, the treatment effect is small and statistically insignificant. The result implies that there is no evidence that the financial incentive increases overall activity levels, as we find in the graphical analysis. The conclusion is robust for different estimation methods.
Panel B presents the effects on duration of active travel in a single trip to workplace and school, separately by location of workplace/school. In this model, the distance between the home address and the destination is controlled for. Again the estimated treatment effects are statistically insignificant in all cases, meaning that activity levels do not differ around the border of the charging zone.

Finally, Table 3 provides the results for general health status.

Since we fail to find that the charge promote active travel around the border, it naturally follows that there is not likely to be a significant difference in health status that is related to physical activity. The regression analysis confirms this – the estimated effects are small and statistically insignificant.

Supplementary analyses

We conduct following supplementary analyses: a) repeat the analyses restricting to those who resided before the congestion charge was implemented; b) probability of travelling during out-of-charge time at least once on the day (those who used car only); c) probability of commuting to workplace/school inside the charging zone. None of these analyses show statistically significant impact at the border of the charging zone (details are not reported in the paper).

6. Discussion and conclusion

As reported by Transportation for London, there have been increases in travel related physical activity level in the central London area since the congestion charge was implemented. However, it has long been unclear whether this trend is really caused by the congestion charging. Despite widely shared high expectations for potential effectiveness in
the social epidemiologic and public health literature, the answer appears to be negative. Other related policies such as the expansion of cycle routes and rental cycle schemes (which are partly funded by revenues earned by the congestion charging) could have generated the trend. Neither can we exclude the possibility that recent social norms favouring active travel may also have been at play.

Below we acknowledge several key issues which potentially limit the interpretability and generalisability of the results.

Depending on the availability of housing properties, individuals can choose where they live. Therefore this can violate a basic assumption of regression-discontinuity design, which is a clear limitation of our identification strategy. This problem is perhaps almost inevitable in similar boundary regression discontinuity design and hence the design is classified as `non-standard' (Lee and Lemieux, 2010). However, this problem is unlikely to affect our main conclusion. As discussed in Section 3, if sedentary individuals are self-selected to live inside the congestion charge zone, the effects of the financial incentive on physical activity levels are overestimated – the true effects must be smaller than what we have obtained. However, the result shows that the effect sizes are small and statistically insignificant, even in the presence of the upward bias. Moreover, we did not find significant effects when, in a preliminary analysis, we restricted the sample to those who resided in the current location before the congestion charge scheme was implemented. In summary, we fully acknowledge that self-sorting could be present in our data, but it unlikely to affect our main conclusion.

Since the current analysis is focused on those living around the border of the congestion charge zone, generalisability of the result is inevitably limited. Compared to people living in greater London area, people in the central area are exposed to wide variety of transportation infrastructure (e.g. bus and the Tube).
The London Travel Demand Survey which we used in this study started from the fiscal year 2005/6. It is unfortunate that we do not have data from 2003 and 2004, when the congestion charge scheme was first implemented. Our analysis should therefore be seen as the assessment of the long term effects of the congestion charge. However, the data cover the periods when the charging zone was extended to the western zone (and the period when the extension was abolished). This might provide an opportunity to investigate the immediate effects. Our preliminary analysis focusing on the period, however, does not show any significant effects.

The amount of charge per day has been updated several times (initially £5 per day; £8 from July 2005 to January 2010; and £10 since then). However, the current analysis does not fully take this into account. In an unreported sub-sample analysis, we estimated the effects for each time period separately. Our conclusion was not affected.

Mindful of the limitations, our result has implications for policy makers who are planning a community level financial incentive to induce preferable behaviours. In a health context, as seen in the previous studies on gym attendance, personal financial incentive schemes can be effective at least for one or two years (Charness and Gneezy, 2009; Royer et al. 2012). However, achieving sustained behaviour change in terms of physical activity – or here more specifically: active commuting – may require either a bigger change in economic incentives or an accompanying set of interventions alongside the economic incentive alone.
References


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Figure 1: Congestion charge zone map (retrieved from Transport for London)

Note: In January 2010, the western extension zone (violet area) was abolished.
Figure 2: The map of the study area and the distribution of study households, LTDS 2005-2011.

Note: The blue area represents the congestion charge area from February 2007 to January 2011, when the charging zone incorporated the western extension.
Figure 3: Graphical analysis of the boundary discontinuity at the border of the charging zone (physical activity level and health status), estimation sample.

Note: For the aggregated data, individuals within the same bin (25 metres’ band) are grouped together.
<table>
<thead>
<tr>
<th></th>
<th>Full sample</th>
<th></th>
<th>Estimation sample</th>
<th></th>
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</thead>
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<td></td>
<td>Mean</td>
<td>S.D.</td>
<td>Mean</td>
<td>S.D.</td>
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<td>35.20</td>
<td>31.17</td>
<td>36.55</td>
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<td>Duration of active travel to workplace/school per trip (minutes)</td>
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<td>11.66</td>
<td>13.05</td>
<td>10.45</td>
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<td>Reporting illness</td>
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<td></td>
<td>10.6%</td>
<td></td>
</tr>
<tr>
<td>Car ownership</td>
<td>74.4%</td>
<td></td>
<td>54.2%</td>
<td></td>
</tr>
<tr>
<td>Total duration of active travel per day (minutes, car owners only)</td>
<td>21.21</td>
<td>34.37</td>
<td>29.33</td>
<td>34.41</td>
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<tr>
<td>Duration of active travel to workplace/school per trip (minutes, car owners only)</td>
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<td>11.75</td>
<td>11.98</td>
<td>10.48</td>
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<td>Age</td>
<td>40.00</td>
<td>21.24</td>
<td>38.32</td>
<td>20.06</td>
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<tr>
<td>Female</td>
<td>52.5%</td>
<td></td>
<td>52.3%</td>
<td></td>
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<tr>
<td>Household income (above £25,000)</td>
<td>53.1%</td>
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<td>43.9%</td>
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<td>3.03</td>
<td>11.95</td>
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<tr>
<td>Distance between workplace/school and home address (kilometres, car owners only)</td>
<td>4.66</td>
<td>11.32</td>
<td>3.45</td>
<td>14.22</td>
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<tr>
<td>Observations</td>
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<td></td>
<td>8582</td>
<td></td>
</tr>
</tbody>
</table>

Note: The estimation sample includes individuals living within 2 kilometres distance from the border of the charging zone.
Table 2: The effects of the London Congestion Charge on log duration of time spent on active travel (walking and cycling).

<table>
<thead>
<tr>
<th></th>
<th>(1) All Local linear</th>
<th>(1) All Polynomial</th>
<th>(2) Car owners only Local linear</th>
<th>(2) Car owners only Polynomial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean of outcome variable</td>
<td>32.5 minutes</td>
<td>31.2 minutes</td>
<td>29.6 minutes</td>
<td>29.3 minutes</td>
</tr>
<tr>
<td>Treatment effect</td>
<td>-0.025</td>
<td>-0.073</td>
<td>0.024</td>
<td>-0.092</td>
</tr>
<tr>
<td>Spatial fixed effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Covariates</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>0.834</td>
<td></td>
<td>1.563</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>4402</td>
<td>8582</td>
<td>3727</td>
<td>4655</td>
</tr>
</tbody>
</table>

Panel A: Log total duration of active travel per day

Panel B: Log duration of active travel to workplace/school per trip

Work/School Inside the Zone

<table>
<thead>
<tr>
<th>Mean of outcome variable</th>
<th>14.4 minutes</th>
<th>14.8 minutes</th>
<th>14.3 minutes</th>
<th>14.3 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment effect</td>
<td>0.133</td>
<td>0.104</td>
<td>0.140</td>
<td>0.061</td>
</tr>
<tr>
<td>Spatial fixed effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Covariates</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>1.031</td>
<td>1.616</td>
<td>0.932</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>1036</td>
<td>1616</td>
<td>492</td>
<td>873</td>
</tr>
</tbody>
</table>

Work/School Outside the Zone

<table>
<thead>
<tr>
<th>Mean of outcome variable</th>
<th>11.7 minutes</th>
<th>11.6 minutes</th>
<th>10.5 minutes</th>
<th>10.2 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment effect</td>
<td>0.005</td>
<td>0.073</td>
<td>0.237</td>
<td>0.574</td>
</tr>
<tr>
<td>Spatial fixed effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Covariates</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bandwidth (kilometres)</td>
<td>1.221</td>
<td>1.972</td>
<td>1.185</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>1213</td>
<td>1972</td>
<td>651</td>
<td>1144</td>
</tr>
</tbody>
</table>

Notes: ** p<0.01, * p<0.05. Robust standard errors adjusted for spatial correlations. The Imbens-Kalyanaraman algorithm (2012) is used for bandwidths selection. Quartic polynomial is used. Covariates include age, gender, household income (six dummy variables), and year dummies. In the analysis presented in Panel B, an additional control variable, distance between home address and workplace/school, is included in the model.
Table 3: The effects of the London Congestion Charge on general health status (probability of reporting illness)

<table>
<thead>
<tr>
<th></th>
<th>All</th>
<th>Car owners only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Local linear</td>
<td>Polynomial</td>
</tr>
<tr>
<td>Mean of outcome variable</td>
<td>10.5%</td>
<td>10.6%</td>
</tr>
<tr>
<td></td>
<td>-0.001</td>
<td>-0.051</td>
</tr>
<tr>
<td>Treatment effect</td>
<td>(0.016)</td>
<td>(0.041)</td>
</tr>
<tr>
<td>Spatial fixed effects</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Covariates</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>1.648</td>
<td>.</td>
</tr>
<tr>
<td>Observations</td>
<td>7119</td>
<td>8083</td>
</tr>
</tbody>
</table>

See notes for Table 2.