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Martin, Adam, Morciano, Marcello and Suhrcke, Marc orcid.org/0000-0001-7263-8626 (2020) Determinants of bicycle commuting and the effect of bicycle infrastructure investment in London: evidence from UK Census microdata. Economics and Human Biology. 100945. ISSN 1570-677X

https://doi.org/10.1016/j.ehb.2020.100945

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• Title

Determinants of bicycle commuting and the effect of bicycle infrastructure investment in London: evidence from UK Census microdata

Abstract

Worldwide, concern about physical inactivity and excessive car dependence has encouraged ambitious targets and policies to promote cycling. But policy making is hindered by limited knowledge about why cycling prevalence and trends vary greatly between different geographic areas (e.g. in London (UK) <1% cycle to work in Harrow compared to >15% in Hackney) and individuals (e.g. by age or gender). The role of cycle infrastructure investment in explaining part of these patterns and trends is also unknown. We linked individual-level data on 317,117 London commuters (including 11,199 cyclists) in the 2001 and 2011 UK Census to relevant geographic data, including on area-level cycling infrastructure investment during the period. Whilst cycle commuting increased over time on average, concentration curves and indices demonstrated that in contrast with England as a whole, cycling in London shifted from being dominated by commuters with lower socioeconomic status to commuters with higher socioeconomic status. In our first set of regression analyses, we showed that observed differences and time trends in cycling prevalence were partially explained by area-level differences in topography, greenspace, footpaths and crime levels and by differences and changes in population structures. In the second, we conducted a cost-effectiveness analysis which showed that expenditure on cycling infrastructure was associated with increased cycling at a marginal rate of £4,915 per additional commuter cyclist, with some variation between groups: ethnic minorities were more responsive, and females, older people and those with lower socioeconomic status appeared less responsive. If planned increases in expenditure in England for the period 2020-25 were as cost-effective, and were sustained for the whole decade, our study suggests that cycling prevalence could increase in England by 0.5 to 1.1 percentage points. More research is necessary to determine whether such investment in cycling infrastructure constitutes good or equitable value for money.

1. Introduction

Worldwide, current interest and investment in policies to promote cycling has been prompted by concern about physical inactivity arising from excessive car dependence and, more recently, about the potential for Covid-19 transmission on public transport.[1-7] Since cycling is in principle a financially very affordable way to travel and to exercise, such policies might be regarded as potentially more beneficial for people with lower socioeconomic status (SES), who typically are less active than those with higher SES and for whom both alternative travel modes and forms of exercise can be prohibitively expensive. People with lower SES are also more likely to be required to travel to work during the Covid-19 pandemic because they cannot work from home.[8] If cycling at least partially displaces car journeys, then people living in disadvantaged urban residential areas suffering disproportionately from heavier road traffic could also benefit most from environmental improvements (e.g. less air pollution).[9 10] Hence, such policies have the rare potential to not only boost overall population-level health and wellbeing but also to tackle inequalities in health and accessibility (i.e. being able to reach workplaces and other destinations easily).[11-14]

Despite these ambitions for cycling, there remains a shortage of evidence to guide decision-makers about the most cost-effective approaches to promoting cycling at the population-level whilst also – ideally – addressing any socioeconomic inequalities in cycling. Internationally, few quantitative studies have examined reasons why cycling varies between different geographic areas, and how and why it varies between different socioeconomic groups. Literature reviews also highlight a lack of economic evaluations and equity impact assessments of population-level interventions to promote cycling,[3 15-18] including new cycling infrastructure. For example, two controlled studies of substantial infrastructure investments in several towns or cities did not include an economic evaluation, despite identifying only modest impacts on cycle commuting.[19 20]

In England, existing data show the proportion of commuters who cycle to work is amongst the lowest in Europe (3% vs e.g. 9% in Germany and 25% in Denmark and the Netherlands [4]) and has virtually not changed for decades. Evidence also shows that female and older commuters [21-24] and those living in more socioeconomically deprived areas are less likely to cycle (although individual-level SES characteristics have not been studied directly) [23 25 26]. In London, cycling prevalence increased amongst commuters between 2001 and 2011 (from 2.5% to 4.3%), with substantial area-level heterogeneity (ranging between the 32 boroughs from 0.8% to 15.6% in 2011).[23 27] Our study is motivated by the opportunity to exploit these differences in the level and trends in cycle commuting across population subgroups and geographic areas in London, which may be indicative of untapped potential for more cycling nationwide.

Our study used a large representative sample (5% of the total population) of anonymised individual records from the UK Census data of commuters aged 16–74, living in London in 2001 or 2011. We first describe the socio-demographic characteristics of cyclists and their changes over time, including by using as an inequality measure the concentration index of SES–related inequality in cycling. By exploiting substantial borough-level heterogeneity in cycle commuting, and in the time-trends and levels of expenditure in cycling, we then examine two research questions:

RQ1: To what extent can borough-level differences in the likelihood of cycling, and time-trends in the likelihood of cycling, be explained by individual-level SES and demographic characteristics, or by local geographic features?RQ2: To what extent can borough-level time-trends in the likelihood of cycle commuting be explained by differences in cycle infrastructure expenditure, after controlling for demographic and SES-related changes in the population structure?

2. Methodology

2.1 Data

Data were taken from anonymised individual records of the UK Census held on Sunday 29th April 2001 and Sunday 27th March 2011.[28 29] Employed people aged 16–74 at the time the data were gathered were asked “How do you usually travel to work?" for the longest part, by distance, of their usual journey. Among the eleven options available, those responding “Bicycle” defined our population of interest compared with those reporting any other mode including train, metro, bus, taxi, motorcycle, car or on foot. Following other comparable studies that analysed responses to this question using (aggregate-level) UK Census data [19 21 23 24], participants who responded with "Work mainly at or from home" were excluded.

Our main analyses specifically focus on London residents in 2001 (n=151,245) and 2011 (n=182,495) with no missing data on covariates (95.0% of participants, n=144,707 in 2001 and 172,410 in 2011).

We use three sets of covariates:

Individual-level data: The following variables were selected for our study based on factors identified in other studies as having a potential impact on the likelihood of cycling. A list of dummy variables generated for use in the subsequent analyses are shown in brackets. [iii]

- *Demographics:* gender (with male in the reference category), age (aged 16-24, aged 25-29, aged 40-49, aged 50-59, aged 60-64, aged >=65, with aged 30-39, the median age, in reference category), self-reported health (Not good, Fairly good, with Good in the reference category), ethnicity (eleven ethnic minority categories, with White British in the reference category).
- *Socioeconomic and employment-related characteristics:* highest qualification ('<5 GCSEs or equivalent,' '>5 GCSEs or 1 A-level or equivalent,' '>1 A-level or equivalent,' 'at least degree or equivalent,' 'other or unknown qualifications,' with 'no qualifications' in the reference category)[iii], working hours (<16 hours per week, 16-30 hours, >48 hours with 31-48 hours in the reference category), National Statistics Socio-economic Classification (NS-SEC),

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[i] For each variable, unless stated otherwise, the number of dummy variables used in the analyses reflect the number of available responses in the 2001 Census dataset. For some variables, there were more categories in the 2011 data (e.g. n=35 NS-SEC categories, versus n=9 in 2001 data) and, for consistency, these were re-categorised for use in most analyses to match the 2001 categories (see Appendix T5a for details).

[ii] Excluded variables asked in the census questionnaire but not included in this study are listed in the Appendix T5b.

[iii] GCSE is a qualification generally taken by students in secondary school aged 15-16. A-level is a further education qualification often taken when students are aged 17-18.

a widely used occupation-based classification of an individual's socio-economic position (large employers and higher managerial occupations (I.i), higher professional occupations (I.ii), lower managerial and professional occupations (II), Intermediate occupations (III), small employers and own account workers (IV), lower supervisory and technical occupations (V), semi-routine occupations (VI), with routine occupations (VII) in the reference category), house ownership ('rents from local authority', 'rents privately or lives rent free', with 'home owner or shared-owner or mortgage holder' in the reference category), distance to work (no fixed workplace, 5km-20km, >20km, with <5km, the most common category, in the reference category).

Geographic data: We capture area-level variation in the likelihood of cycling using the London borough of residence (n=32). In most analyses, dummy variables are used for each borough, with 'Westminster,' the most central borough, and 'City of London' (a neighbouring area not strictly a London borough) combined in the reference category. For some descriptive statistics, boroughs are grouped using a statutory definition of 'Inner London' (n=12 boroughs plus 'City of London') and 'Outer London' (n=20). We linked borough-level data on the following environmental characteristics identified in other studies as having some potential impact on the likelihood of cycling:[21 24 30 31]

- Time-invariant characteristics: *hilliness* measures the average percentage incline for all commuters in the borough, based on their individual home and work locations (ranging from 0.63% to 2.56%). Accessed from the UK Department for Transport's (DfT) propensity to cycle tool [30], a 1% increase in this measure is equivalent to a 1m increase in the vertical elevation per 100m of distance horizontally. We also used measures from the Office for National Statistic's Generalised Land Use Database[32] on the proportion of land used for *path* (ranging from 0.34% to 2.18%), *greenspace* (4.83% to 59.32%) and *water* (ranging from 0.11% to 22.23%).
- Time-varying characteristics: *crime rates* (since higher rates might deter cyclists[21 33]) - reported crimes per thousand of the population (Source: Metropolitan Police Service, [32] for years 2001/2 and 2010/11, ranging from 59.55 to 424.29)*; traffic volume* - million vehicle

kilometres travelled by all motor vehicles by borough (Source: Department for Transport, National Road Traffic Survey,[32] ranging from 7.99 to 48.17 per km^2) and *Public Transport Accessibility Level (PTAL)* – a measure of the accessibility to the public transport network, taking into account walk access time and service availability, using a score from 0 (very poor access) to 6b (excellent access) (ranging in London boroughs from 2.4 to 6.3 but available only in 2011). [34]

Cycle infrastructure expenditure: allocated annual expenditure at the borough-level[iv][35 36], gathered from Greater London's transport authority (Transport for London) on a yearly basis for the period 2001/02 to 2010/11. The data were adjusted to 2019 £GBP using HM Treasury's GDP deflator and converted to £ per general population (per capita), to enable comparisons with contemporary policy documents which tend to use this metric for illustrating future spending commitments,[1 2 37] and to £ per km^2 to capture the area-level density of new cycle infrastructure as a predictor of changes in the likelihood of cycling, independent of population density.

2.2 Analysis

2.2.1 Descriptive statistics

In this section, the socio-demographic characteristics of cyclists and their changes over time are described. The results are reported in Section 3.1.

Borough-level and time variations of cycling prevalence, and their relationship with cycle infrastructure expenditure and SES-related inequality, were reported graphically in scatterplots. Locally weighted scatterplot smoothing[38] and Spearman's rank-order correlation were used to assess

[iv] In this period, ring-fenced cycling infrastructure spending was allocated via 'Borough Spending Plans (BSP)' and 'Local Implementation Plans (LIP).'

the relationship between these variables at the area-level prior to more detailed investigation involving adjustment for area- and individual-level characteristics in the regression analyses.

To address the absence of evidence on individual-level SES-related inequality in cycling, two appropriate tools that are commonly used in a variety of other research settings were applied: the concentration index (CI) and concentration curve.

The area-specific (k) CI for each census year (t) is calculated as follows[v]:[39-41]

$$CI_{t,k} = \frac{2}{N\mu}\sum_{i=1}^{n} y_i r_i - 1 - \frac{1}{N}$$

where k is an individual London borough or macro-area (England, Inner London, Outer London). y_i is the binary commute mode variable (=1 if cyclist, =0 otherwise) for each individual (i = i….n) for n individuals in the dataset. μ is the mean value of y_i for all individuals. $r_i = i/N$ is the fractional rank of individual i in the distribution of eight NS-SEC categories where $i = 1$ is an individual in the lowest ranking NS-SEC category (VII) and $i = N$ is an individual in the highest ranking NS-SEC category (I.i).

Bounded between -1 and 1, a negative value of CI indicates a disproportionate concentration of cycling amongst commuters in lower SES categories, and a positive value indicates that cycling is more common amongst commuters in higher SES categories. A value of zero would indicate perfect equality in the likelihood of cycling across all SES categories. Tests of the null hypothesis of equality of the CI values were calculated between years for each London borough using a *z*-test that is valid for large samples.[42]

[v] Given the binary nature of our outcome variable (cycling), the CIs were normalised since the bounds of the possible values of the CI would otherwise be determined by the proportion cycle commuters (See Wagstaff 2005). This enabled unbiased comparisons of CIs between boroughs and years. We also addressed the possibility that the small number of SES groups (n=8) might lead to an underestimate of the CI by estimating CIs using the more granular detail that is only available in 2011 (n=35) as a sensitivity analysis (See Appendix T1b).

The concentration curves are plots of the cumulative share of cyclists against the cumulative share of the commuter population ordered from lowest to highest SES category. These were generated for the three macro-areas by census year and for selected population subgroups.

2.2.2 Regression

In this section, multivariate regressions were used to answer the two specific research questions stated in the Introduction. The results are reported in Section 3.2.

RQ1: *Explaining differences in the probability of cycling among boroughs and individuals (model 1)*

We first estimate the following logistic model separately for 2001 and 2011 to assess borough level differences in the probability of cycling:

Model 1A: $y_i^* = \beta_1 + \beta_2 \boldsymbol{B}_{\boldsymbol{k,i}} + \epsilon_i$

where $y = 1$ denotes the probability of observing cycling for individual i, y_i^* represents the latent individual's cycling propensity (where $y=1$ if $y_i^* \geq 0$ and 0 otherwise) in 2001 or 2011 modelled as a function of boroughs-specific effects, with $\boldsymbol{B}$ being a vector of K (k=1...31) borough dummy variables and a classical error term. The borough fixed-effect design accounts for (observable and unobservable) determinants of y that differ across boroughs but do not change over time.

In Model 1B we also include as covariate a vector ($\mathbf{X_{j,i}}$) capturing individual-level characteristics assumed to influence the probability of cycling. Model 1C is a variant of model 1B, including a further set of controlling characteristics, constructed at borough-level using the geographic data listed above in Section 2.1.

To address concerns stated in the Introduction about lower cycling prevalence amongst some population subgroups[21-24], we additionally ran separate analyses with an extended model (1D) that includes an interaction term $X_{g,i} \cdot \boldsymbol{B}_{\boldsymbol{k,i}}$ where g represents a population subgroup. These subgroups are selected based on existing literature (age, gender and lower SES - see 1.1 Introduction) and the estimated coefficients for individual-characteristics in model 1B.

Explaining changes in the probability of cycling among boroughs over time (model 2)

We then use logistic models to assess the presence of diverging time trends among boroughs using pooled data from 2001 and 2011, beginning with a simple model to assess changes over time:

Model 2A: $y_i^* = \gamma_1 + \gamma_2 T_i + \varepsilon_i$

where T_i is a binary variable representing census year (=1 if 2011 and =0 if 2001). The coefficient γ_2 captures the change in the log odds of cycling in 2011 when compared to 2001. As in model 1, we augmented Model 2A by controlling for individual-level characteristics (Model 2B), and also with a borough-level fixed effect $\boldsymbol{B_{k,i}}$ and a borough-level interaction term $T_i \,.\, \boldsymbol{B_{k,i}}$, without (2C) and with (2D) controlling individual-level characteristics.

RQ2: The association between borough-level infrastructure expenditure and changes in the likelihood of cycling is estimated using the following (linear-log) first differences model:

Model 3: $\Delta y \;\; = \beta_1 + \beta_2 \Delta \mathbf{X}_\mathbf{j} + \beta_3(S_i) \;\; + \epsilon_i$

where Δy is the borough-level change in the proportion of commuters who cycle between 2001 and 2011 and $\Delta \mathbf{X}_\mathbf{j}$ is the borough-level change in the individual-level characteristics captured by the dummy variable covariates listed in Section 2.1 above.[vi] Si measures the log of the total cycle infrastructure expenditure per km^2 at the borough-level between 2001 and 2011.

In this setting, a one percent increase in expenditure per km^2 is associated with an estimated $\beta_3/100$ unit increase in the proportion of commuters who cycle. We used our model to predict the possible effect on commuter cycling prevalence of higher levels of infrastructure expenditure and compared this with current Government targets for commuter cycling. These higher expenditure levels ranged from £7.00 (reflecting a longstanding Government ambition for England set in 2010[1] that, following recent commitments,[5] may be sustained in many English towns and cities during the period 2020-2025) to £15.00 (reflecting more ambitious levels that may soon be met or exceeded in certain places, e.g. Greater London, Greater Manchester[2] and the Republic of Ireland[6]) per capita per year.[vii]

To aid comparisons with alternative interventions to promote cycle commuting, our model was also used to calculate the (marginal) infrastructure cost per additional commuter cyclist (dependent on the area-level size of the commuter population size in the 2011 Census and infrastructure expenditure during the period) as follows:

$$\begin{matrix} Infrastructure\ cost \\ per\ additional\ cyclist \end{matrix} = \frac{Total\ area\ level\ spending\ (£)\ *\ 0.01}{Area\ level\ commuter\ population\ *\ (\beta_3\ /100)}$$

Model 3 was run for the whole sample. To address the possibility that infrastructure spending could help boost cycling amongst population groups where it is less common, we also ran the model separately for selected population subgroups so that the possible differential effect of expenditure

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[vi] Since a multicollinearity and over-specification problem occurs when all the individual-level dummy variable covariates are used in computing $\Delta \mathbf{X_j}$, in part because at the borough-level an increase/decrease (e.g. proportion aged>40) in one covariate necessarily leads to a decrease/increase in another covariate (e.g. proportion aged <40), we tested different model specifications reported in Appendix T4. Our preferred model includes groups of covariates identified in model 1B (Figure 4) as having a statistically significant association with the likelihood of cycling and provide the best goodness-of-fit statistics (including AIC and BIC).

[vii] The 2010 ambition for cycling expenditure was £6.00per capita per year, which is equivalent to £7.05 in 2019 after adjustment using the HM Treasury GDP deflator. Approximately the same expenditure level is now planned in England for the period 2020-2025 for both cycling *and* walking (£400m per year). This will not be distributed evenly across local authorities. Planned expenditure in the Republic of Ireland for cycling alone for the period 2020-2025 is €180m per year, which equates to more than £30 per capita per year.

could be assessed. These subgroups were selected based on existing literature (age, gender and lower SES - see 1.1 Introduction) and the estimated coefficients for individual-characteristics in model 1B.

All analyses were performed in Stata version 14.

3. Results

3.1 Descriptive statistics

Borough-level prevalence and trends in cycling

Prevalence of cycling, and growth in cycling, was always greater in Inner London boroughs (3.8% of commuters cycled in 2001, 7.4% in 2011, 97.1% growth) compared to Outer London (1.9% rising to 2.4%, 29.2% growth) and the national average (3.1% to 3.2%, 2.2% growth) (Figure 1 and 2, with additional detail in Appendix T1 and F1). Growth in cycling varied from 4% in Enfield (to 1.3% in 2011) to 160% in Tower Hamlets (to 6.8% in 2011), and cycling fell in only three boroughs (Barking, Harrow and Sutton, all in Outer London). Cycling was more common amongst men (e.g. 5.6% vs 2.7% female in 2011), white British (e.g. 5.8% vs. ethnic minorities 3.0%), people aged 30-39 (5.5% vs 1.7% aged 60-64) and people with shorter commutes (5.9% if <5km, vs 4.0% if <20km and 1.0% if >20km).

Infrastructure expenditure

Total cycle infrastructure expenditure during the ten-year period was £156,093,248, equivalent to £2.12 per capita per year. It was greater in Inner (£2.78 or £245,453 per km^2) than Outer London (£1.76 or £65,263 per km^2), varying between boroughs from £0.24 (Barnet, £8,890 per km^2) to £7.31 (Camden, £665,158/km^2). The relationship between borough-level cycle infrastructure expenditure was positive and ‘strong’ in relation to change in the proportion of commuters who cycle (Spearman’s rho=0.69) (Figure 2 and Appendix T1).

Socioeconomic inequalities in cycling

Across all boroughs combined, the concentration curve was above the equality line (i.e. cycling was concentrated amongst higher SES groups and the CI was positive) in both years (Figure 3), with the CI increasing between 2001 (CI=0.051) and 2011 (CI=0.172) (Figure 1 and Appendix T1). In Inner London, the concentration curve was above the equality line (and CI positive) in both years for the whole population and in the female and ethnic minority subgroups (selected on the basis of estimated coefficients in regression model 1B below), never crossing the line of equality, and shifting to the right (i.e. more pro-high SES inequality) between years (the CI for Inner London changed from 0.097 to 0.156) (Figure 3 and Appendix Figure 2). The shift was notably smaller amongst females than males. The Outer London concentration curve for the whole population also shifted over time to the right (the CI shifted from negative (-0.048) to positive (0.076) values).

For comparison with the national average, evidence of a pro-lower SES inequality was found in England as a whole: the CI was negative in both years, except in the case of the ethnic minorities subgroup, and the concentration curve was always to the left (more pro-lower SES) of both Inner and Outer London (Figures 1 and 3).

Turning to specific boroughs, eighteen (of 32, including 2/12 in Inner London and 16/20 in Outer London) had a negative (i.e. pro-lower SES inequality) CI in 2001 (56%), falling to eleven (of 32) in 2011 (34%). In twelve boroughs there were statistically significant changes in the index between years, of which eleven were in a positive direction (i.e. more pro-higher SES), including a change from a negative to a positive index in six boroughs. In just one borough (Bexley), there was a statistically significant change from positive to negative.

A positive relationship between the borough-level proportion of cycle commuters and the CI was indicated in a Spearman’s test to be ‘strong’ (rho=0.53) and increasing over time, both in terms of the smoothed curve (shifting to the left between years) and Spearman's coefficient (rho=0.34 in 2001 and 0.60 in 2011) (Figure 1).

3.2 Regression

RQ1:

For the sake of brevity, marginal effects (computed at covariates mean values) are reported in the text and in Figures 4 and 5 whereas estimated coefficients are in Appendix T2 and T3.

Explaining differences in the probability of cycling among boroughs

Model 1 confirmed large differences in the likelihood of cycling between boroughs, without (model 1A) and with controls for individual-level (model 1B) and area-level (model 1C) characteristics (Figure 4 and Appendix T2). The inclusion of individual-level SES and demographic characteristics improved the goodness-of-fit statistics (R^2, AIC and BIC) in both years.

After controlling for individual-level characteristics, a statistically significant positive borough-effect was observed in both years in eight (of 32) boroughs, and a statistically significant negative borough-effect was observed in both years in eight further boroughs (Model 1B) (Figure 4). A statistically significant increase in the magnitude of the borough-effect was observed between years in two boroughs where a positive borough-effect was estimated (e.g. in Hackney, where cycling was most prevalent in both years, the marginal effect increased from 1.5 percentage points to 3.3 points) and in fifteen boroughs where a negative borough-effect was estimated (e.g. in Havering, where cycling was least prevalent in both years, the marginal effect changed from -1.5 percentage points to -3.3 points). In five boroughs, the borough-effect changed from positive to negative between years, including two cases where there was a statistically significant change (in Kingston and Merton).

When comparing model 1A to 1B (Figure 4), the addition of individual-level characteristics reduced the magnitude of the borough-level effect in 61% of boroughs (19/31) in 2001 and 74% of boroughs (23/31) in 2011. For example, in 2011, the magnitude of the borough-level marginal effect on the probability of cycling fell by >2 percentage points in ten (Outer) London boroughs, after controlling individual-level characteristics (In Harrow, where the marginal effect fell the most, the borough-effect changed from -6 points to -3.3 points).

Explaining differences in the probability of cycling among individuals

The largest marginal effects on the probability of cycling (after controlling borough- and all other individual-level effects) were amongst people with the longest commutes (>20km: -2.7 percentage points in 2001 and -4.1 points in 2011) and those in seven (of eleven) ethnic minority groups (model 1B) (Figure 5 and Appendix T2). These seven groups were associated with a ≥1 point reduction in the probability of cycling in 2001 and a ≥2 reduction in 2011 when compared to White British. The largest effects were in 2011 amongst three 'Asian/Asian British' ethnic minority groups (e.g. Bangladeshi: -5.1).

Other characteristics associated with a statistically significant lower probability of cycling in both years were being female, aged <30 and >50, all other ethnic minority groups (with a single exception in 2001), SES categories I.i, I.ii, II, III or IV (compared to category VII, with one exception in 2011), commute distances >5km, less than 'Good' health, and full-time work. With the exception of the SES variables, the marginal effects typically increased in magnitude between years and in no instance was there a statistically significant reduction in their magnitude. For example, the marginal effect associated with being female changed from -1.4 percentage points in 2001 to -2.0 points in 2011.

Based on these results, commuters who were female, aged>50 or from ethnic minority groups were selected for subgroup analysis. Whilst the marginal effects for these subgroups varied between boroughs in terms of their magnitude, the direction of effect was not reversed in any borough (model

1D). Amongst women, for example, the largest marginal effect was in Enfield (-5.4 points), and the smallest was in Kensington and Chelsea (-0.04 points).

Using local geographic data to explain differences in the probability of cycling

The inclusion of specific geographic factors in Model 1C did not improve goodness-of-fit statistics significantly when compared to Model 1B (Appendix T2). Such covariates, computed at borough-level, are highly correlated with the fixed effects. As such, their inclusion had no significant impact on any of the coefficients for the individual-level characteristics but did alter the estimates associated with the borough-level effects. The specific factors that had a statistically significant association ($p<0.05$) with the likelihood of cycling were land slope, greenspace, footpath, reported crimes and public transport accessibility. However, none of these effects were statistically significant in both years (PTAL was available only in 2011) and, as these geographic-features vary only at the borough-level and sample sizes are not equal between boroughs, it is probable that the p-values (and standard errors) are underestimated.[43]

Explaining changes in the probability of cycling among boroughs over time

Model 2 confirmed large, statistically significant over-time increases in cycling in London overall (models 2A and 2B), and in 20 boroughs (models 2C and 2D) (Appendix T3). The addition of the individual-level SES and demographic characteristics (comparing model 2A to 2B, and 2C to 2D) and the borough-specific time trends (comparing 2A to 2C, and 2B to 2D) improved the model fit on all three measures (R^2, AIC and BIC). Inclusion of the individual-level characteristics decreased the estimated magnitude of the over-time change in the likelihood of cycling in London overall (from 1.74 percentage points in model 2A to 1.24 in 2B) and in 23 (of 32) boroughs (comparing model 2C to 2D). For example, in Tower Hamlets where growth in cycling was greatest, the effect reduced from 2.68 to 1.98 percentage points. Consistent with the descriptive statistics, a reduction in cycling was observed between years in three boroughs before controlling for individual-level characteristics (model 2C). However, after controlling for individual-level characteristics (model 2D), the reduction was either smaller in magnitude (in Harrow and Sutton) or indicated an over-time increase in cycling (Barking).

RQ2:

Model 3 (Table 1 and Appendix T4) showed the relationship between infrastructure expenditure and change in the borough-level prevalence of cycling was positive in models with and without controls for borough-level population changes, the latter improving model fit on all three measures (R^2, AIC and BIC) whilst reducing the overall magnitude of effect. The beta coefficient (β_3=0.0123 before controlling for population changes and β_3=0.00870 after) is an estimate of the effect of a one percent increase in expenditure (per km^2) on the proportion of commuters who cycle to work. Effect sizes were larger in the ethnic minority subgroup but smaller in female, older age (>50) and lower SES (V, VI and VII) subgroups. Our model predicts that if annual expenditure were increased from the observed £2.12 to £7.00 or £15.00 per capita over a ten-year period (£367,280 or £781,448 per km^2), then cycling in London would have increased by 2.89 or 3.54 percentage points, rather than the observed 1.74 points. The (marginal) cost per additional cyclist is £4,915 across all boroughs, £6,153 in Inner London, £4,174 in Outer London, and ranging between boroughs from £587 in Barnet to £17,577 in Camden (Appendix T6a).

Table 1: Model 3

VARIABLES	(1) Full sample	(2) Full sample	(3) Females only	(4) Ethnic minorities only	(5) Age >50 only	(6) NS-SEC V to VII only
Log £ invested in cycling per km^2	0.0123***	0.00870**	0.00796**	0.0104***	0.00677**	0.00537*
Covariates	NONE	YES	YES	YES	YES	YES
Borough-level observations	32	32	32	32	32	32
Individual-level observations[#]	333,740	333,740	156,346	151,472	66,274	110,588
AIC	-172.1	-182.8	-185.9	-188.5	-186.8	-187.7
BIC	-169.0	-174.0	-178.6	-181.2	-180.9	-178.9
R^2	0.371	0.651	0.525	0.458	0.247	0.352
Adjusted R^2	0.350	0.584	0.455	0.377	0.167	0.228

Notes:

- Included covariates (excluding column 1): population changes at the borough-level in terms of gender, age group and ethnicity.
- In the sub-group analyses, gender changes were excluded from the analysis in column 3, ethnicity changes were excluded from column 4 and age changes were excluded from column 5.
- Statistical significance: *** p<0.001, ** p<0.01, * p<0.05.
- Individual-level observations refers to the number of individuals used to calculate the change in borough-level means that were used as covariates.

4. Discussion

4.1 What this study adds

This study exploits substantial heterogeneity in the likelihood of cycling amongst London commuters, and is the first to use individual-level census data to examine the role of individual- and area-level characteristics in explaining this variation. It demonstrates the importance of controlling for differences and changes in population structure when evaluating policy changes and assessing area-level differences and time trends in cycling prevalence. After controlling for individual- and area-level characteristics, we showed that women and ethnic minorities were less likely to cycle. In contrast with England, cycling in London became increasingly concentrated over time among higher socioeconomic groups. The study is also the first study to include an economic evaluation of cycle infrastructure expenditure and found that increased expenditure was associated with more cycling at a rate of £4,915 per additional commuter cyclist.

4.1.1 RQ1

The estimates of the borough-effects and time trends were significantly influenced by the decision of adjusting or not for differences in individual-level characteristics. Inclusion of the individual-level characteristics generally reduced the magnitude of the borough-effects, indicating that large borough-level differences in cycling can be partially explained by differences in the characteristics of commuters who live there, including by age group, gender, ethnicity and work-related factors. This finding could influence policy-makers' views about which areas have the greatest potential for more cycling and hence decisions about where to invest scarce resources in promoting cycling. If certain areas have low cycling prevalence in unadjusted analyses, but these are due to predominantly non-modifiable factors including different population structures or different topography, then it might be better to focus investment in those areas where cycling prevalence is lowest after those factors have been controlled for.

This study also reinforces the challenge policy-makers face since, even after controlling for the various observable characteristics, much between-borough variation in cycling remained unexplained. Without a better guide to the causes of that variation, it remains unknown how feasible it is to deliver stated ambitions for substantially more cycling in areas where cycling is rare.[30 44 45] For example, the Government has previously set ambitious and laudable targets to increase cycling in England, including doubling the number of "cycle trips" between 2015 and 2025.[46] The DfT's propensity to cycle tool aids their delivery by estimating the commuter cycling prevalence that would be required in specific towns and cities to meet specified national targets, after accounting for local factors (e.g. differences in hilliness, typical commute distances and baseline commuter cycling prevalence).[30] For London, the tool suggests in a 'Government target' scenario that commuter cycling prevalence could increase from 4.3% in 2011 to 7.9%, or to 22% in a 'Go Dutch' scenario (which adjusts commuter cycling prevalence observed in the Netherlands for differences in topography and commute distances observed in England). But no accompanying advice is provided about the resources or time period needed for these expectations to be achieved.

Our finding that women were less likely to cycle is consistent with other existing studies of the whole country using aggregate-level UK Census data.[21 23 24] Nevertheless it is striking that our study found this relationship held across all 32 London boroughs, even after controlling for borough-level fixed effects and multiple other individual-level characteristics. Our analyses based on (univariate) concentration indices showed that, over time, as cycling increased, it become more concentrated amongst higher SES groups (although the concentration curves by population subgroup indicated that this shift was predominantly amongst White British people and men). Yet, our (multivariate) regression analyses showed that the effect of SES on the likelihood of cycling was smaller than other factors. In particular, inequalities in the likelihood of cycling were greatest between any of the ethnic minority groups and the White British population (even after controlling for borough-level fixed effects and other individual-level SES and demographic characteristics) and were increasing over time. The effect of these rising inequalities in cycling on inequalities in health and accessibility (i.e. being able to reach places easily) in cities warrants further study, however we are unaware of other studies from the UK or other low-cycling countries that have used individual-level data to examine the role of SES or ethnicity in explaining propensity to cycle, and only a small number from high-cycling countries (e.g. the Netherlands [47 48]).

The observable area-level characteristics that we found to be associated with cycling, including topography, greenspace, footpaths and crime, were consistent with previous studies of the whole country using aggregate-level UK Census data.[21 24] However, the causal effect of these characteristics on cycling (or physical activity more generally) has rarely been examined,[49] not least because of very limited opportunities to observe temporal changes. Other factors included in those previous studies found to be significantly associated with cycling were the physical condition of the highway, rainfall, temperature and traffic volumes. In our study, we did not find traffic volume to have a statistically significant effect, but this could have been due to little variation between London boroughs compared to the variation observed with the entire country. For this reason, we did not include the weather-related factors in our models.

4.1.2 RQ2

Our study suggests that cycle infrastructure expenditure affects commuter cycling prevalence. Our (non-linear) first-differences regression model was used to predict cycling prevalence in London if annual infrastructure expenditure had been sustained during the period 2001-2011 at £7.00 or £15.00 per capita per year (rather than £2.12). These higher expenditure levels would have been associated with an increase in commuter cycling prevalence from 2.52% in 2001 to 5.4% or 6.2% (rather than 4.27%) after accounting for the changes in population structure that occurred during the period. Thus our study indicates, for the first time, that these higher expenditure levels could have enabled substantial progress towards current Government targets in London (7.9% [30]).Our model also estimates a mean infrastructure cost per additional cyclist of £4,915 (after controlling for changes in population structure). This varied in our model between boroughs due to the non-linear relationship between additional spending and increased cycling prevalence. An absence of other studies estimating the cost-effectiveness of policies to promote cycling (on any cycling-related outcome) makes it difficult to judge how such investment would fare compared to alternative investments.

The only other controlled study that supports a comparison of the costs and effects of such investment is a study of Cycle Demonstration Towns (CDTs),[19] a Government programme that included unprecedented cycle infrastructure investment in 18 selected English towns or cities. Using aggregate-level UK Census data on cycle mode share, the 18 CDTs (where average annual infrastructure expenditure was £5.63 per capita over a ten-year period) were combined into a single (intervention) group and compared with a combined group of selected control towns (where average expenditure was £0.87) (£2019, Appendix T6b). Whilst our study compared 32 different expenditure levels that arose between boroughs, rather than just two groups of English towns, the range of expenditure examined in the CDT study was comparable to our study (averaging £0.24 in Barnet to £7.31 in Camden over the same ten-year period, see Appendix T1a). The study showed that commuter cycling increased on average by 0.69 percentage points,[19] enabling us to calculate a mean infrastructure cost per additional cyclist across all CDTs of £1596 (£2019) (Appendix T6b). This is within the range of our own estimates among lower spending boroughs (Barnet, Enfield, Kensington & Chelsea and Wandsworth, Appendix T6a) but, for London as a whole, our estimates were more than twice as high prior to adjustment for population changes (£3,475) (or three times higher after adjustment for population changes, but the CDT study did not make those adjustments). This is partially explained by our non-linear model specification that accounts for diminishing marginal returns in cycling infrastructure. If the Government's planned expenditure on walking and cycling in England during the period 2020-2025 (£400m per annum)[5] were as cost-effective, and were sustained for ten years, it could be associated with a 0.51 (using the cost-effectiveness estimate in our study without adjustment for population changes observed in London) to 1.10 (using the cost-effectiveness estimate in the CDT study) percentage point increase in cycling prevalence, equivalent to an additional 115,000 to 250,000 commuter cyclists (i.e. an increase to 3.71% or 4.31% when compared to 3.21% recorded in the 2011 census).

A small number of other longitudinal studies have also examined the impact of new cycle infrastructure (on any cycling-related outcome), but unlike our study were not economic evaluations because they didn't include a comparison with costs.[3 15-18 50 51] These studies typically evaluate a specific local infrastructure project and collected their own data (e.g. questionnaires) rather than use (larger) secondary datasets. For example, one before-and-after study showed a new bridge was associated with a substantial 47.5% increase in the number of cyclists entering Glasgow city centre (and apparently no reduction in cyclists using any of the other bridges).[52] Other studies of the Cambridgeshire Guided Busway [20] and infrastructure projects in three English towns (the iConnect study)[53] found a much smaller effect, or no identifiable effect, depending on which measure of exposure and impact was used.[viii] A limitation of those studies was high rates of attrition (a systematic review of cycle commuting interventions concluded that "almost all studies had substantial loss to follow-up"[51]). Similarly, cross-sectional studies of the impact of cycle infrastructure have shown mixed results,[54] including studies using aggregate-level UK Census data.[21 24 45]

In addition to highlighting the shortage of cycle infrastructure studies, a systematic review that included a broader range of interventions to increase commuter cycling only identified three further studies (two observational and one RCT).[51] These were small scale projects such as cycle training in community or workplace settings. Other reviews have identified studies that evaluated policies (e.g. financial incentives, congestion charging for vehicles,[55] and marketing [18]) in terms of promoting cycling more generally (not just amongst commuters) but none of these have included an economic evaluation.

Our study suggests that there appear to be geographical differences in how cycle infrastructure expenditure impacts on commuter cycling prevalence, but also that such impact varies between population groups; in particular ethnic minorities may be more responsive, and female, older and lower-SES commuters may be less so. This may require different, perhaps more targeted, age- or

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[viii] For example, no statistically significant associations were found between exposure to the Cambridgeshire Guided Busway and changes in travel mode or overall physical activity, but there was an association with overall time spent in active commuting among the least active commuters at baseline.

gender-sensitive interventions, for example. Whilst few studies have explored the impact of infrastructure investment on different population groups,[56] some have argued a lack of cycling infrastructure may be more likely to deter female than male cyclists [24] and that certain types of infrastructure may be more conducive to women's cycling than men's cycling (e.g. a stated preference study concluded that traffic segregation was important for encouraging more women to cycle).[57] In England, decision-makers are advised to consider how interventions that promote active travel might increase health inequalities (because participation may be greater amongst higher-SES groups) [10 58] and that "creating a mass cycling culture may require deliberately targeting infrastructure and policies towards currently under-represented groups."[22] Thus future studies should explicitly incorporate equity impact assessment and potentially measure their impact against stated equity objectives.[11]

4.2 Strengths and limitations

Our study included individual-level data on 11,119 cyclists, which is considerably larger than any other study of cycling in the UK or internationally and assessed both individual-level and geographic determinants of cycle commuting. To our knowledge, though dating from 2001 and 2011, the census data we used remains the best available data for addressing our research questions. However, more recent changes in some of the underlying determinants of travel and work behaviours may limit the transferability of our findings to the current situation, not least following the unprecedented changes in commuting during the Covid-19 pandemic.

A potential limitation of our outcome measure (the proportion of commuters whose main mode is cycling) is that it perhaps overlooks more subtle details about cycling behaviours, including amongst commuters whose main mode is cycling (e.g. cycling frequency is unknown) and whose main mode is public transport[59] (e.g. frequency of cycling to/from railway stations or bus stops is unknown)). It also remains unknown how our findings would differ for non-commute journeys, for example in terms of the role of changes in population structure. Nevertheless, our outcome measure is the same as that used in Government cycling targets and the DfT's propensity to cycle tool. Furthermore, another study reported that commuter cycling prevalence was a reasonably good proxy for the proportion of total time spent cycling.[23ix] We also couldn't assess overall physical activity or health (however another study identified no compensatory reductions in recreational physical activity when active travel increased[20]) and didn't address the possibility that cycling infrastructure may additionally encourage more walking and running.

Our study included environmental and policy determinants of cycling and is the first to include an economic evaluation of cycle infrastructure expenditure. One limitation of these analyses was that we couldn't assess the modifiable areal unit problem (i.e. the possibility that results are affected by where area boundaries are drawn).[60] Neither could we assess variation in the quality or type of infrastructure that was built and, although the longitudinal study design partially accounts for temporality, the expenditure was not allocated at random and so we cannot infer a causal effect. Whilst the study investigated the potential effects of infrastructure on people's commute mode choices, it did not consider any potential impact on decisions about whether to commute (versus home working) or whether to work. We used our model to predict the relationship between increased infrastructure expenditure and cycling prevalence over a range of £7.00 to £15.00 annually per capita (or £367,280 to £781,448 per km^2). The cycling prevalence estimates in the upper range may be considered conservative due to our non-linear model and should be treated with some caution where expenditure exceeds the levels observed in our study (£665,158 in Camden).

Our study exploited heterogeneity in the likelihood of cycle commuting and in the levels of cycling infrastructure expenditure. Future research could similarly exploit substantial variation in expenditure between English towns and cities that will arise due to the competitive bidding process through which forthcoming cycling expenditure will be allocated, and examine those areas of the UK and Republic of Ireland where it is expected to substantially exceed the levels observed in our study.[5 6] . Whilst we examined heterogeneity in cost-effectiveness by individual-level characteristics (e.g. gender), an

[ix] That study found correlation between the two measures of rho = 0.77 across populations defined by years of data collection, by region of England and Wales, and by fifth of household income. In general, the same was also true for walking (rho = 0.88 excluding London, where the relationship was weaker due to atypically high public transport use).

interesting aspect would be to identify whether pre-existing geographic features, such as local availability of greenspace, parkland or public transport services,[5 59] might enable or facilitate increased cost-effectiveness in particular geographic areas. The rapid deployment of pop-up cycling infrastructure during the Covid-19 pandemic, which typically includes reallocating road space from cars to bikes to address public transport capacity constraints, ought also be investigated as a potentially lower cost way of promoting cycle commuting.[7] Finally, more research is needed on the cost-effectiveness levels that constitute good and equitable value for money. This could include a conversion of what the estimated changes in cycling might mean for longer-term, overall health outcomes (e.g. in terms of quality-adjusted life years), and answering the (difficult) question of what the relevant cost-effectiveness threshold should be.[61 62]

Acknowledgments

We wish to thank our colleagues at XXX [redacted for blinded peer review] and the XXX at the XXX, as well as participants at the XXX meeting held at XXX in XXX, for their helpful comments on earlier versions of this work. We also wish to thank officials at Transport for London (TfL) who provided the cycling infrastructure expenditure data and discussed it with us. Responsibility for any errors in this paper remains our own.

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ONLINE APPENDIX

Figures:

1 Proportion of commuters who cycle to work in 2001 and 2011 and expenditure on cycling infrastructure 2001-2010

2 Concentration curves by:
   a. Gender
   b. Ethnicity
   c. Age group

Tables:

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2- Full regression model output for models 1
   a. Model 1 A,B,C
   b. Model 1B sensitivity analyses
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      ii. Inclusion of all categories where more granular detail is available in 2011 (e.g. 35 NS-SEC categories)
      iii. Remove people aged >65
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3- Full regression model output for model 2

4- Full regression model output for model 3, including use of alternative covariates in the regression model

5- Variable information:
   a. Recoding 2011 census data categories to match 2001 census data variables
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6- Economic evaluation/Cost-effectiveness calculations (infrastructure cost per additional cyclist)
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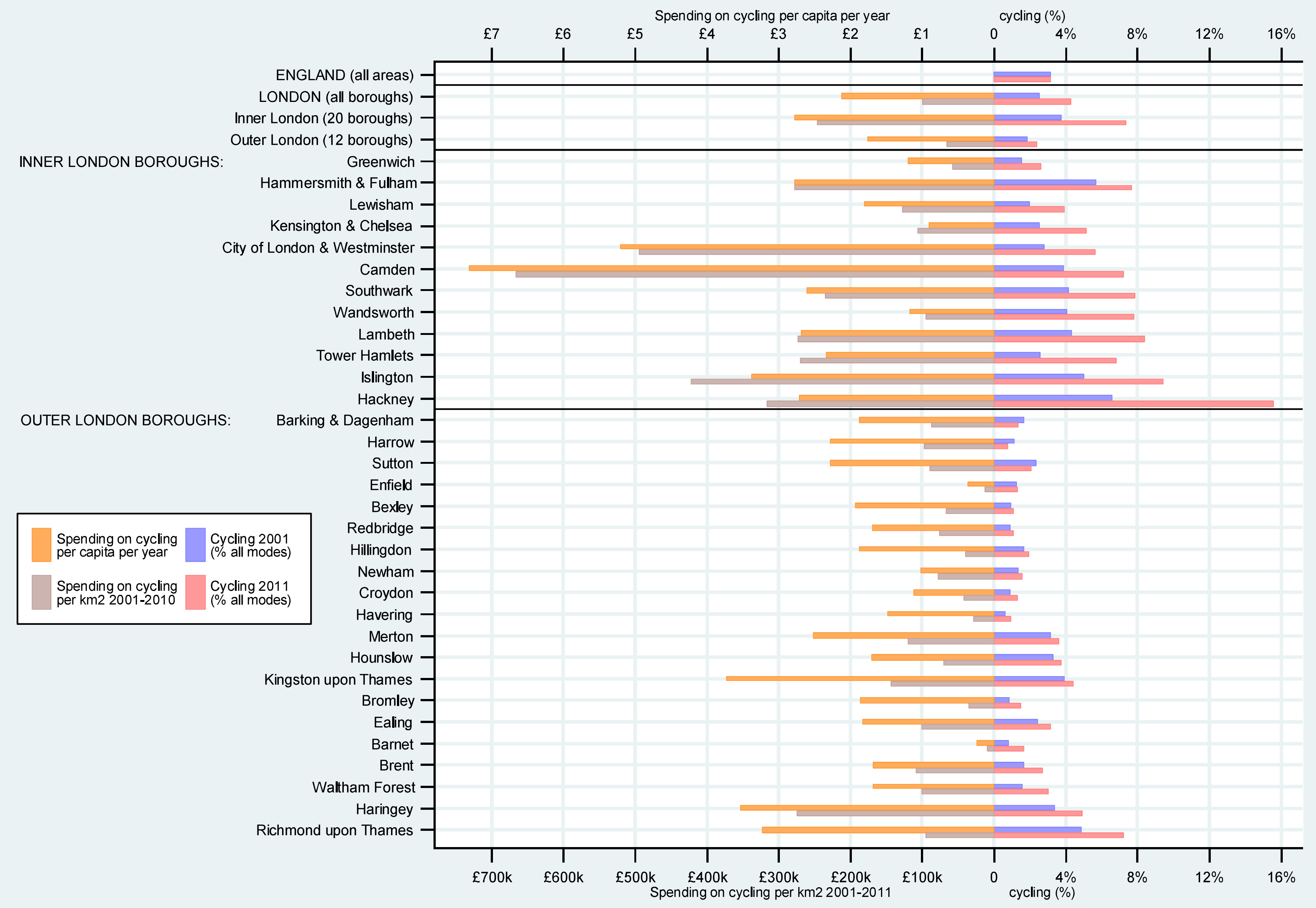
   b. Data on Cycle Demonstration Towns from the study by Goodman et al. (2013) [19]

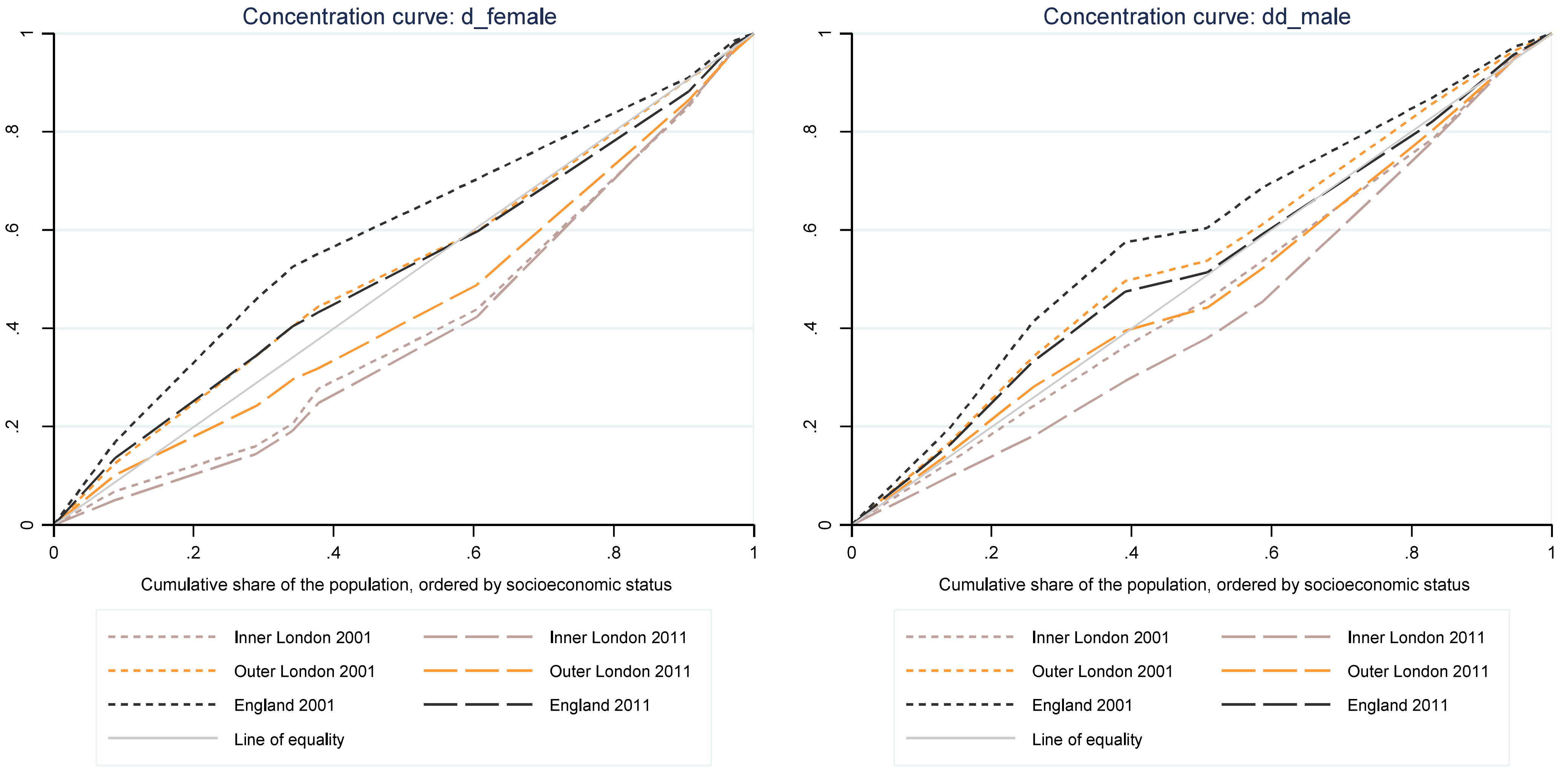
Appendix Figure 1: Proportion of commuters who cycle to work in 2001 and 2011 and expenditure on cycling infrastructure 2001-2010



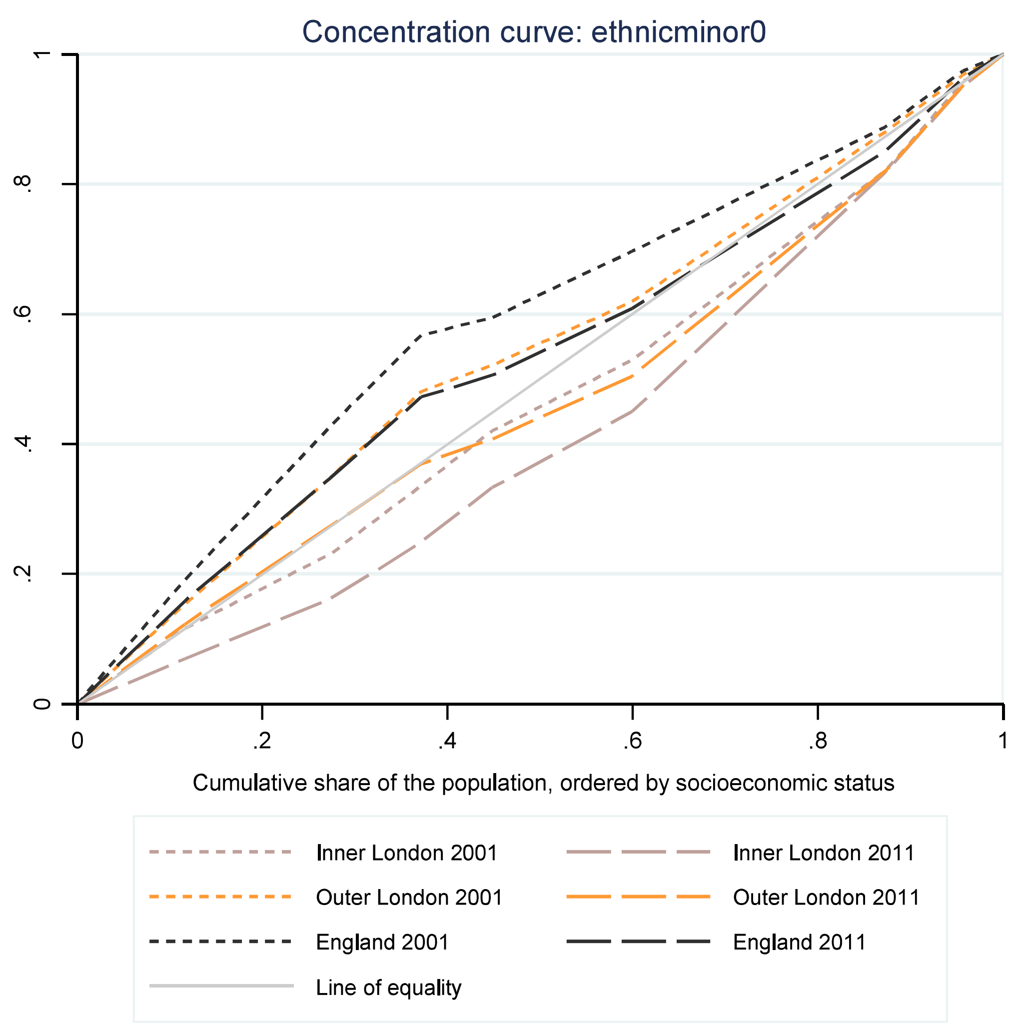
Note: Boroughs are ordered by the change in the proportion of commuters who cycle to work 2001-2011.

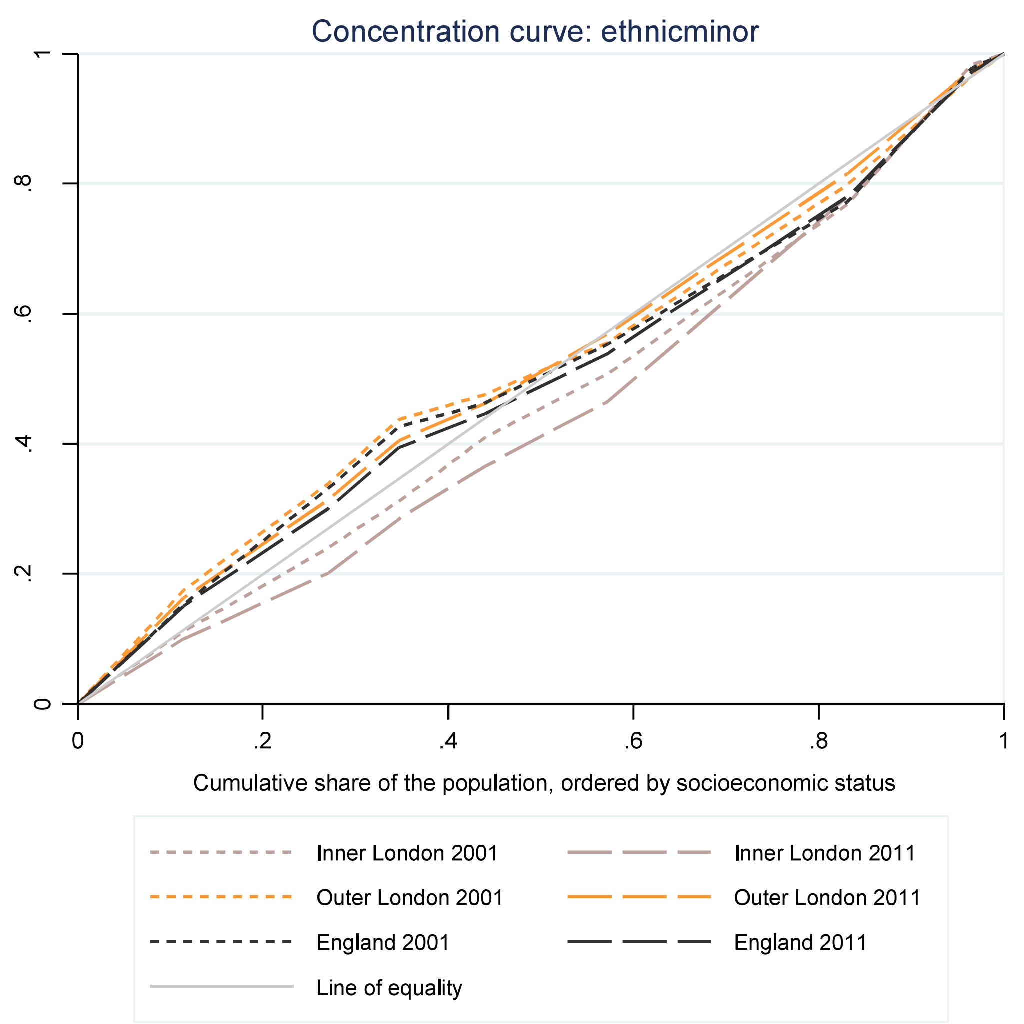
Appendix Figure 2: Concentration curves by (a) gender, (b) ethnicity, (c) age

(a) Gender:

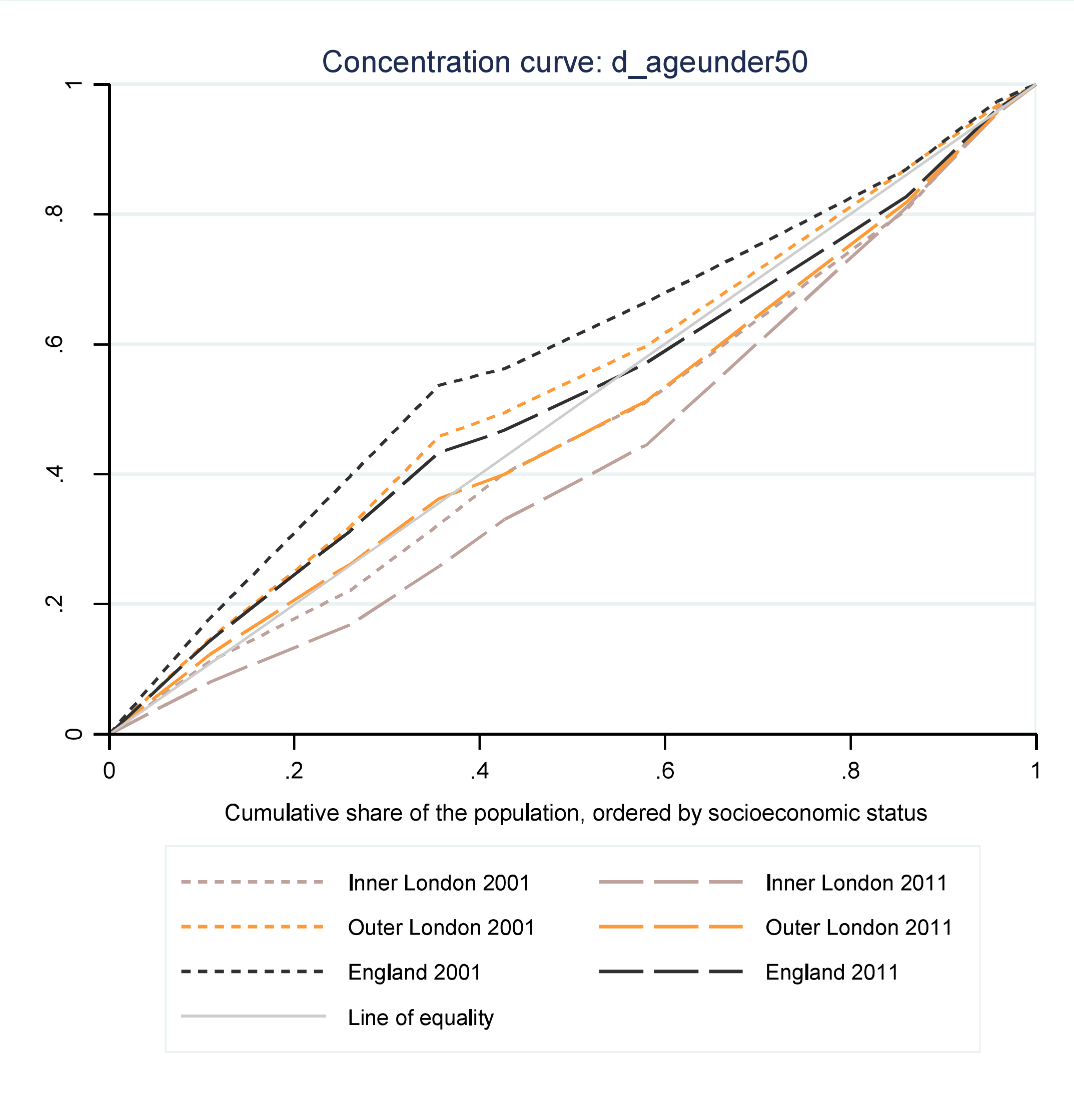


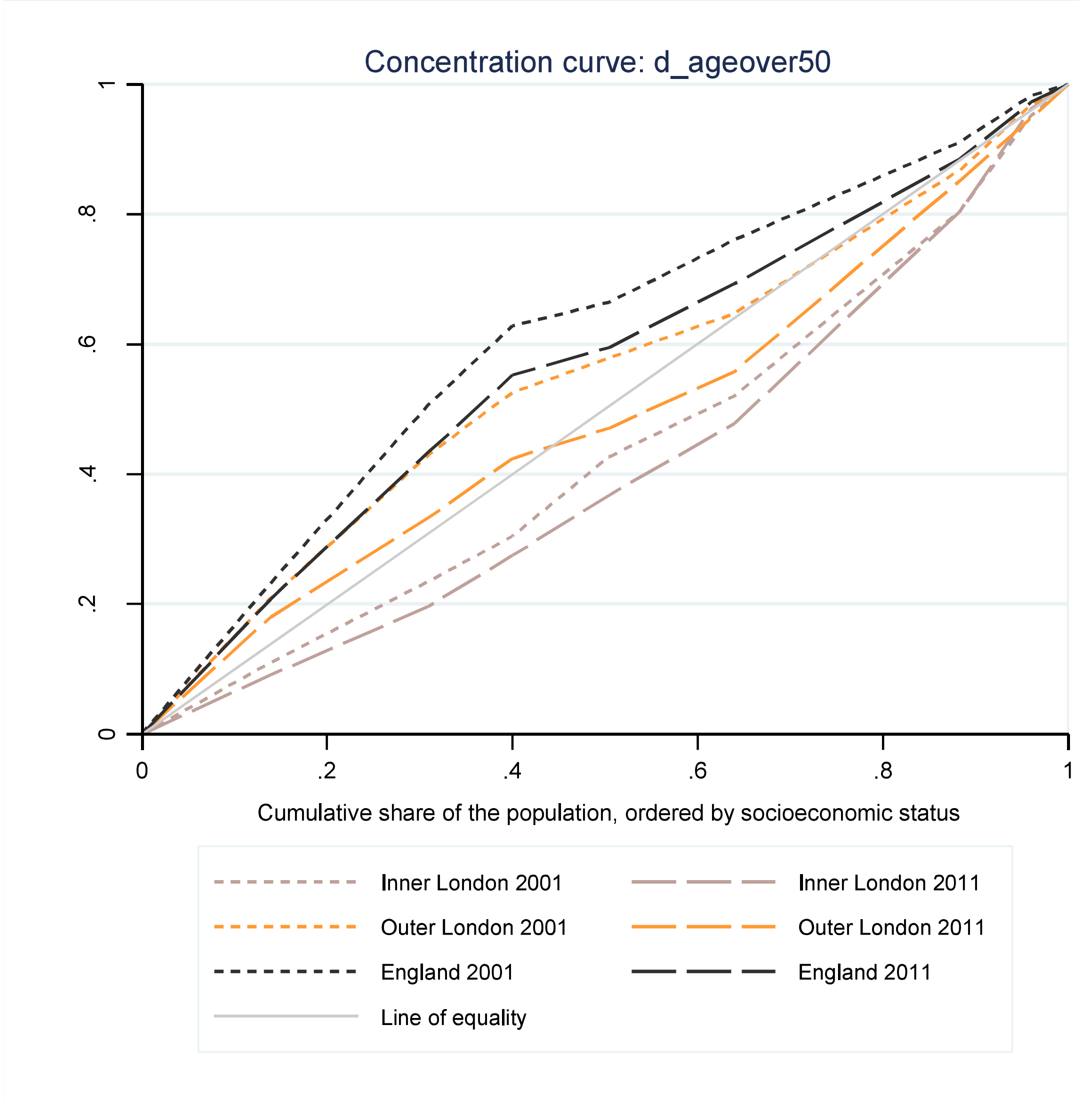
(b) **ethnicity**


Concentration curve: ethnicminor0
0
.2
.4
.6
.8
1
Cumulative share of the population, ordered by socioeconomic status
Inner London 2001
Inner London 2011
Outer London 2001
Outer London 2011
England 2001
England 2011
Line of equality


Concentration curve: ethnicminor
0
.2
.4
.6
.8
1
Cumulative share of the population, ordered by socioeconomic status
Inner London 2001
Inner London 2011
Outer London 2001
Outer London 2011
England 2001
England 2011
Line of equality

(c) **age**


Concentration curve: d_ageunder50
0
.2
.4
.6
.8
1
Cumulative share of the population, ordered by socioeconomic status
Inner London 2001
Inner London 2011
Outer London 2001
Outer London 2011
England 2001
England 2011
Line of equality


Concentration curve: d_ageover50
0
.2
.4
.6
.8
1
Cumulative share of the population, ordered by socioeconomic status
Inner London 2001
Inner London 2011
Outer London 2001
Outer London 2011
England 2001
England 2011
Line of equality

Appendix Table 1a: Descriptive statistics

	Cycling (proportion of commuters)				Concentration index				Cycling investment 2001-2011			
	2011	2001	change	%change	2011	2001	change	p-value	Total	Total	per km2	Annually
By area									£ nominal	£ real	£	per captia
All of England	3.21	3.14	0.06	2%	-0.040	-0.181	0.142	0.00				
Rest of England	3.00	3.25	-0.25	-8%	-0.109	-0.209	0.101	0.00				
All of London	4.27	2.52	1.74	69%	0.172	0.051	0.121	0.00	£125,830,000	£156,093,248	£ 99,470	£ 2.12
Inner London	7.41	3.76	3.65	97%	0.156	0.097	0.059	0.00	£ 58,920,000	£ 73,121,520	£ 245,453	£ 2.78
Greenwich	2.65	1.58	1.07	68%	0.204	0.036	0.168	0.05	£ 2,195,000	£ 2,737,928	£ 57,843	£ 1.20
Lewisham	3.98	2.04	1.94	95%	0.156	0.123	0.033	0.62	£ 3,606,000	£ 4,482,284	£ 127,521	£ 1.81
Kensington and Chelsea	5.19	2.54	2.65	105%	-0.011	-0.040	0.029	0.71	£ 1,049,000	£ 1,281,899	£ 105,732	£ 0.90
City of London and Westminster	5.68	2.85	2.83	99%	0.078	-0.125	0.203	0.00	£ 8,628,000	£ 10,617,262	£ 494,125	£ 5.20
Tower Hamlets	6.84	2.63	4.21	160%	0.111	0.157	-0.046	0.50	£ 4,309,000	£ 5,343,529	£ 270,131	£ 2.34
Camden	7.22	3.91	3.31	85%	0.101	0.132	-0.030	0.59	£ 11,535,000	£ 14,493,325	£ 665,158	£ 7.31
Hammersmith and Fulham	7.65	5.72	1.93	34%	0.112	0.042	0.070	0.17	£ 3,685,000	£ 4,557,374	£ 277,932	£ 2.77
Wandsworth	7.80	4.06	3.74	92%	0.144	0.007	0.137	0.00	£ 2,613,000	£ 3,236,118	£ 94,446	£ 1.17
Southwark	7.84	4.16	3.68	88%	0.189	0.155	0.034	0.48	£ 5,508,000	£ 6,777,843	£ 234,836	£ 2.61
Lambeth	8.38	4.31	4.07	94%	0.177	0.140	0.037	0.39	£ 5,864,000	£ 7,316,295	£ 272,894	£ 2.68
Islington	9.43	5.06	4.38	87%	0.210	0.194	0.016	0.75	£ 5,034,000	£ 6,262,232	£ 421,510	£ 3.38
Hackney	15.61	6.61	9.00	136%	0.229	0.132	0.096	0.03	£ 4,894,000	£ 6,015,434	£ 315,787	£ 2.71
Outer London	2.39	1.85	0.53	29%	0.076	-0.048	0.124	0.00	£ 66,910,000	£ 82,971,728	£ 65,263	£ 1.76
Harrow	0.81	1.11	-0.30	-27%	-0.084	-0.105	0.022	0.86	£ 3,954,000	£ 4,892,978	£ 96,962	£ 2.27
Havering	0.98	0.64	0.34	53%	-0.137	-0.024	-0.113	0.39	£ 2,566,000	£ 3,167,153	£ 28,190	£ 1.48
Redbridge	1.06	0.96	0.11	11%	0.107	-0.193	0.301	0.01	£ 3,422,000	£ 4,265,116	£ 75,597	£ 1.70
Bexley	1.08	1.01	0.07	7%	-0.184	0.069	-0.253	0.03	£ 3,228,000	£ 4,019,985	£ 66,358	£ 1.93
Croydon	1.30	0.96	0.34	35%	-0.005	-0.198	0.194	0.03	£ 2,919,000	£ 3,654,857	£ 42,251	£ 1.12
Enfield	1.32	1.27	0.05	4%	-0.109	0.035	-0.144	0.12	£ 812,000	£ 1,007,119	£ 12,459	£ 0.36
Barking and Dagenham	1.36	1.67	-0.31	-19%	-0.241	-0.095	-0.145	0.21	£ 2,569,000	£ 3,144,232	£ 87,079	£ 1.88
Bromley	1.52	0.91	0.62	68%	-0.123	-0.020	-0.103	0.27	£ 4,158,000	£ 5,196,200	£ 34,610	£ 1.87
Newham	1.61	1.33	0.28	21%	0.163	-0.024	0.187	0.06	£ 2,250,000	£ 2,820,733	£ 77,924	£ 1.02
Barnet	1.68	0.87	0.81	94%	0.167	-0.053	0.219	0.02	£ 635,000	£ 771,201	£ 8,890	£ 0.24
Hillingdon	1.95	1.67	0.28	17%	-0.134	-0.145	0.010	0.90	£ 3,703,000	£ 4,627,661	£ 39,997	£ 1.88
Sutton	2.11	2.34	-0.23	-10%	-0.085	-0.153	0.068	0.42	£ 3,123,000	£ 3,905,208	£ 89,064	£ 2.28
Brent	2.75	1.69	1.07	63%	0.173	0.049	0.124	0.09	£ 3,816,000	£ 4,698,151	£ 108,671	£ 1.68
Waltham Forest	3.02	1.64	1.39	85%	0.092	-0.091	0.182	0.02	£ 3,136,000	£ 3,910,378	£ 100,762	£ 1.68
Ealing	3.19	2.44	0.75	31%	0.181	0.003	0.179	0.00	£ 4,472,000	£ 5,567,931	£ 100,243	£ 1.83
Merton	3.59	3.21	0.38	12%	0.038	-0.115	0.153	0.02	£ 3,696,000	£ 4,523,132	£ 120,217	£ 2.52
Hounslow	3.75	3.35	0.40	12%	-0.061	-0.180	0.119	0.05	£ 3,183,000	£ 3,905,648	£ 69,771	£ 1.71
Kingston upon Thames	4.45	3.95	0.50	13%	0.029	-0.113	0.142	0.04	£ 4,302,000	£ 5,356,735	£ 143,762	£ 3.72
Haringey	4.91	3.44	1.46	43%	0.229	0.158	0.070	0.23	£ 6,526,000	£ 8,104,656	£ 273,821	£ 3.53
Richmond upon Thames	7.23	4.87	2.36	49%	0.050	-0.239	0.288	0.00	£ 4,440,000	£ 5,432,658	£ 94,634	£ 3.23
By population group												
Male	5.60	3.42	2.18	64%								
Female	2.74	1.51	1.22	81%								
AGE: 16 - 24	2.85	1.93	0.92	48%								
25 - 29	4.91	2.82	2.08	74%								
30 - 39	5.54	3.07	2.48	81%								
40 - 49	4.35	2.45	1.90	78%								
50 - 59	3.08	2.00	1.08	54%								
60 - 64	1.73	1.75	-0.01	-1%								
65+	1.73	1.58	0.16	10%								
ETHNICITY: White British	5.76	3.09	2.67	87%								
White Irish	5.54	2.72	2.81	103%								
Other White	5.05	2.71	2.34	86%								
Mixed White Black	3.28	1.87	1.41	76%								
Mixed White & Asian/Other Mixed	4.59	2.90	1.69	58%								
Asian/Asian British: Indian	0.84	0.34	0.51	151%								
Asian/Asian British: Pakistani	0.90	0.54	0.36	66%								
Asian/Asian British: Bangladeshi	0.85	0.73	0.13	17%								
Asian/Asian British: Other Asian	1.61	0.92	0.70	76%								
Black/Black British: Caribbean/Other	2.06	1.12	0.94	84%								
Black/Black British: African	1.37	0.46	0.91	197%								
Chinese and other ethnic groups	2.87	1.14	1.73	152%								
PLACE OF WORK: No fixed place	2.75	1.65	1.10	66%								
Less than 5km	5.93	3.95	1.99	50%								
Less than 20km	4.02	1.83	2.19	119%								
More than 20km	1.00	0.65	0.35	54%								

Notes:
-The p-value refers to a z-test of the null hypothesis of equality in the concentration index values between years ($p<0.005$ may be interpreted as a statistically significant change between 2001 and 2011).
-Annual cycling investment per capita was calculated using the total borough-level population in the 2011 census.

Appendix Table 1b: Concentration index using all 35 NS-SEC categories in 2011

Area	CI 2001	CI 2011	Difference	p-value
Inner London	0.097	0.158	0.062	0.000
Outer London	-0.048	0.073	0.121	0.000
All of London	0.051	0.173	0.123	0.000
Rest of England	-0.209	-0.117	0.093	0.000
All of England	-0.181	-0.045	0.136	0.000
City of London and Westminster	-0.125	0.088	0.213	0.001
Camden	0.132	0.098	-0.034	0.546
Greenwich	0.036	0.198	0.162	0.058
Hackney	0.132	0.219	0.086	0.049
Hammersmith and Fulham	0.042	0.110	0.067	0.186
Islington	0.194	0.220	0.026	0.619
Kensington and Chelsea	-0.040	-0.015	0.025	0.745
Lambeth	0.140	0.187	0.046	0.285
Lewisham	0.123	0.163	0.041	0.548
Southwark	0.155	0.189	0.034	0.484
Tower Hamlets	0.157	0.114	-0.043	0.533
Wandsworth	0.007	0.146	0.138	0.001
Barking and Dagenham	-0.095	-0.275	-0.180	0.121
Barnet	-0.053	0.161	0.213	0.021
Bexley	0.069	-0.214	-0.284	0.014
Brent	0.049	0.168	0.119	0.111
Bromley	-0.020	-0.133	-0.113	0.232
Croydon	-0.198	-0.015	0.183	0.041
Ealing	0.003	0.172	0.170	0.005
Enfield	0.035	-0.113	-0.148	0.115
Haringey	0.158	0.232	0.073	0.217
Harrow	-0.105	-0.088	0.017	0.887
Havering	-0.024	-0.147	-0.123	0.349
Hillingdon	-0.145	-0.144	0.001	0.992
Hounslow	-0.180	-0.064	0.116	0.058
Kingston upon Thames	-0.113	0.034	0.147	0.033
Merton	-0.115	0.034	0.150	0.027
Newham	-0.024	0.150	0.174	0.082
Redbridge	-0.193	0.105	0.298	0.009
Richmond upon Thames	-0.239	0.063	0.301	0.000
Sutton	-0.153	-0.097	0.056	0.510
Waltham Forest	-0.091	0.091	0.182	0.025

Note: The p-value refers to a z-test of the null hypothesis of equality in the concentration index values between years ($p<0.005$ may be interpreted as a statistically significant change between 2001 and 2011).

Appendix Table 2A: Model 1 (2001 and 2011 separately)

VARIABLES	2001: Model 1A	2001: Model 1B	2001: Model 1C	2011: Model 1A	2011: Model 1B	2011: Model 1C	2011: Model 1C +PTAL
Boroughs: Barking and Dagenham	0.570***	0.803	0.520*	0.240***	0.423***	0.233**	0.893
Barnet	0.288***	0.436***	0.850	0.284***	0.396***	9.07e-05	1.279
Bexley	0.319***	0.456***	0.698	0.176***	0.246***	0.144	0.311***
Brent	0.568***	1.089	1.282	0.484***	0.939	0.0968	2.479***
Bromley	0.299***	0.429***	1.623	0.259***	0.321***	0.00166	0.705
Camden	1.381**	1.508**	1.420	1.266**	1.320**	46.62	0.718
Croydon	0.316***	0.499***	1.083	0.225***	0.357***	0.00251	1.031
Ealing	0.795	1.278	1.046	0.552***	0.849	0.00156	2.546***
Enfield	0.422***	0.613**	1.097	0.224***	0.339***	6.87e-05	0.836
Greenwich	0.525***	0.771	0.446*	0.467***	0.655***	0.101	1.134
Hackney	2.355***	3.017***	1.536	3.071***	3.753***	38.89	1.419**
Hammersmith and Fulham	1.993***	2.515***	3.813***	1.366***	1.532***	1.694	1.513
Haringey	1.168	1.794***	1.030	0.876	1.166	23.78	1.116
Harrow	0.363***	0.673*	0.666*	0.134***	0.261***	0.703	0.562**
Havering	0.215***	0.326***	1.365	0.161***	0.244***	6.46e-06	0.810
Hillingdon	0.551***	0.808	4.070	0.329***	0.527***	4.92e-08	3.311**
Hounslow	1.109	1.680***	3.128	0.663***	1.079	3.04e-05	3.524***
Islington	1.753***	1.735***	0.995	1.743***	1.691***	39.15	0.697*
Kensington and Chelsea	0.837	0.955	0.255*	0.924	0.940	13.99	0.674
Kingston upon Thames	1.342*	1.708***	2.488	0.780*	0.920	0.0296	2.486***
Lambeth	1.490***	2.030***	2.385***	1.524***	1.828***	0.932	0.908
Lewisham	0.674**	1.032	0.685*	0.680***	0.938	0.510	1.556***
Merton	1.039	1.486**	0.552	0.621***	0.788*	2.954	Omitted
Newham	0.445***	0.900	0.380***	0.292***	0.648***	0.0788**	Omitted
Redbridge	0.310***	0.545***	1.268	0.174***	0.323***	0.000427	Omitted
Richmond upon Thames	1.610***	2.003***	Omitted	1.285**	1.340**	Omitted	Omitted
Southwark	1.388**	1.675***	Omitted	1.442***	1.721***	Omitted	Omitted
Sutton	0.739*	0.940	Omitted	0.360***	0.444***	Omitted	Omitted
Tower Hamlets	0.879	1.004	Omitted	1.244**	1.450***	Omitted	Omitted
Waltham Forest	0.546***	0.865	Omitted	0.525***	0.832	Omitted	Omitted
Wandsworth	1.375**	1.832***	Omitted	1.407***	1.543***	Omitted	Omitted
Individual characteristics: Female		0.353***	0.353***		0.411***	0.411***	0.411***
Aged 16-24		0.576***	0.576***		0.562***	0.562***	0.562***
Aged 25-29		0.797***	0.797***		0.768***	0.768***	0.768***
Aged 40-49		0.863**	0.863**		1.001	1.001	1.001
Aged 50-59		0.701***	0.701***		0.744***	0.744***	0.744***
Aged 60-64		0.552***	0.552***		0.370***	0.370***	0.370***
Aged 65+		0.438***	0.438***		0.371***	0.371***	0.371***
distwnofixedplace		0.353***	0.353***		0.461***	0.461***	0.461***
distwlessthan20km		0.376***	0.376***		0.592***	0.592***	0.592***
distwmorethan20km		0.140***	0.140***		0.166***	0.166***	0.166***

healthNotGood		0.902	0.902		0.677**	0.677**	0.677**
healthFairlygood		0.855**	0.855**		0.666***	0.666***	0.666***
wrkhrsParttime15hours		1.068	1.068		1.049	1.049	1.049
wrkhrsParttime16to30h		1.138*	1.138*		0.948	0.948	0.948
wrkhrsFulltime49ormor		0.823***	0.823***		0.839***	0.839***	0.839***
highqualOtherquali		1.044	1.044		1.233**	1.233**	1.233**
highqualLevel1		1.275**	1.275**		1.045	1.045	1.045
highqualLevel2		1.268**	1.268**		1.118	1.118	1.118
highqualLevel3		1.459***	1.459***		1.366***	1.366***	1.366***
highqualLevel45		2.296***	2.296***		2.012***	2.012***	2.012***
nssec11Largeemp		0.468***	0.468***		0.653***	0.653***	0.653***
nssec12Higherpr		0.732***	0.732***		0.927	0.927	0.927
nssec2Lowermana		0.650***	0.650***		0.880*	0.880*	0.880*
nssec3Intermedi		0.635***	0.635***		0.745***	0.745***	0.745***
nssec4Smallempl		0.560***	0.560***		0.684***	0.684***	0.684***
nssec5Lowersupe		0.945	0.945		0.921	0.921	0.921
nssec6Semirouti		0.919	0.919		0.933	0.933	0.933
houseRentsLASco		0.895*	0.895*		0.758***	0.758***	0.758***
housePrivateren		0.848***	0.848***		0.968	0.968	0.968
ethWhiteIrish		0.811*	0.811*		0.851*	0.851*	0.851*
ethOtherWhite		0.667***	0.667***		0.716***	0.716***	0.716***
ethMixedWhiteBlack		0.511***	0.511***		0.578***	0.578***	0.578***
ethMixedWhiteandAs		0.785	0.785		0.671***	0.671***	0.671***
ethIndianAsianAsia		0.0978***	0.0978***		0.155***	0.155***	0.155***
ethPakistaniAsianA		0.122***	0.122***		0.160***	0.160***	0.160***
ethBangladeshiAsia		0.182***	0.182***		0.107***	0.107***	0.107***
ethOtherAsianAsian		0.261***	0.261***		0.283***	0.283***	0.283***
ethCaribbeanBlackB		0.365***	0.365***		0.383***	0.383***	0.383***
ethAfricanBlackBla		0.0926***	0.0926***		0.218***	0.218***	0.218***
ethChineseandOther		0.305***	0.305***		0.407***	0.407***	0.407***
Geographic information: Land slope			1.043			0.119***	1.105
Water (% land use)			1.024			0.843	1.074***
Greenspace (% land use)			1.000			0.967***	1.023**
Path (% land use)			14.18*			0.0234	1.837*
Crime rate			0.988**			1.013	0.994***
Traffic volume			0.999			1.011	0.999**
Public transport accessibility							1.826*
Observations	144,707	144,707	144,707	172,410	172,410	172,410	172,410
AIC	33070.9	30422.7	30422.7	57634.6	53052.0	53052.0	53052.0
BIC	33387.1	31134.2	31134.2	57956.4	53776.2	53776.2	53776.2
R2	0.0393	0.119	0.119	0.0678	0.143	0.143	0.143

Table shows the estimated coefficients transformed to odds ratios. *** $p<0.001$, ** $p<0.01$, * $p<0.05$. PTAL Is the public transport accessibility index only available in 2011.
Omitted means that a particular borough-level dummy variable was omitted from the model specification to avoid a collinearity problem.

Appendix Table 2B: Model 1B Sensitivity analyses

(1) Remove by foot and public transport from reference category
(2) Inclusion of all categories where more granular detail is available in 2011 (e.g. 34 NS-SEC categories)
(3) Remove people aged >65

	SENSITIVITY ANALYSIS (1)		(2)	(3)	
VARIABLES	2001: Model 1B	2011: Model 1B	2011: Model 1B	2001: Model 1B	2011: Model 1B
BarkingandDagenham	0.284***	0.131***	0.413***	0.817	0.418***
Barnet	0.151***	0.121***	0.393***	0.447***	0.400***
Bexley	0.151***	0.0687***	0.244***	0.455***	0.239***
Brent	0.470***	0.390***	0.924	1.111	0.942
Bromley	0.159***	0.107***	0.320***	0.438***	0.324***
Camden	1.300	1.431**	1.305**	1.536***	1.309**
Croydon	0.192***	0.122***	0.353***	0.509***	0.361***
Ealing	0.468***	0.292***	0.840	1.295*	0.850
Enfield	0.205***	0.0971***	0.336***	0.616**	0.339***
Greenwich	0.324***	0.292***	0.648***	0.772	0.657***
Hackney	1.820***	3.160***	3.686***	3.051***	3.750***
HammersmithandFulham	1.694***	1.172	1.526***	2.545***	1.531***
Haringey	0.920	0.668***	1.148	1.820***	1.173
Harrow	0.215***	0.0717***	0.259***	0.690*	0.260***
Havering	0.108***	0.0639***	0.242***	0.333***	0.237***
Hillingdon	0.226***	0.119***	0.518***	0.827	0.523***
Hounslow	0.543***	0.321***	1.067	1.690***	1.082
Islington	1.483**	1.852***	1.674***	1.756***	1.679***
KensingtonandChelsea	0.638**	0.602***	0.942	0.954	0.958
KingstonuponThames	0.586***	0.265***	0.912	1.686***	0.914
Lambeth	1.393**	1.514***	1.809***	2.051***	1.833***
Lewisham	0.514***	0.510***	0.927	1.047	0.941
Merton	0.675**	0.341***	0.782*	1.512**	0.783*
Newham	0.441***	0.373***	0.638***	0.915	0.646***
Redbridge	0.207***	0.108***	0.320***	0.555**	0.322***
RichmonduponThames	0.774	0.438***	1.339**	2.019***	1.339**
Southwark	1.180	1.388**	1.703***	1.675***	1.737***
Sutton	0.301***	0.117***	0.438***	0.957	0.433***
TowerHamlets	0.858	1.837***	1.447***	1.021	1.455***
WalthamForest	0.371***	0.356***	0.820	0.879	0.839
Wandsworth	1.099	1.012	1.532***	1.839***	1.538***
female	0.381***	0.453***	0.412***	0.351***	0.412***
age1624	0.937	0.782***	0.572***	0.576***	0.562***

age2529	1.037	1.002	0.768***	0.796***	0.768***
age4049	0.800***	0.795***	0.996	0.862**	1.002
age5059	0.629***	0.539***	0.734***	0.700***	0.745***
age6064	0.503***	0.272***	0.364***	0.551***	0.371***
age65	0.420***	0.269***	0.363***		
distwnofixedplace	0.306***	0.357***	0.430***	0.354***	0.461***
distwlessthan20km	0.439***	0.657***	0.594***	0.377***	0.593***
distwmorethan20km	0.0931***	0.0828***	0.165***	0.137***	0.166***
healthNotGood	0.945	0.668**	0.681**	0.916	0.618***
healthFairlygood	0.870**	0.690***	0.668***	0.857**	0.666***
wrkhrsParttime15hours	1.069	1.030	1.044	1.067	1.065
wrkhrsParttime16to30h	1.003	0.811***	0.949	1.135*	0.945
wrkhrsFulltime49ormor	0.621***	0.661***	0.843***	0.823***	0.836***
highqualOtherquali	0.951	1.454***	1.239**	1.028	1.241**
highqualLevel1	1.146	1.035	1.072	1.267**	1.057
highqualLevel2	1.209*	1.193*	1.140	1.256**	1.119
highqualLevel3	1.489***	1.466***	1.388***	1.449***	1.377***
highqualLevel45	2.701***	2.811***	2.013***	2.289***	2.021***
houseRentsLASco	1.110	0.795***	0.752***	0.891*	0.757***
housePrivateren	1.478***	1.605***	0.965	0.849***	0.968
ethWhiteIrish	0.957	0.896	0.850*	0.802*	0.840*
ethOtherWhite	0.756***	0.829***	0.720***	0.664***	0.714***
ethMixedWhiteBlack	0.519***	0.582***	0.579***	0.514***	0.580***
ethMixedWhiteandAs	0.951	0.736**	0.670***	0.786	0.668***
ethIndianAsianAsia	0.0879***	0.149***	0.158***	0.0981***	0.155***
ethPakistaniAsianA	0.110***	0.120***	0.163***	0.123***	0.161***
ethBangladeshiAsia	0.135***	0.0639***	0.109***	0.182***	0.107***
ethOtherAsianAsian	0.222***	0.282***	0.285***	0.261***	0.285***
ethCaribbeanBlackB	0.380***	0.348***	0.381***	0.370***	0.383***
ethAfricanBlackBla	0.0874***	0.235***	0.213***	0.0930***	0.213***
ethChineseandOther	0.347***	0.436***	0.408***	0.306***	0.408***
nssec2011_1			0.941		
nssec2011_2			0.436		
nssec2011_3.1			0.677		
nssec2011_3.2			0.561		
nssec2011_3.3			0.612		
nssec2011_3.4			0.545		
nssec2011_4.1			0.621		
nssec2011_4.2			0.502		
nssec2011_4.3			0.744		
nssec2011_4.4			0.614		
nssec2011_5			0.533		
nssec2011_6			0.604		
nssec2011_7.1			0.437		
nssec2011_7.2			0.540		

nssec2011_7.3			0.754		
nssec2011_7.4			0.629		
nssec2011_8.1			0.407		
nssec2011_9.1			0.503		
nssec2011_9.2			0.856		
nssec2011_10			0.616		
nssec2011_11.1			0.647		
nssec2011_11.2			0.487		
nssec2011_12.1			0.439		
nssec2011_12.2			0.755		
nssec2011_12.3			1.017		
nssec2011_12.4			0.716		
nssec2011_12.5			0.906		
nssec2011_12.6			0.497		
nssec2011_12.7			0.589		
nssec2011_13.1			0.565		
nssec2011_13.2			0.751		
nssec2011_13.3			0.638		
nssec2011_13.4			0.803		
nssec1.1	0.478***	0.686***		0.460***	0.655***
nssec1.2	0.877	1.231**		0.722***	0.933
nssec2	0.682***	0.928		0.643***	0.882*
nssec3	0.865	0.953		0.629***	0.752***
nssec4	0.414***	0.457***		0.554***	0.689***
nssec5	0.928	0.874		0.934	0.926
nssec6	1.214*	1.267**		0.908	0.938
Observations	65,457	65,120	172,410	142,821	168,296
AIC	22921.4	32066.3	52996.4	30159.6	52395.2
BIC	23575.8	32720.4	53982.0	30860.4	53107.6
r2_p	0.198	0.314	0.145	0.119	0.143

Table shows the estimated coefficients transformed to odds ratios. *** p<0.001, ** p<0.01, * p<0.05. In sensitivity analysis 2, NSSEC category 13.5 was in the reference category.

Appendix Table 2C: Model 1D

VARIABLES	(1) 2001: int= Female	(2) 2011: int= Female	(3) 2001: int= Ethnic minority	(4) 2011: int= Ethnic minority	(5) 2001: int= Age>50	(6) 2011: int= Age>50	(7) 2001: int= NS-SEC V VI or VII	(8) 2011: int= NS-SEC V VI or VII
BarkingandDagenham	0.924	0.530***	0.774	0.417***	0.867	0.420***	0.603	0.607
Barnet	0.476***	0.519***	0.400***	0.369***	0.430***	0.371***	0.393**	0.315***
Bexley	0.626*	0.340***	0.450***	0.248***	0.482***	0.234***	0.265***	0.393***
Brent	1.078	1.134	1.051	1.100	1.164	0.976	0.720	0.867
Bromley	0.468***	0.474***	0.388***	0.308***	0.408***	0.311***	0.297***	0.515**
Camden	1.536**	1.447***	1.517**	1.328*	1.508**	1.208*	0.716	1.282
Croydon	0.661*	0.481***	0.458***	0.306***	0.518***	0.397***	0.423**	0.438**
Ealing	1.387*	0.971	1.178	1.013	1.337*	0.753**	0.993	0.759
Enfield	0.734	0.530***	0.613**	0.337***	0.584**	0.331***	0.392***	0.504**
Greenwich	1.002	0.850	0.733	0.628***	0.772	0.662***	0.469**	0.618
Hackney	2.943***	3.806***	2.888***	3.853***	3.102***	3.733***	1.663*	2.491***
HammersmithandFulham	2.249***	1.644***	2.406***	1.592***	2.364***	1.437***	1.446	1.513
Haringey	2.180***	1.357**	1.896***	1.336*	1.927***	1.208*	0.800	0.803
Harrow	0.729	0.323***	0.690	0.266***	0.577**	0.267***	0.484*	0.332**
Havering	0.419***	0.343***	0.300***	0.239***	0.368***	0.206***	0.242***	0.316***
Hillingdon	0.882	0.693**	0.775	0.541***	0.811	0.454***	0.684	0.723
Hounslow	2.004***	1.363**	1.699***	1.089	1.697***	1.018	1.558	1.430
Islington	1.561**	1.941***	1.655***	1.593***	1.804***	1.602***	0.694	1.097
KensingtonandChelsea	0.768	0.867	1.042	1.008	0.995	0.923	0.710	1.251
KingstonuponThames	1.680**	0.977	1.679***	0.927	1.539**	0.902	1.618	1.012
Lambeth	2.010***	2.083***	2.128***	1.894***	2.115***	1.785***	0.986	1.250
Lewisham	1.176	1.097	0.986	0.898	1.055	0.964	0.478*	0.705
Merton	1.531**	0.967	1.406*	0.720*	1.512**	0.758*	1.226	1.102
Newham	1.079	0.834	0.939	0.496***	1.020	0.604***	0.593	0.462**
Redbridge	0.646*	0.401***	0.566**	0.323***	0.526**	0.280***	0.577	0.350**
RichmonduponThames	1.879***	1.313*	1.983***	1.383**	1.906***	1.332**	2.539***	1.547
Southwark	1.695***	1.945***	1.501**	1.642***	1.795***	1.719***	0.787	1.395
Sutton	1.034	0.640**	0.971	0.452***	1.053	0.437***	0.842	0.567*
TowerHamlets	0.998	1.464***	1.022	1.285*	1.035	1.435***	0.640	1.522
WalthamForest	0.861	1.149	0.775	0.787	0.930	0.812	0.718	0.851
Wandsworth	2.025***	1.843***	1.837***	1.557***	1.815***	1.480***	1.213	1.325
female	0.412***	0.643***	0.352***	0.411***	0.353***	0.412***	0.351***	0.411***
age1624	0.570***	0.557***	0.577***	0.562***	0.575***	0.563***	0.574***	0.560***
age2529	0.793***	0.766***	0.796***	0.768***	0.796***	0.769***	0.795***	0.768***
age4049	0.864**	1.005	0.863**	1.001	0.864**	1.002	0.869**	1.007
age5059	0.701***	0.746***	0.699***	0.744***	0.771	0.604*	0.704***	0.748***

age6064	0.550***	0.367***	0.552***	0.370***	0.606	0.298***	0.554***	0.370***
age65	0.432***	0.370***	0.436***	0.370***	0.472*	0.296***	0.438***	0.372***
ethWhiteIrish	0.812*	0.850*	0.747	0.854	0.812*	0.850*	0.817*	0.854*
ethOtherWhite	0.667***	0.717***	0.629*	0.719*	0.666***	0.717***	0.677***	0.727***
ethMixedWhiteBlack	0.510***	0.576***	0.468**	0.574**	0.511***	0.577***	0.522***	0.589***
ethMixedWhiteandAs	0.785	0.668***	0.726	0.670**	0.787	0.672***	0.797	0.680***
ethIndianAsianAsia	0.0975***	0.154***	0.0907***	0.157***	0.0977***	0.155***	0.0979***	0.157***
ethPakistaniAsianA	0.120***	0.155***	0.114***	0.158***	0.122***	0.161***	0.123***	0.162***
ethBangladeshiAsia	0.182***	0.107***	0.180***	0.0989***	0.179***	0.107***	0.192***	0.107***
ethOtherAsianAsian	0.257***	0.281***	0.242***	0.284***	0.260***	0.284***	0.261***	0.285***
ethCaribbeanBlackB	0.365***	0.384***	0.334***	0.380***	0.366***	0.385***	0.378***	0.397***
ethAfricanBlackBla	0.0922***	0.217***	0.0837***	0.214***	0.0918***	0.219***	0.0958***	0.226***
ethChineseandOther	0.305***	0.407***	0.281***	0.406***	0.304***	0.406***	0.310***	0.414***
int*BarkingandDagenham	0.610	0.476*	1.312	1.039	0.601	1.117	1.315	0.420*
int*Barnet	0.731	0.386***	1.422	1.199	1.053	1.481	1.111	1.313
int*Bexley	0.189**	0.308**	0.896	0.881	0.749	1.353	2.162*	0.425*
int*Brent	1.033	0.545**	1.114	0.768	0.645	0.756	1.701	1.098
int*Bromley	0.740	0.208***	2.294	1.309	1.206	1.261	1.594	0.518*
int*Camden	0.936	0.735	0.970	0.985	1.008	1.807*	2.458**	1.033
int*Croydon	0.289**	0.342***	1.527	1.532	0.820	0.506	1.144	0.730
int*Ealing	0.754	0.654*	1.324	0.662*	0.745	2.012**	1.355	1.147
int*Enfield	0.502	0.125***	0.964	1.010	1.231	1.219	1.808	0.525*
int*Greenwich	0.292**	0.400***	1.319	1.147	0.983	0.983	1.938	1.070
int*Hackney	1.053	0.888	1.167	0.939	0.822	0.970	2.143**	1.626*
int*HammersmithandFulham	1.332	0.777	1.175	0.906	1.575	1.735*	1.992*	1.012
int*Haringey	0.467*	0.614*	0.802	0.715	0.558	0.714	2.745**	1.572
int*Harrow	0.763	0.491	0.869	0.954	1.751	0.984	1.513	0.714
int*Havering	0.357	0.290**	2.695	1.191	0.497	1.985	1.414	0.642
int*Hillingdon	0.746	0.380***	1.270	0.893	0.969	1.982*	1.120	0.564*
int*Hounslow	0.510*	0.452***	0.906	0.970	0.949	1.458	0.955	0.632
int*Islington	1.340	0.634**	1.199	1.183	0.729	1.574	3.068***	1.630
int*KensingtonandChelsea	1.818	1.261	0.760	0.867	0.788	1.172	1.455	0.721
int*KingstonuponThames	1.031	0.804	1.032	0.966	1.549	1.200	1.017	0.884
int*Lambeth	1.032	0.656**	0.783	0.912	0.687	1.206	2.466**	1.560
int*Lewisham	0.635	0.602*	1.209	1.122	0.874	0.808	2.748**	1.412
int*Merton	0.902	0.509**	1.277	1.289	0.907	1.336	1.241	0.641
int*Newham	0.480	0.398**	0.845	1.487	0.375	1.626	1.724	1.602
int*Redbridge	0.540	0.491*	0.702	1.001	1.149	1.896	0.797	0.890
int*RichmonduponThames	1.187	0.993	0.998	0.857	1.263	1.117	0.726	0.847
int*Southwark	0.963	0.669*	1.558	1.122	0.523	0.957	2.605**	1.286
int*Sutton	0.723	0.262***	0.404	0.882	0.479	1.177	1.048	0.694
int*TowerHamlets	1.037	0.964	0.893	1.316	0.772	0.994	1.759	0.944
int*WalthamForest	1.008	0.314***	1.605	1.135	0.628	1.218	1.177	0.953
int*Wandsworth	0.703	0.565***	0.947	0.975	1.123	1.433	1.682	1.190

Observations	144,707	172,410	144,707	172,410	144,707	172,410	144,707	172,410
AIC	30379.4	52922.8	30451.6	53067.5	30436.1	53047.0	30384.4	52980.9
BIC	31397.3	53958.8	31469.5	54103.4	31454.0	54083.0	31402.3	54016.8
r2_p	0.122	0.146	0.120	0.144	0.120	0.144	0.122	0.145

Notes:
-Results are shown in this table for Model 1D where int=interaction where interaction is female (columns 1 and 2), ethnic minority (columns 3 and 4), age>50 (columns 5 and 6) and NSSEC V VI or VII (columns 7 and 8).
-Other individual-level characteristics not listed in the table were (as in Model 1B): distance to work, health, working hours, highest qualification, NSSEC category and accommodation dummies
-Table shows the estimated coefficients transformed to odds ratios
*** $p<0.001$, ** $p<0.01$, * $p<0.05$

Appendix Table 3: Model 2

VARIABLES	(1) Model 2A	(2) Model 2B	(3) Model 2C	(4) Model 2D
2011 dummy	1.741***	1.796***		
BarkingandDagenham			0.570***	0.819
Barnet			0.288***	0.400***
Bexley			0.319***	0.445***
Brent			0.568***	1.022
Bromley			0.299***	0.406***
Camden			1.381**	1.469**
Croydon			0.316***	0.482***
Ealing			0.795	1.182
Enfield			0.422***	0.592***
Greenwich			0.525***	0.741
Hackney			2.355***	2.965***
HammersmithandFulham			1.993***	2.330***
Haringey			1.168	1.618***
Harrow			0.363***	0.629**
Havering			0.215***	0.326***
Hillingdon			0.551***	0.803
Hounslow			1.109	1.636***
Islington			1.753***	1.767***
KensingtonandChelsea			0.837	0.914
KingstonuponThames			1.342*	1.627***
Lambeth			1.490***	1.881***
Lewisham			0.674**	0.969
Merton			1.039	1.376*
Newham			0.445***	0.872
Redbridge			0.310***	0.507***
RichmonduponThames			1.610***	1.830***
Southwark			1.388**	1.670***
Sutton			0.739*	0.926
TowerHamlets			0.879	1.021
WalthamForest			0.546***	0.810
Wandsworth			1.375**	1.651***
CityofLondonandWestminster*2011			1.970***	2.081***
BarkingandDagenham*2011			0.828	1.045
Barnet*2011			1.945***	2.149***
Bexley*2011			1.086	1.144
Brent*2011			1.679***	1.971***
Bromley*2011			1.706**	1.677**
Camden*2011			1.806***	1.883***
Croydon*2011			1.401*	1.554**
Ealing*2011			1.367**	1.547***
Enfield*2011			1.046	1.206
Greenwich*2011			1.750***	1.875***
Hackney*2011			2.569***	2.661***
HammersmithandFulham*2011			1.351***	1.418***
Haringey*2011			1.477***	1.572***
Harrow*2011			0.726	0.886
Havering*2011			1.478	1.525
Hillingdon*2011			1.177	1.350*
Hounslow*2011			1.178	1.382**
Islington*2011			1.958***	1.970***
KensingtonandChelsea*2011			2.175***	2.199***
KingstonuponThames*2011			1.144	1.199
Lambeth*2011			2.015***	2.100***
Lewisham*2011			1.987***	2.094***

Merton*2011			1.177	1.240
Newham*2011			1.294	1.579**
Redbridge*2011			1.103	1.373
RichmonduponThames*2011			1.572***	1.588***
Southwark*2011			2.047***	2.154***
Sutton*2011			0.959	0.992
TowerHamlets*2011			2.788***	2.940***
WalthamForest*2011			1.895***	2.200***
Wandsworth*2011			2.015***	2.053***
Observations	317,117	317,117	317,117	317,117
Other individual-level characteristics	NO	YES	NO	YES
AIC	96114.9	86885.2	90705.4	83649.1
BIC	96136.3	87333.2	91388.1	84758.4
r2_p	0.00798	0.104	0.0651	0.139

Notes:
Other individual-level characteristics were: gender, age, distance to work, ethnicity, health, working hours, highest qualification, NS-SEC category and accommodation dummies
*** p<0.001, ** p<0.01, * p<0.05
Table shows the estimated coefficients transformed to odds ratios

Appendix Table 4: Alternative model specifications for Model 3

VARIABLES	**No covariates**	Add age and gender	**Add ethnicity**	Add NS-SEC categories	Add distance to work	Add health
Change in spending	**0.0123*** **	0.0112***	**0.00870** **	0.00941**	0.00942**	0.00901*
Change in %female		0.294	**0.167**	0.231	0.232	0.236
Change in %16-29		0.184	**0.179**	0.179	0.180	0.216
Change in %50+		-0.455*	**-0.486** **	-0.468*	-0.468*	-0.521*
Change in %Ethnic minorities			**-0.102***	-0.0871	-0.0869	-0.0822
Change in %NSSEC I.i, I.ii				-0.0911	-0.0924	-0.0631
Change in %NSSEC V, VI and VII				0.182	0.182	0.166
Change in %distance to work >5km					0.00200	-0.0277
Change in %not- or fairly-good health						0.188
AIC	**-172.0**	-179.1	**-182.8**	-180.9	-178.9	-177.6
BIC	**-169.0**	-171.8	**-174.0**	-169.1	-165.7	-163.0
R^2	**0.371**	0.583	**0.651**	0.672	0.672	0.680
Adjusted R^2	**0.350**	0.521	**0.584**	0.577	0.558	0.549

Notes:

The unadjusted and preferred models are highlighted in bold and also reported in Table 1 of the main paper.

*** p<0.001, ** p<0.01, * p<0.05

Appendix Table 5a: Recoding 2011 census data categories to match 2001 census data variables

All variables included in the regression analysis were coded the same in the raw data in years 2001 and 2011, except for the following, where we recoded 2011 variables to be consistent with 2001 variables.

	2001	2011
Age		
Distance to work	Less than 5km	Less than 2 km 2 to <5 km
	5 and less than 20	5 to <10 km 10 to <20 km
	20 and over	20 to <40 km 40 to <60km 60km or more
General Heath	Good	Very good health Good health
	Fairly good	Fair health
	Not good	Bad health Very bad health
Hours worked per week	15 hours or less worked	1-15
	16 to 30 hours worked	16-30
	31 to 48 hours worked	31-37 38-48
	49 or more hours worked	49+
National Statistics Socio-Economic Classification (NS-SEC) 2001: Analytic categories 2011: Operational categories See Table 2 here:	1.1 Large employers & higher managerial	1 2
	1.2 Higher professional occupations	3.1 3.2 3.3 3.4
	2 Lower managerial and professional	4.1 4.2 4.3 4.4 5 6
	3 Intermediate occupations	7.1 7.2 7.3 7.4
	4 Small employers and own account wo	8.1 8.2 9.1 9.2
	5 Lower supervisory and technical oc	10 11.1 11.2
	6 Semi-routine	12.1 12.2 12.3 12.4 12.5 12.6 12.7
	7 Routine occupations	13.1 13.2 13.3 13.4 13.5

Appendix Table 5b: Census variables not included in the regression analyses

furn	Accommodation Furnished (Scotland)
selfcont	Accommodation Self-Contained
agehrp	Age of household reference person
ahchuk11	Alternative Household Composition
scgpuk11c	Approximated social grade
natidbpuk11	British national identity
carsh	Cars/Vans Owned or Available for Use
rtntypeg	Census return by internet or paper
cenheat0	Central Heating
cenheat	Central heating
combgn	Community Background - Religion or Religion Brought Up In (Northern Ireland)
wpzhome	Comparison of where you live and work
cobirta	Country of Birth
cobg	Country of birth
cobhukrcg	Country of birth of household reference person
country	Country of residence
dfdisp	DEFRA: Dispersed Pop
dflgmtwn	DEFRA: Large Market Twn Pop
dflgurb	DEFRA: Large Urb Pop
dfmjurb	DEFRA: Major Urb Pop
dfothurb	DEFRA: Other Urb Pop
dfrutnp1	DEFRA: Rural Twn Pop
dfrutnp2	DEFRA: Rural Twn Pop (Includ Lrge Market Twn Pop)
dftotal	DEFRA: Total Pop
dftotrup	DEFRA: Total Rural Pop (Includ Lrge Market Twn Pop)
dftoturb	DEFRA: Total Urb Pop(Exclud. Lrge Market Twn Pop)
dftotr_1	DEFRA: Total rural percent (Including Lrge Market Twn Pop)
dfvilp	DEFRA: Village Pop
defra	DEFRA: urban/rural type (numerical)
fndepcha	Dependent Children in Family
deprived	Deprivation indicators of a household
movefromg	Distance moved from address one year ago
distmova	Distance of Move for Migrants (km)
econach	Economic Activity (last week)
freconac	Economic Position of Family Reference Person
ecopuk11	Economically active
depedhuk11	Education selected characteristics, household indicator
depemhuk11	Employment selected characteristics, household indicator
empstat	Employment type
langprf	English proficiency
clients09	Establishment caters for specific group (acute illness care)
clients13	Establishment caters for specific group (armed forces personnel)
clients15	Establishment caters for specific group (asylum seekers)
clients08	Establishment caters for specific group (chronic illness care)
clients06	Establishment caters for specific group (end of life care)
clients17	Establishment caters for specific group (homeless people)
clients04	Establishment caters for specific group (intermediate
clients02	Establishment caters for specific group (learning disability)
clients03	Establishment caters for specific group (mental illness)
clients18	Establishment caters for specific group (nurses/doctors)
clients10	Establishment caters for specific group (older people)

clients21	Establishment caters for specific group (other)
clients16	Establishment caters for specific group (paying guests)
clients01	Establishment caters for specific group (physical disability)
clients14	Establishment caters for specific group (prisoners/offenders)
clients07	Establishment caters for specific group (respite care)
clients11	Establishment caters for specific group (school children)
clients20	Establishment caters for specific group (seasonal/temporary workers)
clients19	Establishment caters for specific group (staff)
clients05	Establishment caters for specific group (substance misuse)
clients12	Establishment caters for specific group (university and/or college students)
ethhuk11	Ethnic group of household reference person
everwork	Ever worked
famtypa	Family Type
dpcfamuk11	Family dependent children
fmspuk11	Family status
genind	Generation Indicator
region	Government Office Region
dephdhuk11	Health and disability selected characteristics, household indicator
hmptpuk	Hhd headship (ODPM)
hedind	Household Education indicator
hempind	Household Employment indicator
hhtlhind	Household health and disability indicator
hhsgind	Household housing indicator
hhldlang11	Household language
mltrlg	Household multiple religion indicator
residence_type	Household or communal establishment
nsshuk11	Household reference person NS-SEC
scghuk11	Household reference person social grade
stahuka	Household with Students Away During Term Time
dephshuk11	Housing selected characteristics, household indicator
indgpuk11	Industry of business
intention	Intention to stay in the UK
iscog	International Standard Classification of occs 2 digit
natidipuk11	Irish national identity
lastyrwrkg	Last year worked
llti	Limiting Long Term Illnes
larpuk11	Living arrangements
disability	Long-term health problem
lowflora	Lowest floor level of household living acommodation
mainglangg	Main language
marstat	Marital Status
marstata	Marital Status
miginda	Migration Indicator
meighuk11	Multiple ethnic identifier
frnssec8	NS-SEC Social-Economic Classifications of Family Reference Person
estnaturei	Nature of establishment
densitya	No. of Residents per Room
natidnipuk11	Northern Irish national identity
hnllti	Number in Household with Limiting Long-term Illness
hncarers	Number of Carers in the Household
hnearnra	Number of Employed Adults in Household
roomsflr	Number of Floor Levels (Northern Ireland)

provcare	Number of Hours Care Provided per Week
hnprhlth	Number of Household Members with Poor Health
roomsnum	Number of Rooms Occupied in Household Space
hnresida	Number of Usual Residents in Household
carsnoc	Number of cars and vans
illhuk11g	Number of individuals in household with long-standing illness/disability
housecarer	Number of people in household who provide care
pproomhuk11	Number of persons per room
edisdono	Number of times information donated - edisdono
visitorsg	Number of visitors on census night
occupncy	Occupancy Rating of Household
oncperim	One Number Census status
identityg	Other National identity (not UK and Irish)
psptelog	Other Passports held (Not including UK and Ireland)
natidopuk11	Other national identity
passports	Passports held
penhuk11	Pensioner household
penpuk11	Person of pensionable age indicator
wkpladdewni	Place of work
popbasea	Population Base qualifier
position	Position within communal establishment
profqual	Professional Qualification (England and Wales)
carer	Provision of unpaid care
moveregion	Region of Origin
regiona	Region of Usual Residence
reltohra	Relationship to HRP
relato	Relationship to household reference person
religionew	Religion
relgew	Religion (England and Wales)
relgn	Religion (Northern Ireland)
relgs1	Religion Belongs to (Scotland)
student	Schoolchild or student in full-time education
natidspuk11	Scottish national identity
frsex	Sex of Family Reference Person
single	Single adult household
sizhuk11	Single adult households
workforc	Size of Work Force
hrsocgrd	Social Grade of Household Reference Person
occg	Standard Occupational Classification 2 digit
ceststat	Status in Communal Establishment
stapuk11	Student accommodation
supervisor	Supervisor
supervsr	Supervisor/Foreman
termtima	Term time Address of Students or Schoolchildren
typaccom	Type of accommodation
cemtyp	Type of communal establishment
landlordew	Type of landlord
scaddtyp	Type of second address
unemphist	Unemployment history
bathwc	Use of Bath/Shower/Toilet
add1yr	Usual address one year ago
yradindstud	Usual address one year ago was a student term-time/boarding school address in

natidwpuk11	Welsh national identity
selfcon	Whether accommodation is self-contained
concealed	Whether concealed family
wlshread	Whether reads Welsh (Wales only)
wlshstnd	Whether understands Welsh (Wales only)
popbasesec	Whether usual resident, student living away, or short-term resident
wlshwrit	Whether writes Welsh (Wales only)
mighuk11	Wholly moving household indicator
wg1famuk11	Workers in generation one of family
wrkplcea	Workplace
lastwrka	Year Last Worked
yrarr_yearg	Year of Arrival in UK (England and Wales)
migorgn	region of origin

Appendix Table 6a: Calculation of infrastructure cost per additional cyclist (using data from this study)

We report in our study that the infrastructure cost per additional cyclist was £4,915, ranging between boroughs from £587 (Barnet) to £17,577 (Camden).

This is based on the β_3 coefficient estimated in our first differences model (model 3) which measures the association between propensity to cycle and (the log of) total expenditure per km^2 on cycle infrastructure that occurred at the borough-level between 2001 and 2011. In this setting, a one percent increase in expenditure on cycle infrastructure per km^2 would be associated with an estimated β_3 /100 unit (=0.00772 / 100) increase in the proportion of commuters who cycle to work.

The table below shows how, for each borough, we calculated the infrastructure cost per additional cyclist using borough level data on area (km^2 – column 1), the total commuter population (calculated using 2011 census data – column 2) and current cycling expenditure (between 2001 and 2011 – column 3).

					Without adjustment for population changes		With adjustment for population changes	
	Area (km2)	Spending per km2 (£) 2001-2011	Commuter population	Additional spending associated with a 1% increase in spending per km2	Number of new cyclists associated with a 1% increase in spending per km2	**Infrastructure cost per additional cyclist**	Number of new cyclists associated with a 1% increase in spending per km2	**Infrastructure cost per additional cyclist**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
				= (2) * (3) * 0.01	= (3) * 0.01 * 0.0123107	= (4) / (5)	= (3) * 0.01 * 0.0087018	= (4) / (7)
All of London	1569.24	£ 99,470.41	3649900	£ 1,560,932.50	449.33	**£ 3,473.92**	317.61	**£ 4,914.67**
Inner London	297.90	£ 245,453.20	1365600	£ 731,215.19	168.11	**£ 4,349.50**	118.83	**£ 6,153.36**
Kensington and Chelsea	12.12	£ 105,732.23	69400	£ 12,818.99	8.54	**£ 1,500.42**	6.04	**£ 2,122.68**
Wandsworth	34.26	£ 94,446.12	163240	£ 32,361.18	20.10	**£ 1,610.33**	14.20	**£ 2,278.18**
Greenwich	47.33	£ 57,842.90	110840	£ 27,379.28	13.65	**£ 2,006.52**	9.65	**£ 2,838.68**
Lewisham	35.15	£ 127,521.30	124640	£ 44,822.84	15.34	**£ 2,921.19**	10.85	**£ 4,132.69**
Tower Hamlets	19.78	£ 270,130.66	113960	£ 53,435.29	14.03	**£ 3,808.84**	9.92	**£ 5,388.48**
Lambeth	26.81	£ 272,893.91	152180	£ 73,162.95	18.73	**£ 3,905.27**	13.24	**£ 5,524.90**
Southwark	28.86	£ 234,835.94	139080	£ 67,778.43	17.12	**£ 3,958.62**	12.10	**£ 5,600.38**
Hammersmith and Fulham	16.40	£ 277,931.81	91240	£ 45,573.74	11.23	**£ 4,057.39**	7.94	**£ 5,740.11**
Hackney	19.05	£ 315,786.97	107400	£ 60,154.34	13.22	**£ 4,549.67**	9.35	**£ 6,436.56**
Islington	14.86	£ 421,510.19	97100	£ 62,622.32	11.95	**£ 5,238.74**	8.45	**£ 7,411.41**
City of London and Westminster	21.49	£ 494,125.38	101760	£ 106,172.63	12.53	**£ 8,475.25**	8.85	**£ 11,990.20**
Camden	21.79	£ 665,158.06	94760	£ 144,933.25	11.67	**£ 12,423.97**	8.25	**£ 17,576.56**
Outer London	1271.34	£ 65,263.25	2284300	£ 829,717.25	281.21	**£ 2,950.49**	198.78	**£ 4,174.15**
Barnet	86.75	£ 8,890.10	151100	£ 7,712.01	18.60	**£ 414.59**	13.15	**£ 586.54**
Enfield	80.83	£ 12,459.41	125620	£ 10,071.19	15.46	**£ 651.24**	10.93	**£ 921.33**
Newham	36.20	£ 77,924.27	124080	£ 28,207.33	15.28	**£ 1,846.62**	10.80	**£ 2,612.47**
Croydon	86.50	£ 42,250.91	156920	£ 36,548.57	19.32	**£ 1,891.95**	13.65	**£ 2,676.60**
Havering	112.35	£ 28,190.14	103600	£ 31,671.53	12.75	**£ 2,483.28**	9.02	**£ 3,513.18**
Hounslow	55.98	£ 69,771.23	117480	£ 39,056.48	14.46	**£ 2,700.51**	10.22	**£ 3,820.50**
Brent	43.23	£ 108,671.40	136480	£ 46,981.51	16.80	**£ 2,796.24**	11.88	**£ 3,955.93**
Waltham Forest	38.81	£ 100,762.26	113080	£ 39,103.78	13.92	**£ 2,808.99**	9.84	**£ 3,973.96**
Ealing	55.54	£ 100,243.06	150640	£ 55,679.31	18.54	**£ 3,002.42**	13.11	**£ 4,247.61**
Redbridge	56.42	£ 75,597.16	114820	£ 42,651.16	14.14	**£ 3,017.38**	9.99	**£ 4,268.78**
Hillingdon	115.70	£ 39,996.68	121120	£ 46,276.61	14.91	**£ 3,103.58**	10.54	**£ 4,390.73**
Bromley	150.13	£ 34,610.21	135280	£ 51,962.00	16.65	**£ 3,120.11**	11.77	**£ 4,414.11**
Bexley	60.58	£ 66,357.55	103720	£ 40,199.85	12.77	**£ 3,148.32**	9.03	**£ 4,454.03**
Sutton	43.85	£ 89,064.47	88940	£ 39,052.08	10.95	**£ 3,566.68**	7.74	**£ 5,045.89**
Barking and Dagenham	36.11	£ 87,078.98	70400	£ 31,442.32	8.67	**£ 3,627.93**	6.13	**£ 5,132.55**
Harrow	50.46	£ 96,962.18	103660	£ 48,929.78	12.76	**£ 3,834.24**	9.02	**£ 5,424.42**
Merton	37.62	£ 120,216.98	94760	£ 45,231.32	11.67	**£ 3,877.32**	8.25	**£ 5,485.36**
Richmond upon Thames	57.41	£ 94,634.42	85980	£ 54,326.58	10.58	**£ 5,132.54**	7.48	**£ 7,261.16**
Haringey	29.60	£ 273,820.88	112460	£ 81,046.56	13.84	**£ 5,854.01**	9.79	**£ 8,281.85**
Kingston upon Thames	37.26	£ 143,761.83	74160	£ 53,567.35	9.13	**£ 5,867.43**	6.45	**£ 8,300.83**

Appendix Table 6b: Calculation of infrastructure cost per additional cyclist (using data on Cycle Demonstration Towns from the study by Goodman et al. (2013))

We report in our study that the infrastructure cost per additional cyclist in the study of Cycle Demonstration Towns by Goodman et al. (2013) was £1596. This was based on information reported in the following sentences from the Goodman et al. (2013) paper:

> *"Between October 2005 and March 2011, six Cycling Demonstration Towns (CDTs) increased their spending on cycling to £17 per person per year, through a combination of central government and matched local funding. This is much higher than the average of £1 per person per year for England as a whole, and is comparable to many high-cycling European cities (Sloman et al., 2009). Between April 2008 and March 2011, a further 12 Cycling Cities and Towns (CCTs) increased their spending up to an average of £14 per person per year (personal communication from the Department for Transport)."*

> *"…all towns spent a mixture of capital investment (e.g. building cycle lanes, creating cycle parking) and revenue investment (e.g. promotional activities, cycle training), with an average capital:revenue ratio of 3:1."*

The table below shows how we used this information to calculate that the average spending per person in the general population per year in the 18 cycle demonstration towns during the ten-year period (between March 2001 and March 2011) was £4.89.

	(1) Capital and revenue expenditure per person per year in the 12-months to:										**(2) Capital and revenue expenditure per person during the period Mar-01 to Mar-11**	**(3) Capital and revenue expenditure per person per year during the period Mar-01 to Mar-11**	**(4) Capital expenditure per person per year during the period Mar-01 to Mar-11**
	Mar-02	**Mar-03**	**Mar-04**	**Mar-05**	**Mar-06**	**Mar-07**	**Mar-08**	**Mar-09**	**Mar-10**	**Mar-11**	**=sum of (1)**	**=(2) ÷ 10**	**=(3) * [3 ÷ 4]**
(5) Control towns	£1	£1	£1	£1	£1	£1	£1	£1	£1	£1	£10.00	£1.00	**£0.75**
(6) First wave of CDTs (n=6)	£1	£1	£1	£1	£8.50	£17	£17	£17	£17	£17	£97.50	£9.75	£7.31
(7) Second wave of CDTs (n=12)	£1	£1	£1	£1	£1	£1	£1	£14	£14	£14	£49.00	£4.90	£3.68
(8) Both CDT waves combined (n=18)	£1	£1	£1	£1	£3.50	£6.33	£6.33	£15	£15	£15	£65.17	£6.52	**£4.89**

The paper also reported that: *"Among commuters living in the intervention towns, the prevalence of cycling to work increased from 5.81% in 2001 to 6.78% in2011. Compared with the matched comparison group, this represented an absolute intervention effect of +0.69 (95% CI 0.60, 0.77) percentage points."*

Based in this information (their base case), we calculated that the infrastructure cost per additional cyclist was £1,385.52. The calculation was ((£4.89 - £0.75) * 2.3092) / 0.0069), where 2.3092 was the ratio of the combined general population to the combined commuter population in the 18 cycle demonstration towns calculated using data from the 2011 census.

We assumed that the figures reported in the paper referred to 2011 £GBP and, following adjustment to 2019 £GBP using the HM Treasury GDP deflator, we estimated that the infrastructure cost per additional cyclist was £1595.84 and that the spending levels in the study ranged from £0.87 (in the control towns) to £5.63 (in the intervention towns) per capita per year in 2019 £GBP.

Following the methodological approach adopted by Goodman et al. 2013, we did not adjust these calculations based on different size populations between towns. We also made an assumption that the average capital:revenue ratio of 3:1 applied to the control towns.

Figure 1:

Title:

Relationship between cycle commuting (% of commuters who cycle to work) and concentration index, by borough and year

Notes:

- Spearman's rho =0.5381 (both years combined) (rho=0.3431 in 2001 and 0.6015 in 2011). Test of Ho: Proportion of commuters who cycle and the concentration index are independent Prob > |t| = 0.0000

Figure 2:

Title:

Relationship between cycling infrastructure expenditure and change in cycling commuting (% of commuters who cycle to work), by borough 2001-2011

Notes:

- Outer London boroughs have black outlines
- Spearman's rho = 0.6895. Test of Ho: change in proportion of commuters who cycle and infrastructure investment are independent Prob > |t| = 0.0000

Figure 3:

Title:

Concentration curves

Figure 4:

Title:

Borough-level marginal effects on the probability of cycling, before (model 1A) and after (model 1B) controlling for individual-level effects

Notes:

- Boroughs are ordered by 2001 borough-level marginal effect

Figure 5:

Title:

Individual-level marginal effects on the probability of cycling, after controlling for borough-level fixed effects (model 1B)

Notes:

- Reference categories are age 30-39 (the median age), <5km distance to work (the most common category), NS-SEC category VII and White British

Table 1:

Notes:

- Included covariates (excluding column 1): population changes at the borough-level in terms of gender, age group and ethnicity.
- In the sub-group analyses, gender changes were excluded from the analysis in column 3, ethnicity changes were excluded from column 4 and age changes were excluded from column 5.
- Significance: *** $p<0.001$, ** $p<0.01$, * $p<0.05$.
- Individual-level observations refers to the number of individuals used to calculate the change in borough-level means that were used as covariates.

Figure 1

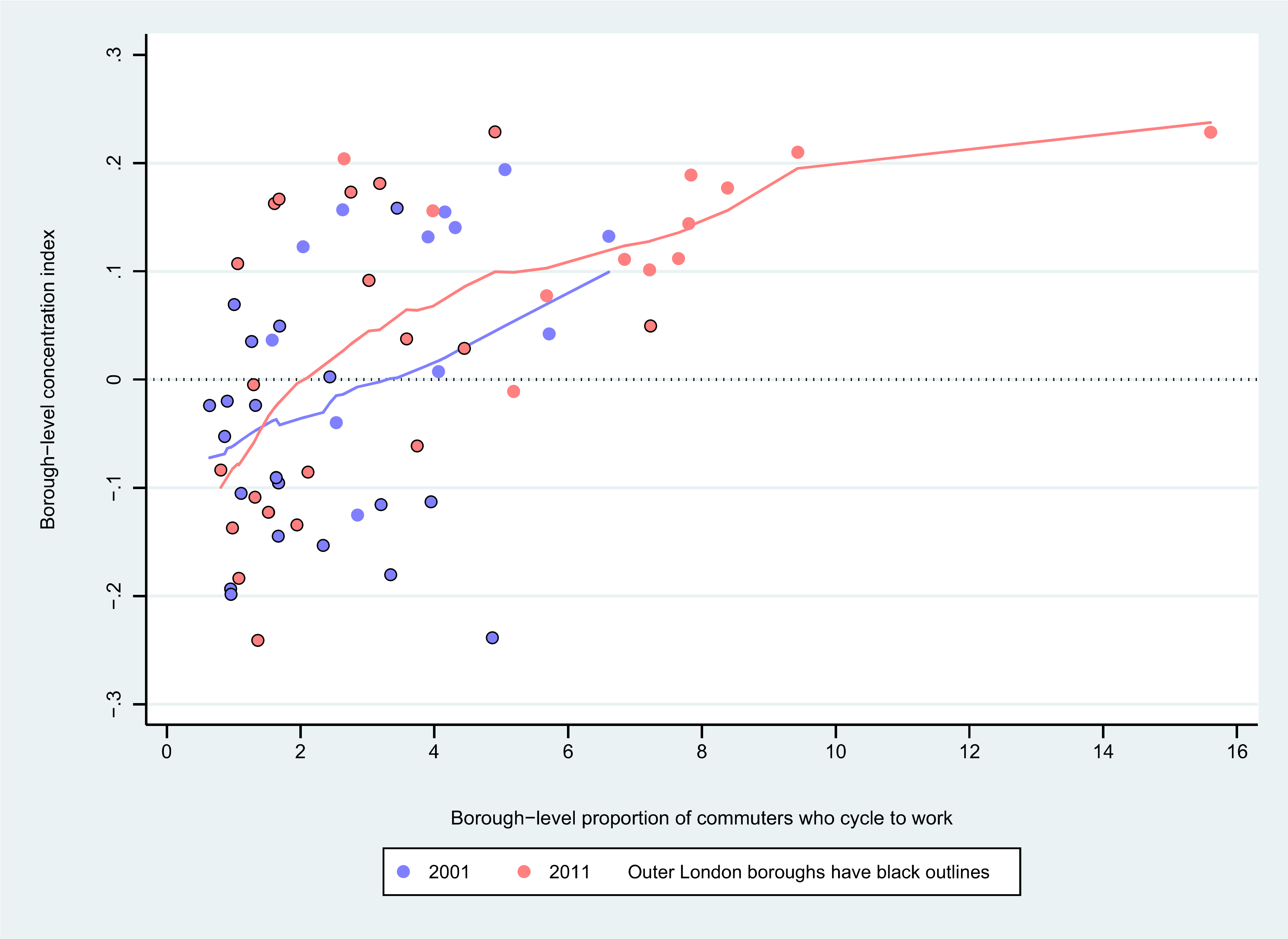

Borough−level concentration index
.3
.2
.1
0
−.1
−.2
−.3
0
2
4
6
8
10
12
14
16
Borough−level proportion of commuters who cycle to work
2001
2011
Outer London boroughs have black outlines

Figure 2

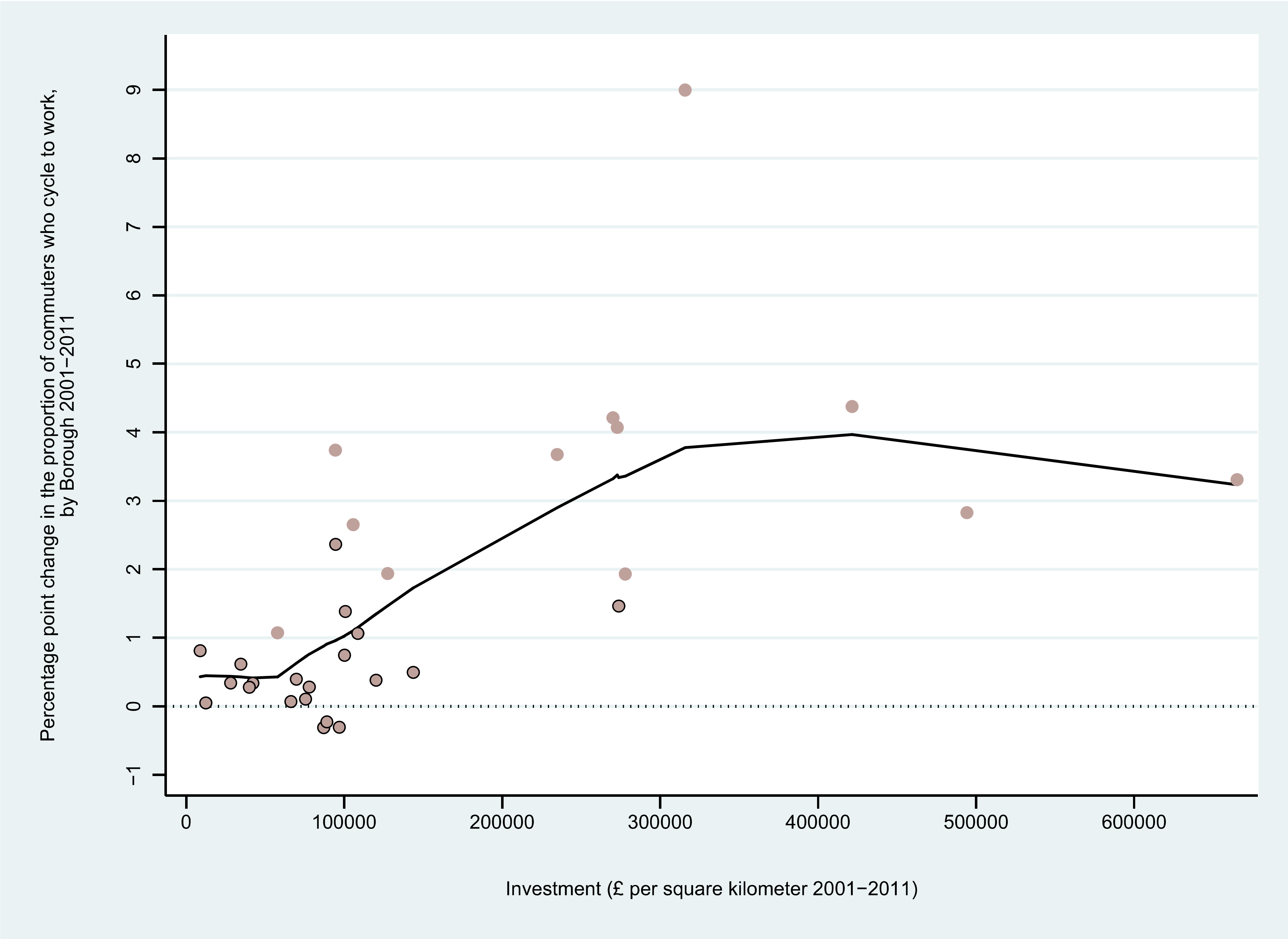

Percentage point change in the proportion of commuters who cycle to work,
by Borough 2001−2011
−1
0
1
2
3
4
5
6
7
8
9
0
100000
200000
300000
400000
500000
600000
Investment (£ per square kilometer 2001−2011)

Figure 3

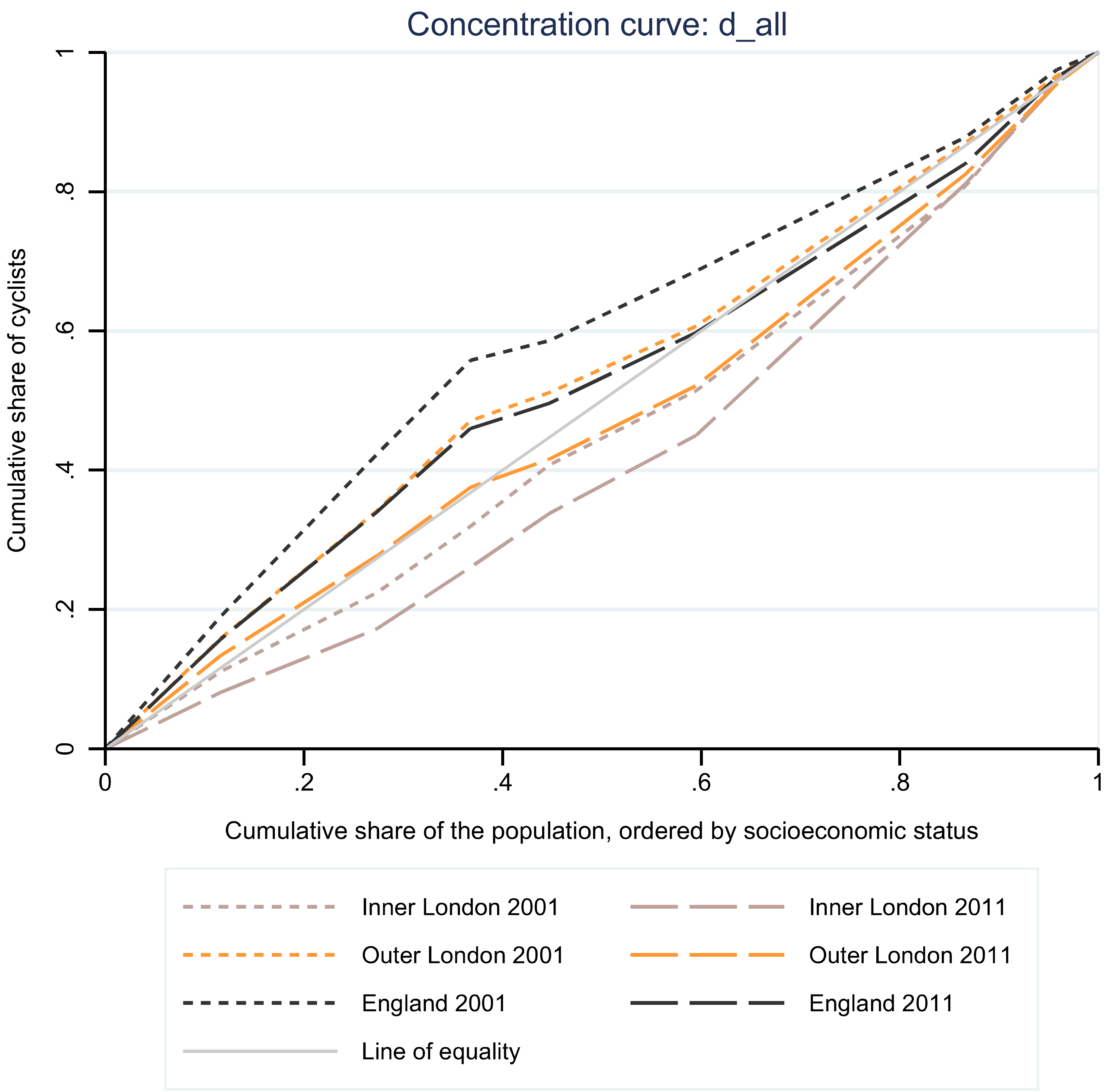

Concentration curve: d_all
Cumulative share of cyclists
0
.2
.4
.6
.8
1
Cumulative share of the population, ordered by socioeconomic status
Inner London 2001
Outer London 2001
England 2001
Line of equality
Inner London 2011
Outer London 2011
England 2011

Figure 4

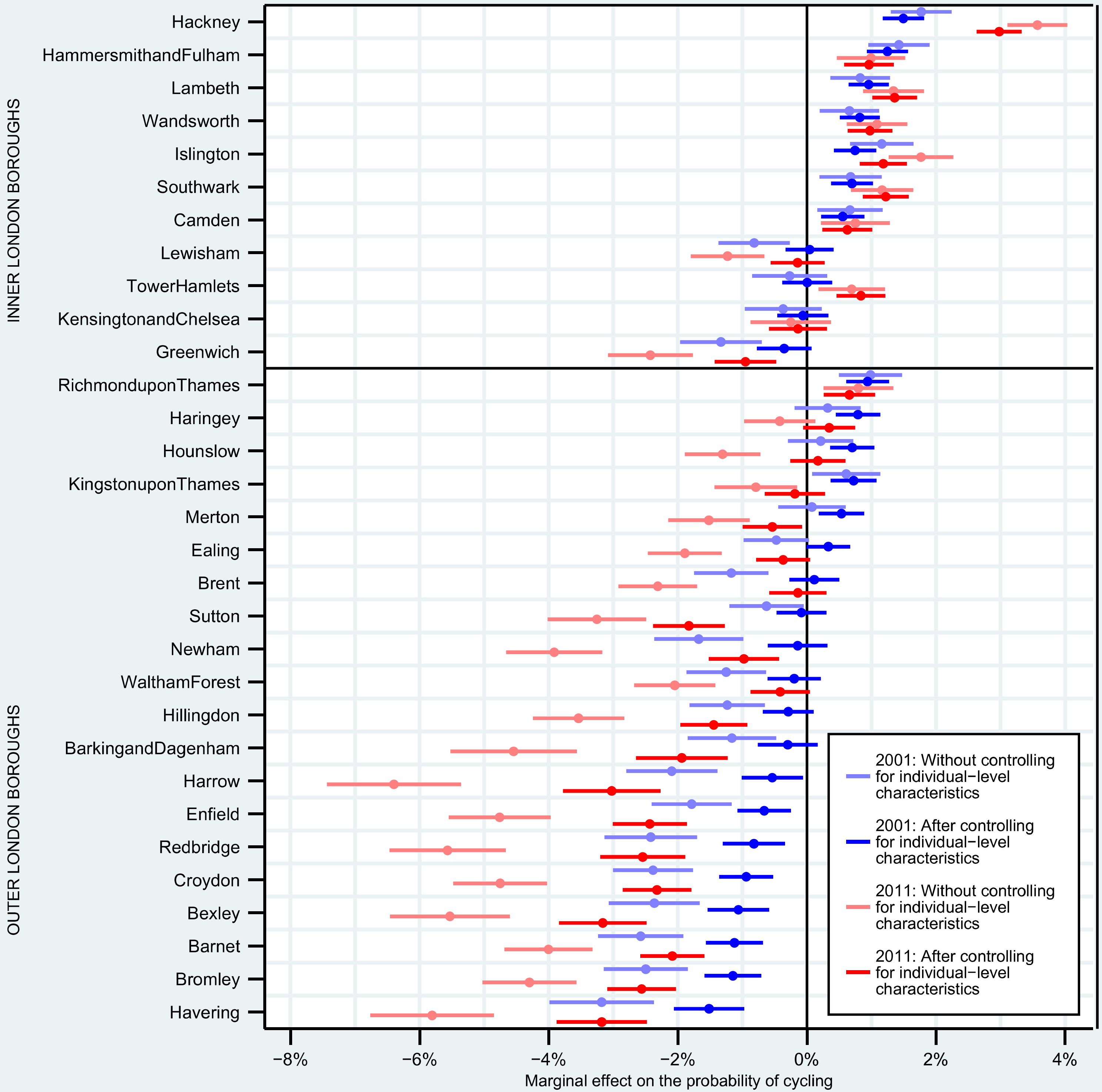
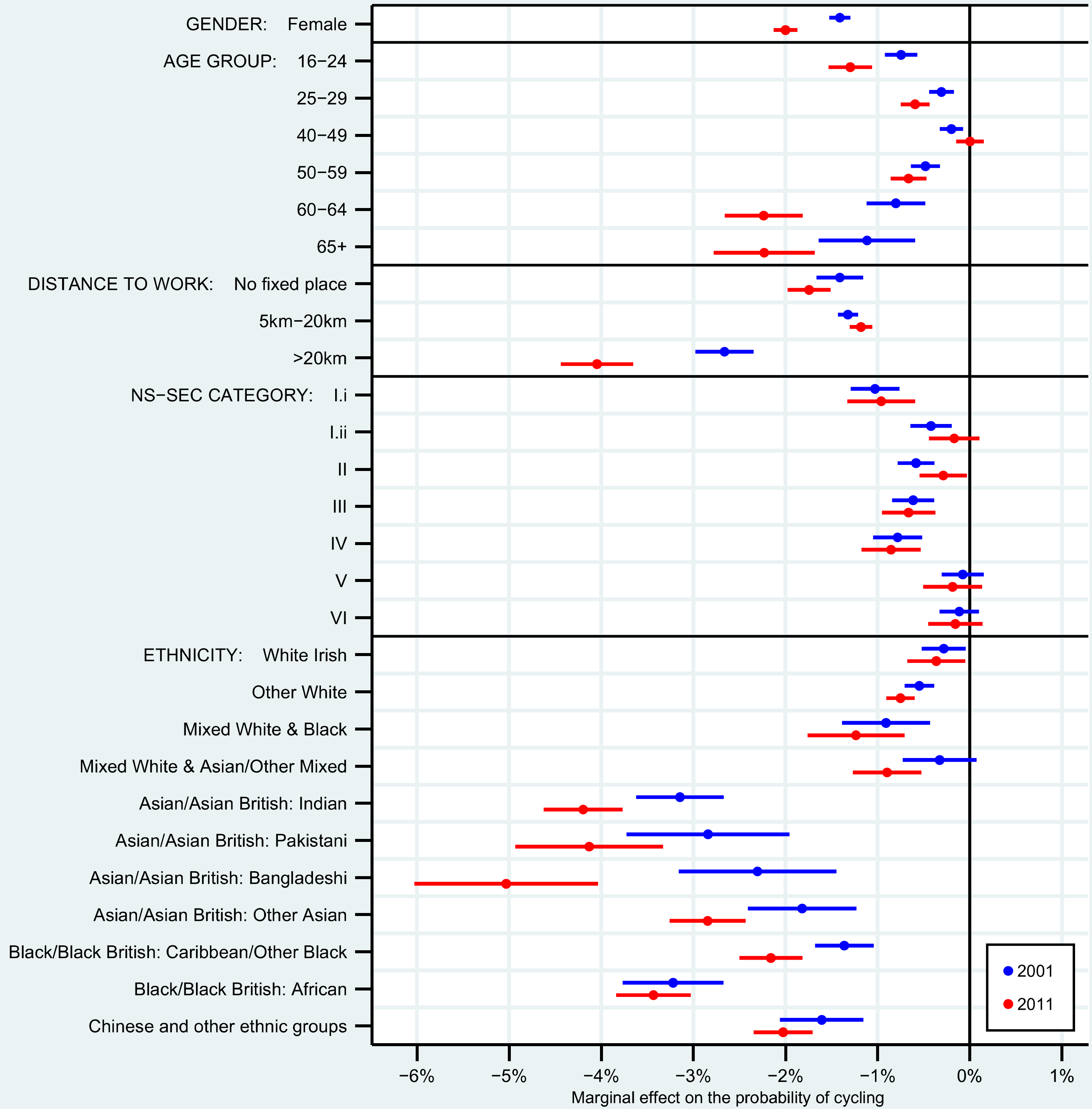

INNER LONDON BOROUGHS
OUTER LONDON BOROUGHS
Hackney
HammersmithandFulham
Lambeth
Wandsworth
Islington
Southwark
Camden
Lewisham
TowerHamlets
KensingtonandChelsea
Greenwich
RichmondupponThames
Haringey
Hounslow
KingstonuponThames
Merton
Ealing
Brent
Sutton
Newham
WalthamForest
Hillingdon
BarkingandDagenham
Harrow
Enfield
Redbridge
Croydon
Bexley
Barnet
Bromley
Havering
−8%
−6%
−4%
−2%
0%
2%
4%
Marginal effect on the probability of cycling
2001: Without controlling for individual−level characteristics
2001: After controlling for individual−level characteristics
2011: Without controlling for individual−level characteristics
2011: After controlling for individual−level characteristics

Figure 5


GENDER: Female
AGE GROUP: 16−24
25−29
40−49
50−59
60−64
65+
DISTANCE TO WORK: No fixed place
5km−20km
>20km
NS−SEC CATEGORY: I.i
I.ii
II
III
IV
V
VI
ETHNICITY: White Irish
Other White
Mixed White & Black
Mixed White & Asian/Other Mixed
Asian/Asian British: Indian
Asian/Asian British: Pakistani
Asian/Asian British: Bangladeshi
Asian/Asian British: Other Asian
Black/Black British: Caribbean/Other Black
Black/Black British: African
Chinese and other ethnic groups
2001
2011
−6%
−5%
−4%
−3%
−2%
−1%
0%
1%
Marginal effect on the probability of cycling