Characterising socio-economic inequalities in exposure to air pollution: a comparison of socio-economic markers and scales of measurement

Anna Goodman[1], Paul Wilkinson[2], Mai Stafford[3], Cathryn Tonne[4,5]

1 Faculty of Epidemiology and Population Health, London School of Hygiene and Tropical Medicine, London, UK

2 Faculty of Social and Environmental Health Research, London School of Hygiene and Tropical Medicine, London, UK

3 Epidemiology & Public Health, UCL Division of Population Health, London, UK

4 Faculty of Social and Environmental Health Research, London School of Hygiene and Tropical Medicine, London, UK

5 MRC-HPA Centre for Environment and Health, Faculty of Medicine, Imperial College London, London, UK

Corresponding author: Cathryn Tonne, Department of Social and Environmental Health Research , London School of Hygiene and Tropical Medicine, 15-17 Tavistock Place, London, WC1H 9SH, UK. Email: cathryn.tonne@lshtm.ac.uk

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Abstract

This study examines traffic-related air pollution in London in relation to area- and individual-level socio-economic position (SEP). Mean air pollution concentrations were generally higher in postcodes of low SEP as classified by small-area markers of deprivation (Index of Multiple Deprivation (IMD) domains) and by the postcode-level ACORN geodemographic marker. There were exceptions, however, including reversed directions of associations in central London and for SEP markers relating to education. ACORN predicted air pollution independently of IMD and explained additional variation at the postcode level, indicating the potential value of using both markers in air pollution epidemiology studies. By contrast, after including IMD and ACORN there remained little relationship between air pollution and individual-level SEP or smoking, suggesting limited residual socio-economic confounding in epidemiological studies with comprehensive area-level adjustment.

Keywords: Air pollution, socioeconomic factors, area deprivation, methods, confounding factors

Introduction

Exposure to traffic-related air pollution is associated with numerous adverse health effects, including all-cause mortality [1-5], cardiovascular events [2, 6-8], lung cancer [2, 9], and respiratory outcomes in children [10, 11]. Individuals of low socio-economic position (SEP) may be more exposed to air pollution and also more susceptible to these adverse health effects [12-16]. Such socio-economic differentials in exposure and health risk can be characterised as a source of environmental injustice, which exacerbates health inequalities via the 'triple jeopardy' of low SEP, polluted environment and impaired health [12, 17, 18].

In air pollution epidemiology research studies, SEP is typically characterised using individual-level and/or small area-level markers. In the UK, a very commonly used small-area marker is the Index of Multiple Deprivation (IMD [19]), which is available at Super Output Area level (containing around 1500 people). The IMD is typically examined as a single summary index of deprivation, although it can also be disaggregated to look at different domains of deprivation. A second less common small-area marker is the ACORN classifier ('A geodemographic Classification system Of Residential Neighbourhoods' [20]), which is available at the postcode level (containing around 50 people). To our knowledge, no previous study has compared the performance of these markers in terms of characterising and adjusting for SEP in epidemiological studies of air pollution and health. It is, however, plausible that they capture different aspects of socio-economic influence. For example, ACORN has a finer geographic resolution than IMD, and also includes additional variables such as age, life stage (e.g. children's age, working vs. retired) and 'lifestyle'.

There is also relatively limited evidence on how well such area-level markers perform against individual-level markers of SEP. Many air pollution studies do not have access to individual-level SEP data, and this is frequently cited as a reason for caution in interpreting their findings. Only a few studies, however, have investigated the likely magnitude of residual confounding by individual SEP and also smoking [21, 22]. These studies found limited additional value from inclusion of individual markers of SEP and smoking after making area-level adjustments.

This paper therefore uses data from London (UK) to 1) characterise in detail the association between air pollution and SEP, comparing different SEP markers and different scales of measurement; and 2) assess the potential for residual confounding in studies lacking individual-level data on SEP and smoking. This paper thereby addresses methodological issues of general relevance for studies investigating air pollution and health, as well as characterizing socio-economic inequalities which are of interest in their own right.

Methods

Setting and participants

We focussed upon residential unit postcodes within the orbital M25 motorway of London (UK). These 7-digit postcodes are used for mail delivery and contain a mean of 14 households and 51 individuals. We excluded the 870 postcodes not classified by ACORN, leaving a total of 186 424 postcodes in our analyses. The centroids of which were nested within 5344 Super Output Areas (SOAs) and 55 boroughs: SOAs contain a mean of around 1500 individuals and are the smallest areas for which census data are made available. For analytical purposes we also defined four zones of London: ‘central London’ (≤5km from Charing Cross, London’s conventional centre); ‘inner London’, (>5km from Charing Cross but in one of the 13 inner London boroughs); ‘outer London’ (the 20 outer London boroughs); and ‘outside London’ (the 22 boroughs outside Greater London but with postcodes inside the M25).

Our individual-level analyses used data from the Whitehall II study, an occupational cohort of London civil servants [23]. Out of 10,308 civil servants first recruited to the Whitehall study in 1985–1988, 6914 (67.1%) participated in the Whitehall II phase 7 follow-up in 2002-2004. Of these, 3654 Phase 7 participants had current residential postcodes within the M25 and formed the study population for this paper. These 3654 individuals had a mean age of 60.6 years (range 50-74) and were 64.0% male.

The study was approved by the London School of Hygiene and Tropical Medicine ethics committee, application number 5410.

Modelled exposure to air pollution

Annual average (2003) nitrogen oxides (NO_x) concentrations were provided by the Environmental Research Group, King’s College London. NO_x was used as a surrogate for traffic-related air pollution because it showed more spatial variation within London than the other modelled pollutants (PM_{10} and NO_2). The modelling approach has been described previously [16, 24]. Briefly, the NO_x contribution for roadways within a 500m buffer around 31 monitoring locations was modelled using ADMS Roads [25] and OSPM [26] and the contribution from the urban background was modelled using ADMS3. Concentrations from these emission-dispersion models were calibrated by fitting regression models to NO_x measurements from the 31 monitoring sites. The regression model was then applied to predict NO_x concentrations on a 20mX20m grid. Postcode average NO_x was calculated by averaging the concentrations for all gridpoints within 25m of the postcode centroid. The correlation between modelled and measured NO_x concentrations was 0.6 at 23 monitoring locations not included in the calibration step.

Markers of socio-economic position

We used markers of SEP measured at three different scales: the SOA, the postcode and the individual.

(i) Super Output Area-level Index of Multiple Deprivation (IMD)

The Index of Multiple Deprivation IMD: [27] is a weighted composite of small-area data relating to ten domains and subdomains (henceforth ‘domains’): income; employment; health; child education; adult education; crime; barriers to housing; barriers to services; indoor environment; and outdoor environment. Data for these domains can also be analysed separately.

Because outdoor environment deprivation is partly based upon modelled concentration of nitrogen dioxide, benzene, sulphur dioxide and particulates, we created an ‘IMD-minus-outdoor environment’ score. We did this adapting an approach previously used to remove the health domain from the full IMD score [28]. As when calculating the full IMD score [27], we standardized and exponentially transformed the non-outdoor environment domains. We then calculated new weights by reallocating the 3% weight of the outdoors environment score across the other domains, in proportion to their original weights (see Supplementary material).

(ii) Postcode-level ACORN classifier (‘A Geodemographic Classification system of Residential Neighbourhoods’)

The ACORN classification [20] starts by categorising census output areas using data from the 2001 UK census. Lifestyle/consumer surveys and publically-available data are then used 1) to reclassify postcodes differing substantially from their surrounding area and 2) to update ACORN annually. In this paper we use the ACORN 2003 mid-level categorization of 17 ‘groups’, ranked by ACORN in order of affluence (details in the Supplementary material).

(iii) Individual-level SEP and smoking status from the Whitehall II cohort

Participants in Phase 7 of the Whitehall II cohort [23] provided their current/most recent employment grade at the civil service, classified as clerical/executive officer (lower);

Higher/Senior executive officer (intermediate); and unified grades 1-7 (higher). Participants also provided information on their highest educational attainment, current household income and smoking habits. We also used the participants' current residential postcodes to assign the NOx, IMD and ACORN measures described above.

Statistical analysis

Analyses focused on the association between NO_x concentrations and the various markers of SEP, analysed by tabulation and linear regression. As NO_x concentrations were positively skewed, we used log NO_x values as the outcome in regression analyses. For ease of interpretation, we converted the regression coefficients (βs) into percent increase for unit change in explanatory factor using the formula [exp(β)-1]*100. We standardized all IMD scores using the London-wide means and standard deviations.

We accounted for spatial autocorrelation by fitting three-level random intercept models, of postcodes (or individuals) nested within SOAs nested within boroughs:

$$Y_{ijk} = \beta_0 + \beta_1 x_{1ijk} + ... + \beta_p x_{pijk} + B_k + S_{jk} + e_{ijk}$$

Where Y_{ijk} is the modelled NO_x concentration for the *i*th postcode/individual in the *j*th SOA in the *k*th borough; $\beta_1 ... \beta_p$ are the parameters for the fixed effects of interest ($x_{1ijk} ... x_{pijk}$), for example different ACORN groups; B_k is a random intercept for NO_x levels in the *k*th borough; S_{jk} is a random intercept for NO_x in the *j*th SOA in the *k*th borough; and e_{ijk} is the residual error term. Random intercepts were assumed to be normally distributed, allowing for different variance parameters for each random intercept and the residual error and were estimated using maximum likelihood estimation. We quantified spatial autocorrelation in NO_x using intraclass correlation coefficients (between-group variance/total variance), with the between-group variance equal to the variance of that level plus all higher levels. We also present R^2 values calculated as the percent reduction in each component of the model variance, as compared to the model without any covariates.

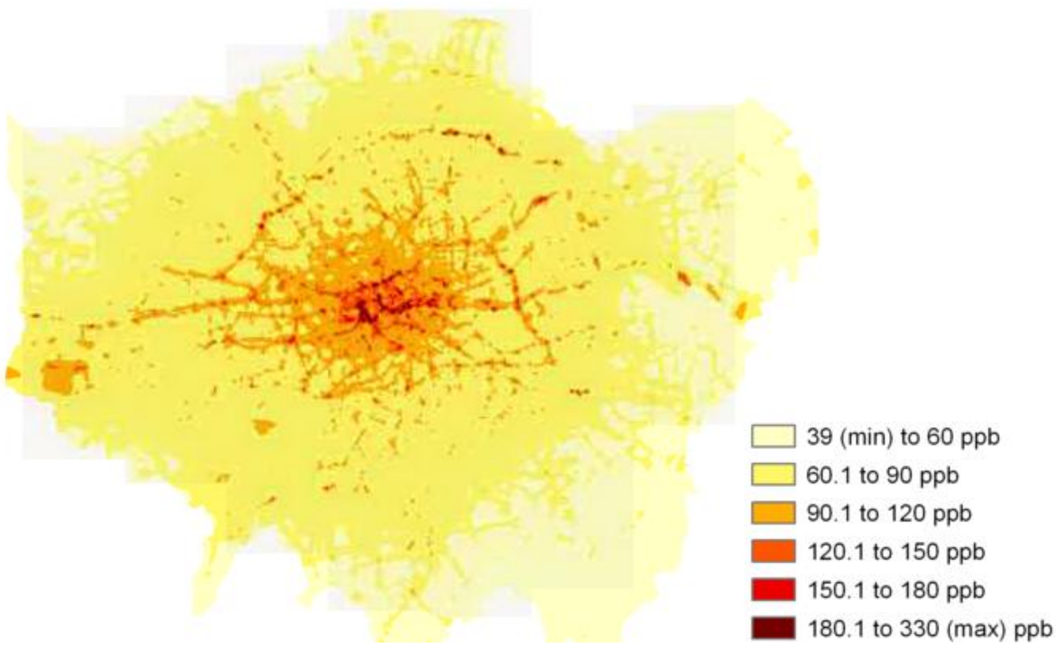
Among Whitehall II participants, the frequency of missing covariate data was 0-14.7%. We used multiple imputation to impute missing values under an assumption of missing at random, combining estimates across imputation models [29]. We used five imputations for these models, including in our imputation models all explanatory and outcome variables used in our models. We conducted statistical analyses in Stata 11.0, and created maps using ArcGIS.

Results

Air pollution and area deprivation

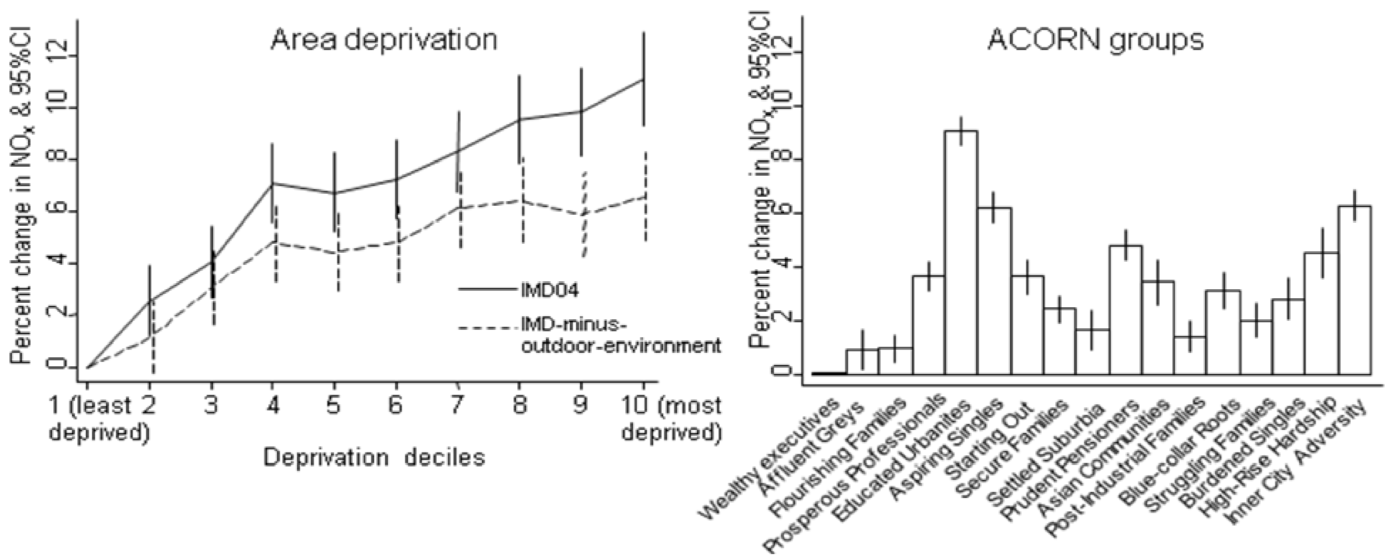
NO_x concentrations generally fell steadily at increasing distance from central London, from a mean of 136 parts per billion (range 88 to 415) in the 2km around Charing Cross to 40-60 parts per billion on the outskirts (**Error! Reference source not found.**; graphs for IMD in the Supplementary material). There was substantial spatial autocorrelation in NO_x concentrations. In a model without any covariates, the correlation between the NO_x concentrations of postcodes in the same borough but different SOAs was 0.66, and the correlation between postcodes in the same SOA was 0.77. As shown in **Error! Reference source not found.**, accounting for this autocorrelation substantially increased the standard errors and simultaneously decreased the effect sizes of the IMD scores. Allowing for spatial autocorrelation, each standard deviation (SD) increase in the full IMD score was associated with a 2.7% increase in NO_x concentration (95%CI 2.3 to 3.1; see also **Error! Reference source not found.**). When repeated using the IMD-minus-outdoor-environment score, however, this attenuated to a 1.6% increase in NO_x (95%CI 1.2 to 2.0), suggesting that the inclusion of an air quality indicator within the IMD introduced substantial circularity when examining its association with air pollution. Notably, the simple linear regression analysis which ignored both this circularity and the spatial autocorrelation produced an effect estimate which was an order of magnitude too large (13.4% vs. 1.6%).

Figure 1: Smoothed postcode averages for traffic-related air pollution (NO_x) across Greater London.



ppb=parts per billion. Postcode average NO_x concentrations were smoothed using ordinary kriging and an exponential semivariogram model.

Figure 2: Percent increase in NO_x concentrations by the full IMD and ACORN scores, in residential postcodes in London (N=186 424)



Our subsequent analyses focussed upon the separate IMD domains. The Pearson correlations between these domains was usually below 0.75 (see Supplementary material), with the exception of values >0.85 between income, employment and health.

The strength of association with NO_x concentrations showed appreciable variation by domain. This included a negative association for adult education and barriers to services, i.e. areas with greater deprivation in these respects had less air pollution; comparatively weak positive associations for child education and income, and appreciably stronger positive associations for outdoor environment and housing (**Error! Reference source not found.**). These associations were all approximately linear (graphs in Supplementary material) and persisted in multivariable analyses, albeit often with some attenuation of effect sizes (**Error! Reference source not found.** column 1).

Table 1: Association (unadjusted) between NO_x concentrations and the 2004 IMD score and its component domains for 186,424 postcodes of London

	Percent increase (95% CI) in NO_x concentration per standard deviate increase in explanatory variable	
	Without adjustment for spatial auto-correlation	**Allowing for spatial auto-correlation†**
Full IMD score (z-score)	13.6 (13.4, 13.7)	2.7 (2.3, 3.2)
IMD-minus-outdoor-environment (z-score)	11.5 (11.3, 11.6)	1.6 (1.2, 2.0)
Income (z-score)	6.7 (6.6, 6.9)	1.1 (0.8, 1.5)
Employment (z-score)	8.1 (8.0, 8.3)	1.5 (1.1, 1.8)
Health (z-score)	10.2 (10.1, 10.3)	2.5 (2.0, 3.0)
Education: child (z-score)	7.8 (7.6, 7.9)	1.1 (0.7, 1.5)
Education: adult (z-score)	-11.9 (-12.0, -11.8)	-2.2 (-2.5, -1.8)
Crime (z-score)	8.5 (8.3, 8.6)	3.5 (3.1, 3.8)
Barriers: housing (z-score)	24.9 (24.8, 25.1)	13.1 (12.1, 14.2)
Barriers: service (z-score)	-15.1 (-15.2, -15.0)	-3.0 (-3.4, -2.7)
Environment: indoor (z-score)	19.7 (19.6, 19.9)	4.7 (4.3, 5.1)
Environment: outdoor (z-score)	26.6 (26.5, 26.7)	10.6 (10.1, 11.0)

†We adjusted for spatial autocorrelation using a three level random intercept model in which postcodes were nested within SOAs which were nested in boroughs.

Table 2: Percent increase in NO_x concentrations in relation to IMD domain z-scores and ACORN group.

			Percent increase (95% CI) in NO_x per unit increase in value in explanatory factor		
		N postcodes	IMD domains †	ACORN group	Model containing both IMD domains + ACORN group$^{\$}$:
IMD domains (z-scores)	Employment	186 424	1.3 (0.8, 1.8)		1.1 (0.6, 1.6)
	Education: child	186 424	0.5 (0.1, 1.0)		0.1 (-0.4, 0.6)
	Education: adult	186 424	-5.1 (-5.6, -4.6)		-3.8 (-4.3, -3.3)
	Crime	186 424	1.9 (1.5, 2.3)		1.8 (1.4, 2.1)
	Barriers: housing	186 424	11.1 (9.8, 12.5)		9.7 (8.4, 11.0)
	Barriers: service	186 424	-1.3 (-1.7, -1.0)		-1.2 (-1.6, -0.9)
	Environment: indoor	186 424	1.3 (0.9, 1.7)		0.8 (0.4, 1.2)
ACORN group	Wealthy executives	9184		0	0
	Affluent Greys	2131		0.9 (0.2, 1.7)	0.9 (0.2, 1.6)
	Flourishing Families	7675		1.0 (0.5, 1.5)	1.0 (0.5, 1.5)
	Prosperous Professionals	9455		3.6 (3.1, 4.2)	3.0 (2.5, 3.6)
	Educated Urbanites	59 238		9.1 (8.5, 9.6)	8.1 (7.5, 8.6)
	Aspiring Singles	17934		6.2 (5.7, 6.8)	5.5 (5.0, 6.1)
	Starting Out	4730		3.6 (3.0, 4.3)	3.1 (2.5, 3.8)
	Secure Families	19 411		2.4 (1.9, 2.9)	2.3 (1.8, 2.8)
	Settled Suburbia	2288		1.7 (0.9, 2.4)	1.7 (0.9, 2.5)
	Prudent Pensioners	5446		4.8 (4.2, 5.4)	4.4 (3.8, 5.0)
	Asian Communities	2662		3.4 (2.6, 4.3)	2.7 (1.9, 3.6)
	Post-Industrial Families	8162		1.4 (0.8, 2.0)	1.4 (0.8, 2.0)
	Blue-collar Roots	4004		3.1 (2.5, 3.8)	2.9 (2.2, 3.6)
	Struggling Families	6431		2.0 (1.4, 2.6)	1.7 (1.1, 2.4)
	Burdened Singles	2382		2.8 (2.1, 3.6)	2.3 (1.6, 3.1)
	High-Rise Hardship	1261		4.5 (3.6, 5.5)	3.8 (2.9, 4.8)
	Inner City Adversity	24 030		6.3 (5.7, 6.8)	5.4 (4.8, 6.0)
Model components of variance	Level 3: Borough-level		0.01	0.04	0.01
	Level 2: SOA-level		0.01	0.01	0.01
	Level 1: Postcode-level		0.02	0.02	0.02
Intra-class correlation	Level 3: Within boroughs		0.32	0.63	0.33
	Level 2: Within SOAs		0.54	0.77	0.55
R^2 (percent of variance explained)	Total R^2		0.55	0.13	0.55
	Level 3: Borough level R^2		0.79	0.17	0.78
	Level 2: SOA level R^2		0.24	0.10	0.25
	Level 1: Postcode level R^2		0.00	0.01	0.01

IMD=Indices of Multiple Deprivation, SOA=Super Output Area. †Results for individual domains are adjusted for all other variables shown in the column. Outdoor environment IMD domain not entered due to the circularity of using it to predict air pollution; income and health IMD domains omitted due to collinearity with IMD employment.

There was also strong evidence that these associations were not uniform across all zones of London ($p<0.001$ for interaction between all 10 domains and zone of London except child education for which $p=0.08$; full results in Supplementary material). Point estimates of positive or negative associations were generally largest in outer London, usually followed by inner London. Outside London the associations were weaker or non-significant while in central London most associations were non-significant or in the reverse direction; that is, in central London higher SEP was associated with higher NO_x

concentrations. The overall positive association between the full IMD score and air pollution therefore concealed heterogeneity both by deprivation type and across different zones of the city.

ACORN as a complementary socioeconomic indicator at the postcode level

We next examined the potential of ACORN to substitute or complement IMD. There was strong evidence of heterogeneity in NO_x exposure across the ACORN groups (**Error! Reference source not found.** and **Error! Reference source not found.**). The lowest NO_x exposure was for ‘Wealthy executives’, the most affluent ACORN group (rank 1/17). Unlike for IMD, however, air pollution did not then show a progressive association with ACORN rank. For example, the groups with the highest NO_x concentrations were ‘Educated urbanites’ (rank 5/17; NO_x exposure 9.08% higher than Wealthy executives) followed by ‘Inner city adversity’ (rank 17/17) and ‘Aspiring singles’ (rank 6/17). It was also notable that the 17 ACORN groups had a Spearman’s correlation of only 0.45 with the IMD deciles. This low correlation reflected comparatively high IMD scores in groups like ‘Educated urbanites’, ‘Aspiring singles’ and ‘Asian communities’ (see Supplementary material).

The IMD and ACORN effect sizes decreased relatively modestly in multivariable analyses including both markers simultaneously (**Error! Reference source not found.** column 3). Both markers likewise independently predicted NO_x concentrations in analyses stratified by zone of London (see Supplementary material). ACORN’s finer geographic resolution also meant that although overall it explained less NO_x variance than IMD (R^2=0.13 for ACORN, R^2=0.55 for IMD), it did uniquely explain a small part of the residual variation at the postcode level (R^2=0.01 for ACORN, R^2=0.00 for IMD).

Low potential for residual confounding by individual-level characteristics

IMD and ACORN were associated with all individual-level SEP and smoking variables in the Whitehall II cohort, with stronger associations for ACORN (see Supplementary material). In (unadjusted) analyses of the individual-level Whitehall II data, NO_x exposure was associated with low employment grade, low household income and current smoking ($p<0.002$ for heterogeneity) but not with highest education ($p>0.6$; see also **Error! Reference source not found.**). Nevertheless the differences in NO_x concentration across the fairly broad categories of each of these variables were modest (mainly less than 2%). This was substantially smaller than the differences of up to around 20% per standard deviate change in IMD domain or the variation across ACORN groups (Table 3). Moreover, adjusting for these area-level markers caused the individual-level associations to become only weakly significant for smoking (p=0.02 for heterogeneity) and non-significant for SEP ($p\geq0.06$ for heterogeneity).

Table 3: Percent increase in NO_x concentration in relation to SEP and smoking, with and without adjustment for IMD domains and ACORN

			Number of individuals	Percent increase (95%CI) in NO_x				
				Unadjusted	Adjusted for			
					Individual-level factors only	Individual-level factors plus ACORN	Individual-level factors plus IMD	Individual-level factors plus IMD and ACORN
Individual-level markers	Grade	Lower	1123	0	0	0	0	0
		Intermediate	1054	-1.1 (-1.9, -0.3)	-1.1 (-1.9, -0.2)	-1.0 (-1.9, -0.1)	-0.8 (-1.7, 0.0)	-0.8 (-1.6, 0.0)
		Higher	1412	-1.7 (-2.5, -0.9)	-1.6 (-2.6, -0.6)	-1.5 (-2.4, -0.5)	-1.2 (-2.1, -0.2)	-1.1 (-2.1, -0.2)
	Highest education	None	357	0	0	0	0	0
		O-levels	797	0.2 (-1.0, 1.4)	0.6 (-0.6, 1.8)	0.7 (-0.6, 2.0)	0.4 (-0.8, 1.6)	0.5 (-0.8, 1.7)
		A/S level	805	-0.4 (-1.6, 0.7)	0.5 (-0.7, 1.7)	0.5 (-0.7, 1.7)	0.0 (-1.2, 1.1)	0.1 (-1.0, 1.3)
		BA/BSc	716	-0.5 (-1.7, 0.8)	0.8 (-0.6, 2.2)	0.8 (-0.6, 2.3)	0.2 (-1.1, 1.6)	0.4 (-1.0, 1.8)
		Postgraduate	442	-0.3 (-1.6, 1.1)	1.2 (-0.2, 2.7)	1.5 (0.0, 3.0)	0.6 (-0.9, 2.1)	1.0 (-0.5, 2.5)
	Household income last year	<£20 000	869	0	0	0	0	0
		£20 000-34 999	935	-0.1 (-1.0, 0.7)	0.2 (-0.6, 1.1)	0.5 (-0.4, 1.3)	0.3 (-0.6, 1.1)	0.4 (-0.4, 1.3)
		£35 000-64 999	1062	-1.4 (-2.2, -0.5)	-0.9 (-1.8, 0.0)	-0.4 (-1.3, 0.5)	-0.8 (-1.7, 0.1)	-0.6 (-1.4, 0.3)
		≥£70 000	504	-1.2 (-2.2, -0.2)	-0.5 (-1.7, 0.6)	0.1 (-1.1, 1.2)	-0.6 (-1.7, 0.6)	-0.2 (-1.3, 0.9)
	Smoking	Never	1881	0	0	0	0	0
		Ex-smoker	1389	-0.2 (-0.8, 0.5)	0.0 (-0.7, 0.6)	0.1 (-0.5, 0.7)	0.0 (-0.6, 0.6)	0.0 (-0.6, 0.6)
		Current smoker	345	1.9 (0.8, 3.0)	1.9 (0.8, 3.0)	1.5 (0.4, 2.6)	1.6 (0.6, 2.7)	1.5 (0.4, 2.6)
Postcode-level markers	ACORN group	Wealthy executives	302	0		0		0
		Affluent Greys	62	0.4 (-2.2, 3.1)		0.4 (-2.2, 3.1)		0.2 (-2.5, 3.0)
		Flourishing Families	301	1.6 (0.0, 3.2)		1.6 (0.0, 3.2)		1.3 (-0.3, 2.9)
		Prosperous Professionals	386	6.3 (4.5, 8.1)		6.2 (4.5, 8.0)		2.8 (1.1, 4.6)
		Educated Urbanites	832	13.4 (11.5, 15.3)		13.2 (11.3, 15.1)		7.1 (5.2, 9.1)
		Aspiring Singles	285	8.2 (6.1, 10.3)		7.6 (5.5, 9.8)		3.2 (1.0, 5.3)
		Starting Out	104	8.3 (5.9, 10.7)		8.0 (5.6, 10.4)		4.4 (2.1, 6.9)
		Secure Families	504	4.0 (2.4, 5.7)		3.8 (2.1, 5.5)		2.8 (1.1, 4.6)
		Settled Suburbia	74	1.0 (-1.5, 3.5)		0.6 (-1.8, 3.2)		0.5 (-2.0, 3.1)
		Prudent Pensioners	114	4.7 (2.4, 7.0)		4.4 (2.1, 6.8)		2.1 (-0.2, 4.5)
		Asian Communities	30	7.6 (2.7, 12.8)		6.9 (2.0, 12.0)		3.0 (-1.8, 7.9)
		Post-Industrial Families	167	3.9 (1.7, 6.1)		3.6 (1.4, 5.7)		2.7 (0.5, 5.0)
		Blue-collar Roots	54	7.2 (4.0, 10.5)		6.9 (3.7, 10.2)		5.0 (1.8, 8.3)
		Struggling Families	46	0.7 (-2.8, 4.2)		0.2 (-3.3, 3.7)		-1.6 (-5.1, 2.1)

		Burdened Singles	10	6.1 (-0.8, 13.5)		5.6 (-1.4, 13.0)		1.3 (-5.2, 8.4)
		High-Rise Hardship	10	19.1 (11.5, 27.3)		17.7 (10.1, 25.8)		12.3 (5.2, 19.9)
		Inner City Adversity	156	17.2 (14.3, 20.1)		16.4 (13.4, 19.4)		10.4 (7.3, 13.5)
SOA-level markers	**IMD domains (z-scores)**	**Employment**	3654	3.0 (2.3, 3.8)			1.8 (0.8, 2.8)	1.1 (0.1, 2.2)
		Education: child	3654	2.4 (1.8, 3.0)			1.5 (0.7, 2.4)	1.2 (0.4, 2.0)
		Education: adult	3654	-1.1 (-1.8, -0.5)			-4.6 (-5.5, -3.7)	-3.7 (-4.7, -2.7)
		Crime	3654	3.3 (2.6, 3.9)			1.3 (0.6, 1.9)	1.3 (0.7, 2.0)
		Barriers: housing	3654	13.1 (11.6, 14.7)			7.9 (6.0, 9.9)	6.4 (4.5, 8.4)
		Barriers: service	3654	-3.3 (-3.9, -2.7)			-1.6 (-2.2, -1.0)	-1.5 (-2.1, -0.9)
		Environment: indoor	3654	4.4 (3.8, 5.0)			0.8 (0.1, 1.5)	0.4 (-0.3, 1.1)
	Model components of variance	**Level 3: Borough-level**			0.07	0.02	0.05	0.02
		Level 2: SOA-level			0.01	0.01	0.01	0.01
		Level 1: Individual-level			0.00	0.00	0.00	0.00
	Intra-class correlation	**Level 3: Within boroughs**			0.83	0.64	0.81	0.66
		Level 2: Within SOAs			0.94	0.86	0.93	0.86
	R^2 (percent of variance explained)	**Total**			0.01	0.61	0.24	0.60
		Level 3: Borough level R^2			0.01	0.70	0.27	0.69
		Level 2: SOA-level R^2			0.02	0.24	0.19	0.27
		Level 1: Individual-level R^2			0.00	0.00	0.00	0.03

IMD=Indices of Multiple Deprivation, SOA=Super Output Area.

Discussion

This paper confirms an important substantive issue of environmental justice: across London as a whole, mean air pollution (as reflected in NO_x concentrations) is greater for areas and individuals with lower socio-economic position/greater deprivation. The magnitude of the association was substantially over-estimated, however, by ignoring spatial autocorrelation in NO_x and by ignoring the inclusion of an 'air quality' indicator in the full IMD score. This overall association also concealed heterogeneity by geographical zone and by type of SEP, including reversed directions of association in central London and for SEP markers related to adult education. In models including multiple SEP markers, air pollution was independently predicted by both the IMD z-scores and the 17-group ACORN classifications. This indicates that ACORN may be a useful area-based complement to IMD in air pollution epidemiology studies seeking to adjust for socio-demographic characteristics. By contrast, NO_x variation was relatively small across the (comparatively broad) markers of individual-level SEP status, and after adjusting for area-based markers there was little evidence of the potential for residual confounding by individual-level SEP and smoking. This suggests that finely-categorized area markers of deprivation show clearer association with air pollution than broad SEP groupings based on individual data. It further suggests that there is little disadvantage in lacking such individual-level markers of SEP for studies of air pollution and health which have good small-area data.

Our study replicates the recent demonstration that ignoring spatial autocorrelation substantially overestimated the magnitude of socio-economic inequalities in air pollution exposure [30]Our study also demonstrates that the association between area SEP and air pollution was substantially overestimated by the inclusion of an 'air quality' indicator within the IMD scores released by the government in 2004 [19] and 2007 [31]. This circularity may have led to overestimation of the association between SEP and air pollution in British studies using these IMD scores [14, 16]. We therefore recommend that air pollution epidemiology studies enter the IMD domains separately, excluding the outdoor environment domain and also the health domain, as previously acknowledged [28, 32]. We further recommend considering ACORN as a second complementary marker, given that ACORN was independently associated with NO_x, unlike IMD, explained some of the smallest scale variation that is most likely to cause residual confounding by individual SEP.

In investigating whether IMD and ACORN are likely to provide adequate adjustment for confounding by SEP, our analysis of the Whitehall II data revealed that traffic-related air pollution was more closely related to area-level than individual-level SEP. Moreover, adjusting for IMD and ACORN eliminated much of the relationship with individual SEP and smoking, a finding consistent with previous research [21, 22]. This stronger association with area-level markers may partly reflect their finer categorisation; for example 17 ACORN groups vs. 3-5 categories for our individual-level SEP markers. While in this sense we were not comparing like with like, in practice few epidemiological studies have detailed data beyond relatively broad categorisations of individual SEP. Our findings suggest that air pollution epidemiology studies without individual-level data of this sort are unlikely to suffer substantial residual confounding if they use comprehensive area-level adjustment.

Yet even comprehensive area-level adjustment is unlikely to account fully for the multiple systematic differences in values and preferences which influence where people live. The socio-demographic and socio-economic characteristics we considered are probably among the most important differences for health, but do not capture all differences. For example, neighbourhoods in London with comparable levels of economic capital may have very different levels of social capital [33]. Like most studies, we lacked area-level data on characteristics such as this, and therefore cannot estimate the magnitude of this additional residual confounding in air pollution epidemiology studies. Another limitation is our use of NO_x concentration at the residential postcode as a surrogate for personal exposure to traffic related air pollution. This ignores potential socio-economic differences in activity patterns, time spent at residence or occupational exposure (although variability in the latter may have been reduced by our use of an occupational cohort).

Finally, it is unclear how far our substantive findings are generalisable outside of London. For example, disaggregating the ‘child education’ and ‘adult education’ IMD domains revealed that air pollution levels were *higher* in areas with many skilled adults, an anomaly consistent with the fact that ‘Educated urbanites’ were the most exposed ACORN group. Educational attainment was likewise the only individual-level SEP marker not associated with air pollution in Whitehall II. This distinctive association of education with air pollution has not previously been documented in the UK, and may not apply outside London – although consistent previous findings from Montreal [34] suggest at least the potential for generalisability.

Yet even if these findings prove entirely context-specific, they illustrate several important general principles. First, air pollution may show different associations with different area- and individual-level SEP markers. Studies should therefore not assume that all dimensions of SEP can be used interchangeably when adjusting for confounding, and if possible should explore a range of SEP indicators. Second, the magnitude and even direction of the association with SEP may differ between geographical zones. Examining local socio-geographic contexts is therefore essential [34], and may also highlight opportunities for testing hypotheses using informative exceptions (e.g. affluent city centres exposed to high air pollution [34, 35]).

In summary, small-area markers of socio-economic position appear to perform well in showing variations in exposure to traffic-related air pollution (NO_x) and in allowing adjustment for confounding by socio-economic status in environmental epidemiological studies of air pollution and health. The associations with air pollution may vary between different domains of SEP and between larger geographical zones. Further study of these associations will provide greater insights into the inequalities that arise from the interrelationship between air pollution, socio-economic position and health.

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Competing interests

None

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Characterising socio-economic inequalities in air pollution: Supplementary material

Table 4: Domains and indicators of the English Indices of Multiple Deprivation, 2004

Domain	Sub-domain	Indicator variables (year of collection)	Original weight	Redis-tributed weight
Income Deprivation		1. Adults and children in Income Support households (2001). 2. Adults and children in Income Based Job Seekers Allowance households (2001). 3. Adults and children in Working Families Tax Credit households with equivalised income (excl. housing benefits) below 60% of median before housing costs (2001). 4. Adults and children in Disabled Person's Tax Credit households whose equivalised income (excl. housing benefits) below 60% of median before housing costs (2001). 5. National Asylum Support Service supported asylum seekers in England in receipt of subsistence only and accommodation support (2002).	22.5%	23.2%
Employment Deprivation		6. Unemployment claimant count (JUVOS) of women aged 18-59 and men aged 18-64 averaged over 4 quarters (2001). 7. Incapacity Benefit claimants (women aged 18-59 and men aged 18-64) (2001). 8. Severe Disablement Allowance claimants (women aged 18-59, men aged 18-64) (2001). 9. Participants in New Deal for 18-24 year olds not in the claimant count (2001). 10. Participants in New Deal for 25 year olds not included in the claimant count (2001). 11. Participants in New Deal for Lone Parents aged 18 and over (2001).	22.5%	23.2%
Health Deprivation and Disability		12. Years of Potential Life Lost (1997-2001). 13. Comparative Illness and Disability Ratio (2001). 14. Measures of emergency admissions to hospital (1999-2002). 15. Adults under 60 suffering from mood or anxiety disorders (1997-2002).	13.5%	13.9%
Education, Skills and Training Deprivation	**Child**	16. Average points score of children at Key Stage 2 (2002). 17. Average points score of children at Key Stage 3 (2002). 18. Average points score of children at Key Stage 4 (2002). 19. Proportion of young people not staying on in school or school level education above 16 (2001). 20. Proportion of those aged under 21 not entering Higher Education (1999-2002). 21. Secondary school absence rate (2001-2002).	6.75%	7.0%
	Adult	22. Proportions of working age adults (aged 25-54) in the area with no or low qualifications (2001).	6.75%	7.0%
Crime		23. Burglary (4 recorded crime offence types, April 2002-March 2003). 24. Theft (5 recorded crime offence types, April 2002-March 2003, constrained to CDRP level). 25. Criminal damage (10 recorded crime offence types, April 2002-March 2003). 26. Violence (14 recorded crime offence types, April 2002-March 2003).	9.3%	9.6%
Barriers to Housing and Services	**Housing**	27. Household overcrowding (2001). 28. LA level percentage of households for whom a decision on their application for assistance under the homeless provisions of housing legislation has been made, assigned to SOAs (2002). 29. Difficulty of access to owner-occupation (2002).	4.65%	4.8%
	Distance to services	30. Road distance to GP premises (2003). 31. Road distance to a supermarket or convenience store (2002). 32. Road distance to a primary school (2001-2002). 33. Road distance to a Post Office (2003).	4.65%	4.8%
The Living Environment	**Indoor**	34. Social and private housing in poor condition (2001). 35. Houses without central heating (2001).	6.2%	6.4%
	Outdoor	36. Air quality *[modelled concentration of Nitrogen Dioxide, Benzene, Sulphur Dioxide and particulates]* (2001). 37. Road traffic accidents involving injury to pedestrians and cyclists (2000-2002).	3.1%	0%

Source: 1. Office of the Deputy Prime Minister. The English Indices of deprivation 2004 (revised), 2004.

Table 5: ACORN categories, groups and types

ACORN category	ACORN group	ACORN TYPE
Wealthy achievers	Wealthy executives	1. Wealthy Mature Professionals, Large Houses 2. Wealthy Working Families with Mortgages 3. Villages with Wealthy Commuters 4. Well-Off Managers, Larger Houses
	Affluent Greys	5. Older Affluent Professionals 6. Farming Communities 7. Old People, Detached Homes 8. Mature Couples, Smaller Detached Homes
	Flourishing Families	9. Older Families, Prosperous Suburbs 10. Well-Off Working Families with Mortgage 11. Well-Off Managers, Detached Houses 12. Large Families and Houses in Rural Areas
Urban prosperity	Prosperous Professionals	13. Well-Off Professionals, Larger Houses and Converted Flats 14. Older Professionals in Suburban Houses and Apartments
	Educated Urbanites	15. Affluent Urban Professionals, Flats 16. Prosperous Young Professionals, Flats 17. Young Educated Workers, Flats 18. Multi-Ethnic Young, Converted Flats 19. Suburban Privately Renting Professional
	Aspiring Singles	20. Student Flats and Cosmopolitan Sharers 21. Singles and Sharers, Multi-Ethnic Areas 22. Low-Income Singles, Small Rented Flats 23. Student Terraces
Comfortably off	Starting Out	24. Young Couples, Flats and Terraces 25. White-Collar Singles and Sharers, Terraces
	Secure Families	26. Younger White-Collar Couples with Mortgages 27. Middle-Income, Home-Owning Areas 28. Working Families with Mortgages 29. Mature Families in Suburban Semis 30. Established Home-Owning Workers 31. Home-Owning Asian Family Areas
	Settled Suburbia	32. Retired Home Owners 33. Middle-Income, Older Couples 34. Lower Incomes, Older People, Semis
	Prudent Pensioners	35. Elderly Singles, Purpose-Built Flats 36. Older People, Flats
Moderate means	Asian Communities	37. Crowded Asian Terraces 38. Low-Income Asian Families
	Post-Industrial Families	39. Skilled Older Families, Terraces 40. Young Working Families
	Blue-collar Roots	41. Skilled Workers, Semis and Terraces 42. Home-Owning Families, Terraces 43. Older People, Rented Terraces
Hard-pressed	Struggling Families	44. Low-Income Larger Families, Semis 45. Low-Income, Older People, Smaller Semis 46. Low-Income, Routine Jobs, Terraces and flats 47. Low-Income Families, Terraced Estates 48. Families and Single Parents, Semis and terraces 49. Large Families and Single Parents, Many children
	Burdened Singles	50. Single Elderly People, Council Flats 51. Single Parents and Pensioners, Council terraces 52. Families and Single Parents, Council Flats
	High-Rise Hardship	53. Old People, Many High-Rise Flats 54. Singles and Single Parents, High-Rise Estates
	Inner City Adversity	55. Multi-Ethnic, Purpose-Built Estates 56. Multi-Ethnic, Crowded Flats

Source: CACI. *The ACORN user guide*. London: CACI, 2009.

Figure 3: Distribution of the Index of Multiple Deprivation (IMD) score and domains across residential postcodes in London.

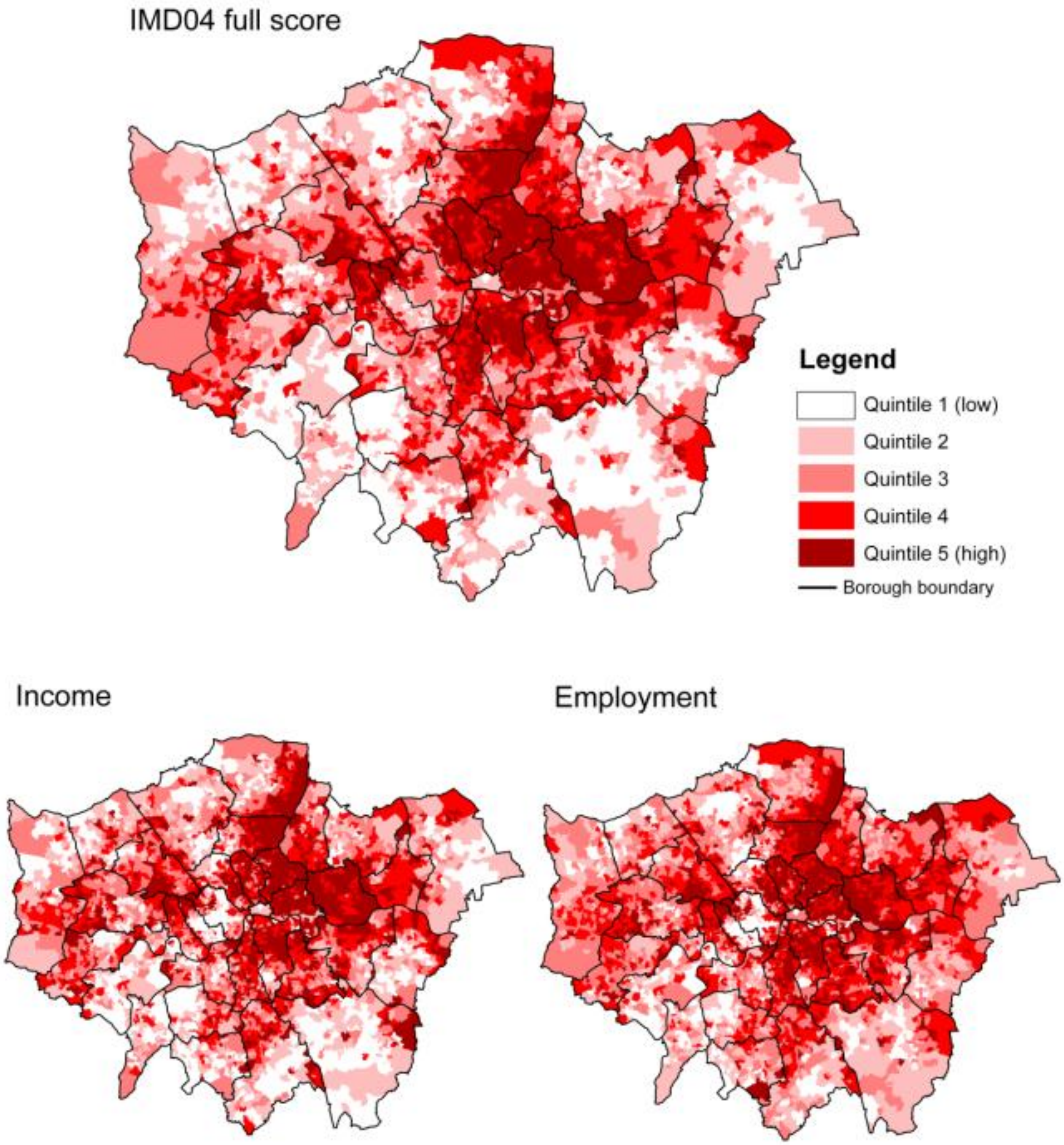


Figure 3 continued

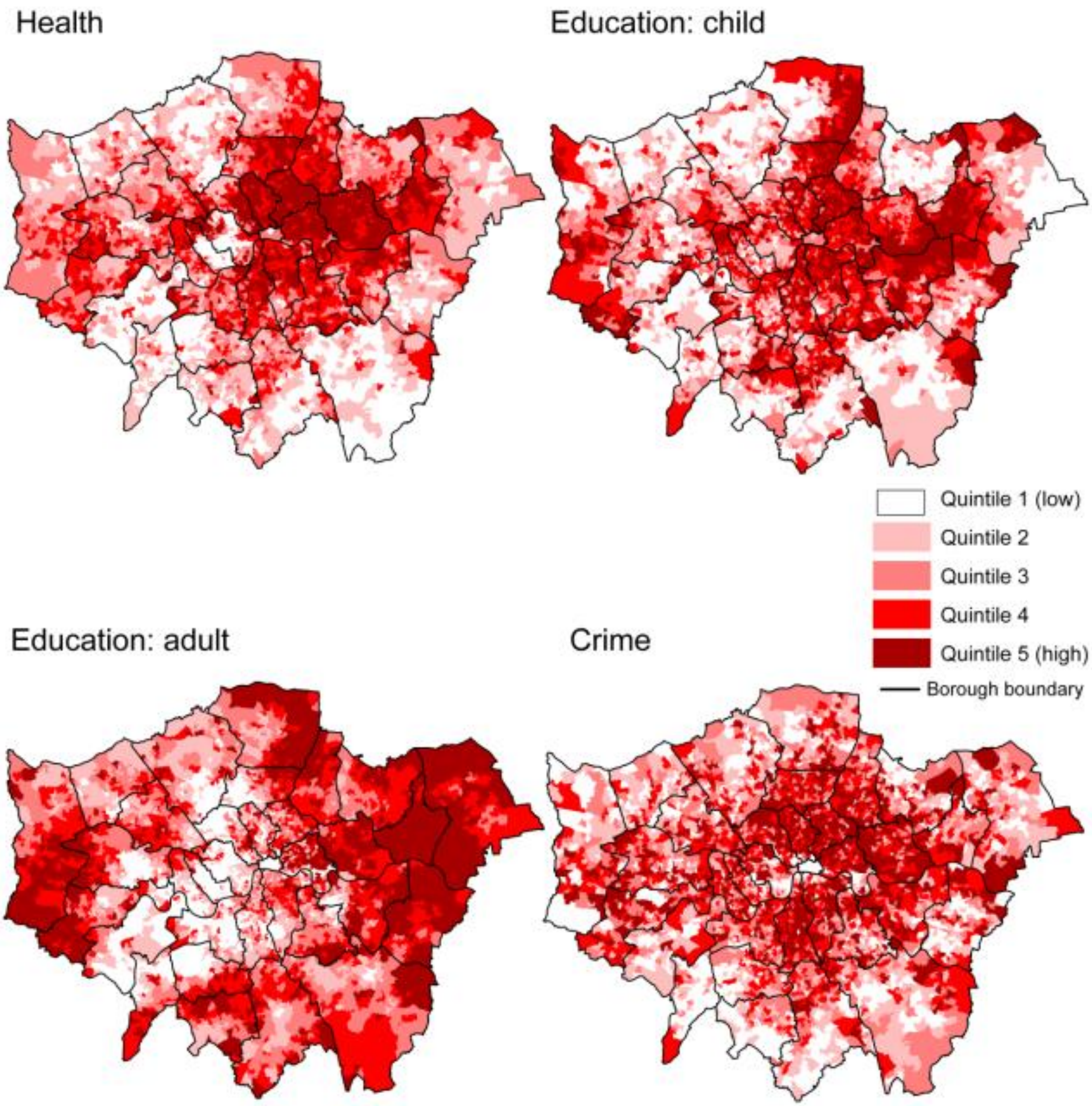


Figure 3 continued

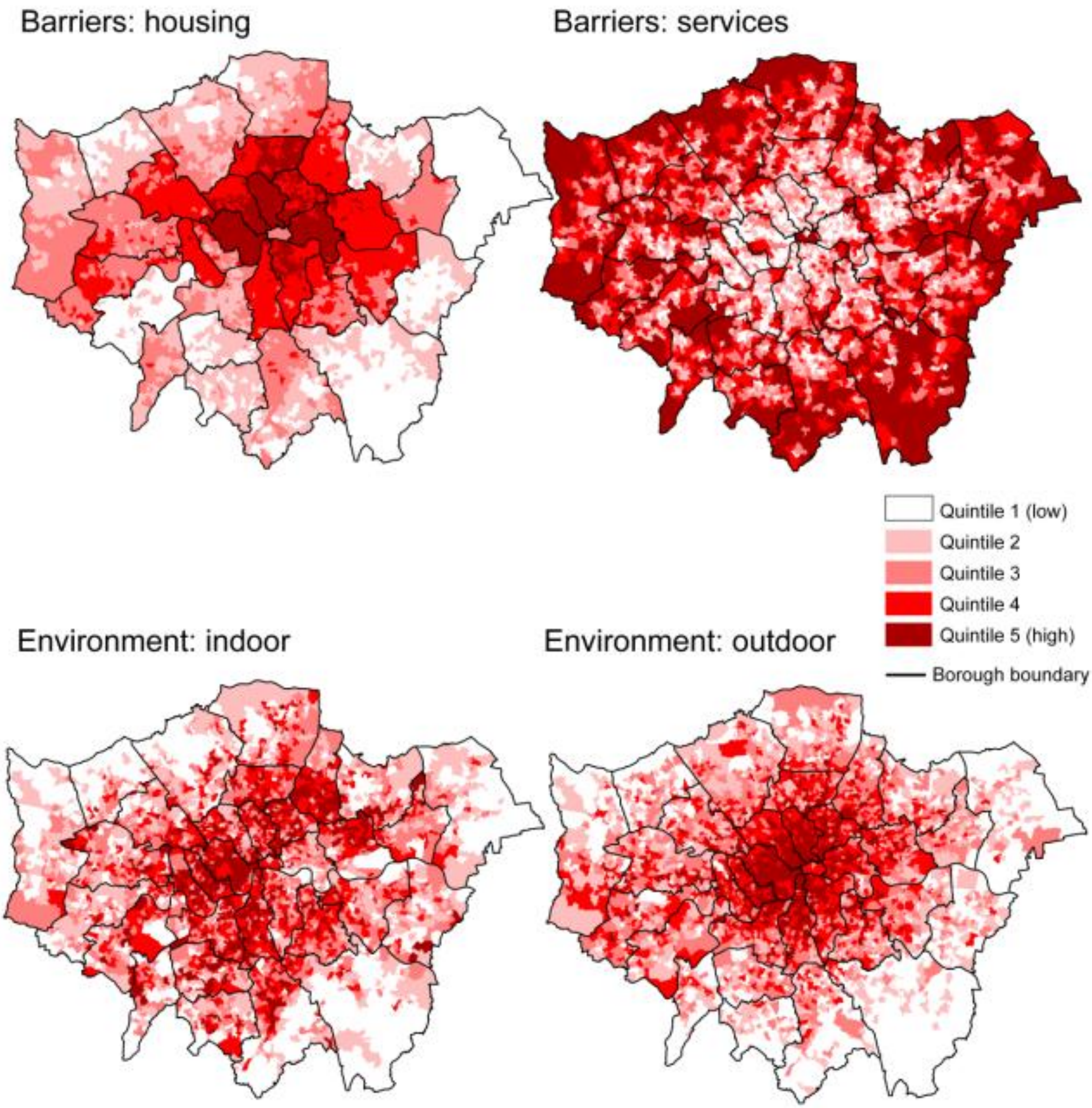
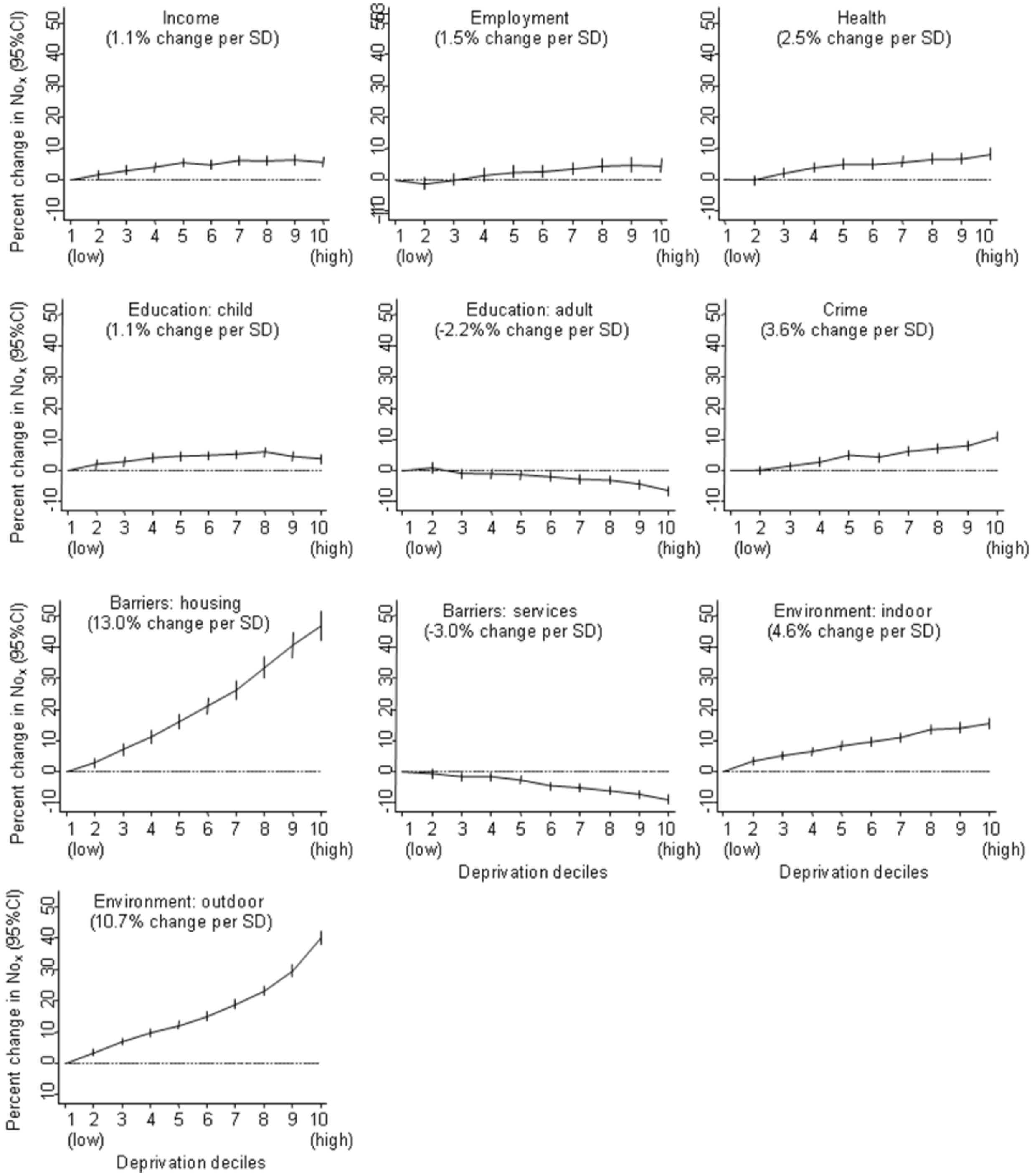


Table 6: Pearson correlation coefficients for the association between the IMD domains for 186 424 residential postcodes in London

	Full IMD04	IMD-minus-outdoor-env.	Income	Employ-ment	Health	Educ: child	Educ: adult	Crime	Barriers: housing	Barriers: service	Env: indoor	Env: outdoor
Full IMD04	1											
IMD-minus-outdoor-env.	0.99	1										
Income	0.94	0.96	1									
Employment	0.93	0.95	0.93	1								
Health	0.89	0.89	0.84	0.87	1							
Education: child	0.75	0.76	0.72	0.66	0.70	1						
Education: adult	0.35	0.41	0.50	0.45	0.39	0.45	1					
Crime	0.65	0.56	0.53	0.52	0.55	0.44	0.12	1				
Barriers: housing	0.72	0.68	0.54	0.54	0.63	0.50	-0.16	0.45	1			
Barriers: service	-0.43	-0.38	-0.32	-0.36	-0.41	-0.31	0.17	-0.34	-0.59	1		
Env: indoor	0.46	0.40	0.28	0.32	0.39	0.35	-0.24	0.35	0.62	-0.59	1	
Env: outdoor	0.55	0.46	0.32	0.36	0.41	0.34	-0.31	0.46	0.73	-0.60	0.62	1

Educ=education; env=environment

Figure 4: Percent change in NO_x concentrations by IMD domains, in residential postcodes in London (N=186 424)



Values obtained from univariable regression analyses entering each IMD score in turn, and including three level random intercept model in which postcodes were nested within SOAs which were nested in boroughs.

Table 7: Association between NO_x concentrations and the 2004 IMD domains across zones of London

	Adjusting for spatial autocorrelation†: percent change (95%CI) in NO_x				
	London-wide	**Central London**	**Non-central inner London**	**Outer London**	**Outside London**
	N=186 424	**N=30 429**	**N=38 995**	**N=92 975**	**N=24 025**
Full IMD04 (z-score)	2.7 (2.3, 3.2)	-2.1 (-3.5, -0.8)	2.8 (2.1, 3.5)	3.5 (2.9, 4.0)	0.8 (-0.5, 2.2)
IMD-minus-outdoor-env (z-score)	1.6 (1.2, 2.0)	-2.3 (-3.6, -1.0)	1.5 (0.8, 2.2)	2.2 (1.7, 2.8)	0.3 (-1.0, 1.6)
Income (z-score)	1.1 (0.8, 1.5)	-2.8 (-3.9, -1.7)	1.0 (0.4, 1.6)	1.9 (1.4, 2.4)	0.6 (-0.7, 1.9)
Employment (z-score)	1.5 (1.1, 1.8)	-1.8 (-2.9, -0.8)	1.3 (0.7, 1.8)	2.5 (1.9, 3.0)	1.2 (-0.2, 2.6)
Health (z-score)	2.5 (2.0, 3.0)	-1.0 (-2.4, 0.4)	2.4 (1.6, 3.3)	3.6 (2.9, 4.2)	1.5 (0.5, 2.5)
Education: child (z-score)	1.1 (0.7, 1.5)	-2.0 (-4.0, 0.1)	1.0 (0.1, 1.9)	1.0 (0.6, 1.5)	0.8 (0.1, 1.5)
Education: adult (z-score)	-2.2 (-2.5, -1.8)	-3.3 (-4.6, -2.0)	-1.8 (-2.4, -1.1)	-3.1 (-3.6, -2.6)	1.1 (0.2, 2.0)
Crime (z-score)	3.5 (3.1, 3.8)	-1.9 (-3.0, -0.8)	4.6 (3.9, 5.3)	4.6 (4.1, 5.1)	1.8 (0.7, 2.9)
Barriers: housing (z-score)	13.1 (12.1, 14.2)	2.7 (-1.6, 7.2)	13.1 (10.6, 15.8)	14.1 (12.8, 15.5)	3.2 (1.6, 4.9)
Barriers: service (z-score)	-3.0 (-3.4, -2.7)	-0.5 (-2.1, 1.3)	-1.9 (-2.6, -1.2)	-3.5 (-3.9, -3.0)	-2.2 (-2.8, -1.5)
Environment: indoor (z-score)	4.7 (4.3, 5.1)	3.9 (2.1, 5.8)	3.0 (2.1, 4.0)	5.5 (5.1, 6.0)	1.9 (1.1, 2.7)
Environment: outdoor (z-score)	10.6 (10.1, 11.0)	10.9 (9.0, 12.8)	10.6 (9.8, 11.3)	10.2 (9.6, 10.8)	4.7 (3.5, 5.9)

†We adjusted for spatial autocorrelation using a three level random intercept model in which postcodes were nested within SOAs which were nested in boroughs.

Figure 5: Mean IMD04 score by ACORN group in residential postcodes in London (N=186 424)

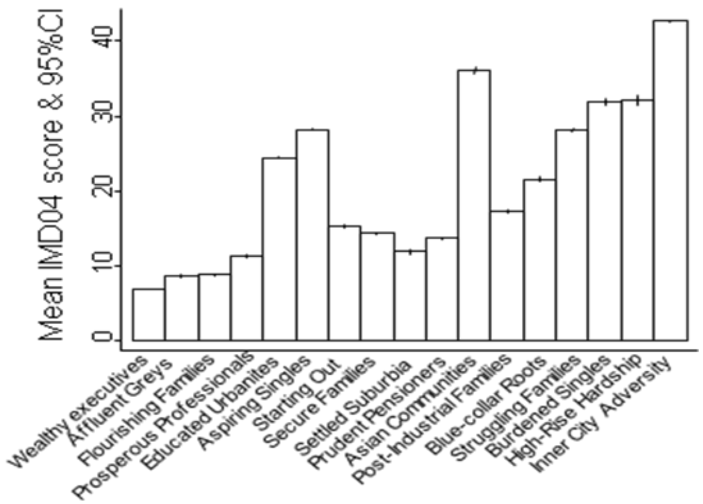


Table 8: Percent change in NO_x concentrations in multivariable analyses of IMD domains and ACORN across different parts of London

		Percent increase (95% CI) in NO_x per unit increase in value in explanatory factor				
		London-wide (N=186 424)	Central London (N=30 429)	Non-central inner London (N=38 995)	Outer London (N=92 975)	Outside London (N=24 025)
IMD domains (z-score)	Employment	1.1 (0.6, 1.6)	0.2 (-1.4, 1.9)	1.6 (0.7, 2.4)	1.2 (0.5, 1.9)	-1.4 (-3.4, 0.6)
	Education: child	0.1 (-0.4, 0.6)	-0.9 (-3.0, 1.3)	0.8 (-0.2, 1.7)	0.2 (-0.5, 0.8)	-0.2 (-1.5, 1.1)
	Education: adult	-3.8 (-4.3, -3.3)	-1.9 (-4.0, 0.3)	-4.1 (-5.0, -3.2)	-4.9 (-5.5, -4.3)	1.1 (-0.5, 2.7)
	Crime	1.8 (1.4, 2.1)	-1.6 (-2.7, -0.5)	3.3 (2.6, 4.0)	2.5 (2.1, 3.0)	1.1 (-0.1, 2.3)
	Barriers: housing	9.7 (8.4, 11.0)	7.5 (3.4, 11.7)	12.6 (9.5, 15.7)	7.6 (6.0, 9.2)	0.0 (-2.2, 2.2)
	Barriers: service	-1.2 (-1.6, -0.9)	-0.2 (-1.9, 1.4)	-0.5 (-1.1, 0.2)	-1.1 (-1.5, -0.6)	-1.5 (-2.2, -0.8)
	Environment: indoor	0.8 (0.4, 1.2)	2.5 (0.8, 4.2)	0.7 (-0.1, 1.6)	1.1 (0.6, 1.6)	0.4 (-0.5, 1.4)
ACORN group	Wealthy executives	-7.5 (-7.9, -7.0)	[empty cell]	-5.0 (-8.5, -1.4)	-6.9 (-7.5, -6.4)	-7.6 (-8.3, -6.8)
	Affluent Greys	-6.6 (-7.3, -5.9)	[empty cell]	[empty cell]	-5.9 (-6.7, -5.1)	-6.7 (-7.6, -5.8)
	Flourishing Families	-6.6 (-7.0, -6.1)	[-8.1 (-22.4, 8.8)]	-5.0 (-7.9, -2.0)	-6.1 (-6.6, -5.7)	-6.4 (-7.1, -5.6)
	Prosperous Professionals	-4.7 (-5.0, -4.3)	-4.2 (-7.4, -0.9)	-4.5 (-5.4, -3.6)	-4.6 (-5.0, -4.2)	-3.5 (-4.3, -2.7)
	Educated Urbanites	0	0	0	0	0
	Aspiring Singles	-2.3 (-2.7, -2.0)	-6.2 (-9.2, -3.2)	-3.2 (-3.8, -2.7)	-1.1 (-1.4, -0.7)	-2.7 (-3.9, -1.5)
	Starting Out	-4.6 (-5.0, -4.1)	[-14.1 (-30.6, 6.4)]	-4.9 (-6.3, -3.5)	-4.3 (-4.8, -3.8)	-3.3 (-4.2, -2.4)
	Secure Families	-5.3 (-5.7, -5.0)	[empty cell]	-4.1 (-5.6, -2.6)	-4.4 (-4.7, -4.0)	-5.7 (-6.5, -5.0)
	Settled Suburbia	-5.9 (-6.5, -5.2)	[empty cell]	[-3.8 (-11.0, 4.0)]	-5.2 (-5.9, -4.5)	-5.8 (-6.8, -4.9)
	Prudent Pensioners	-3.4 (-3.8, -2.9)	[empty cell]	-1.8 (-3.8, 0.3)	-2.6 (-3.1, -2.1)	-3.6 (-4.4, -2.8)
	Asian Communities	-4.9 (-5.6, -4.3)	-9.3 (-13.1, -5.2)	-5.0 (-6.6, -3.4)	-3.4 (-4.1, -2.7)	[-8.3 (-13.6, -2.6)]
	Post-Industrial Families	-6.2 (-6.6, -5.8)	[empty cell]	-6.3 (-7.9, -4.7)	-5.2 (-5.7, -4.8)	-6.4 (-7.2, -5.5)
	Blue-collar Roots	-4.8 (-5.3, -4.3)	[-9.3 (-21.5, 4.7)]	-4.4 (-6.3, -2.4)	-3.7 (-4.3, -3.2)	-4.9 (-5.9, -4.0)
	Struggling Families	-5.8 (-6.3, -5.4)	[-7.9 (-18.2, 3.7)]	-5.0 (-6.5, -3.5)	-4.5 (-5.1, -4.0)	-6.6 (-7.5, -5.8)
	Burdened Singles	-5.3 (-5.9, -4.7)	[-15.0 (-22.7, -6.5)]	-4.2 (-5.7, -2.6)	-4.0 (-4.7, -3.3)	-6.4 (-7.6, -5.3)
	High-Rise Hardship	-3.9 (-4.7, -3.1)	-7.7 (-11.1, -4.2)	-2.7 (-4.4, -1.0)	-2.0 (-3.0, -1.1)	-8.0 (-9.7, -6.4)
	Inner City Adversity	-2.5 (-2.8, -2.2)	-4.7 (-5.4, -4.0)	-1.9 (-2.4, -1.4)	-1.0 (-1.5, -0.5)	[-5.5 (-17.3, 7.9)]
Model components of variance	Level 3: Borough-level	0.01	0.00	0.01	0.00	0.00
	Level 2: SOA-level	0.01	0.01	0.01	0.01	0.01
	Level 1: Postcode-level	0.02	0.03	0.02	0.01	0.01
Intra-class correlation	Level 3: Within boroughs	0.33	0.03	0.21	0.12	0.21
	Level 2: Within SOAs	0.55	0.26	0.43	0.44	0.49
R^2 (percent of variance explained)	Total	0.55	0.10	0.22	0.39	0.07
	Level 3: Borough level	0.78	0.70	0.48	0.80	0.11
	Level 2: SOA-level	0.25	0.12	0.29	0.35	0.12
	Level 1: Postcode-level	0.01	0.01	0.01	0.02	0.02

All variables are adjusted for all other variables in the column. Note that unlike in the main text the baseline ACORN group used here is 'educated urbanites' as this is one of the only groups with over 200 individuals in each part of London. Cells in square brackets correspond to values based on fewer than 20 individuals.

Figure 6: Percent high individual-level SEP and current smokers by IMD04 deciles and ACORN categories, in the Whitehall II cohort (N=3654)

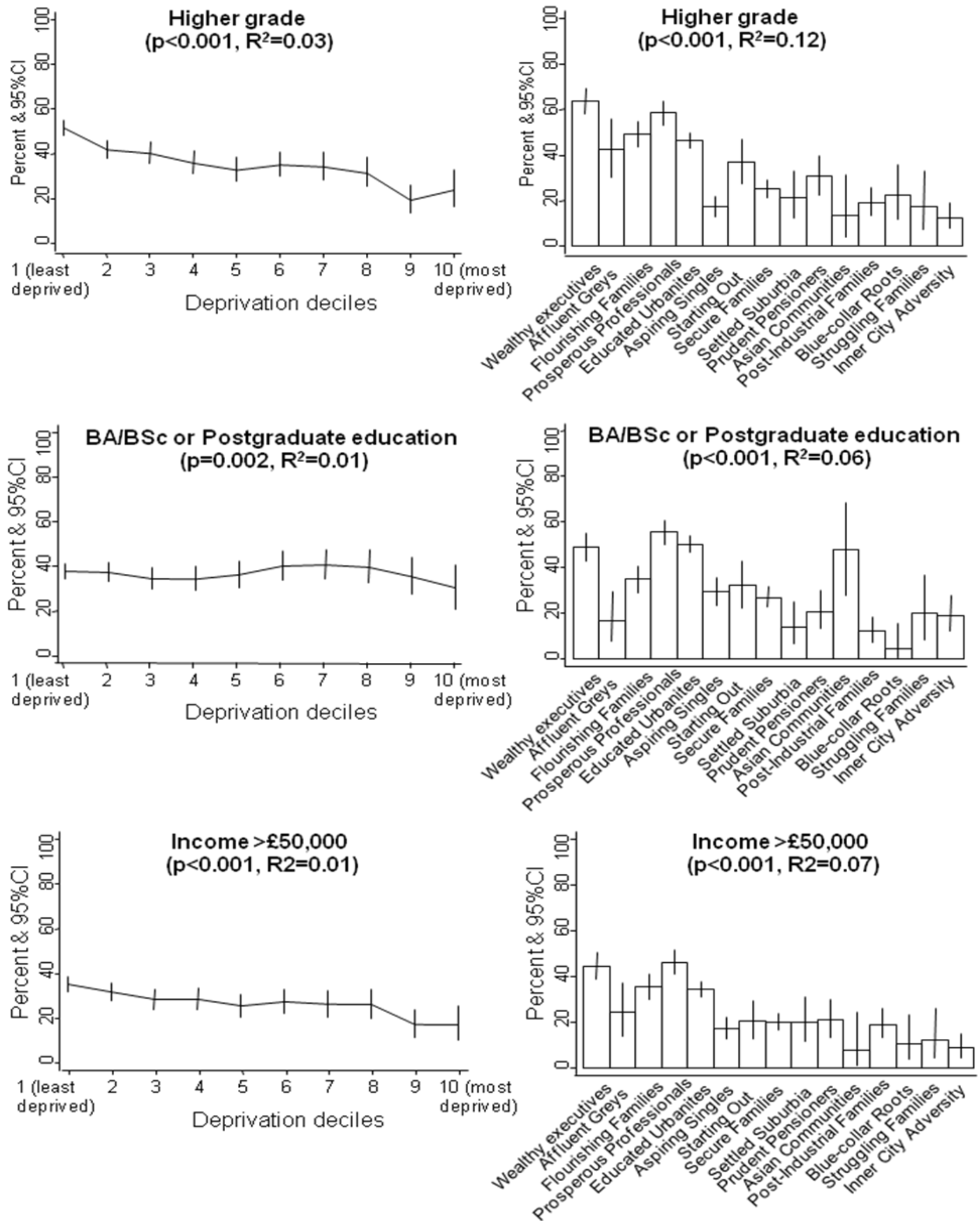
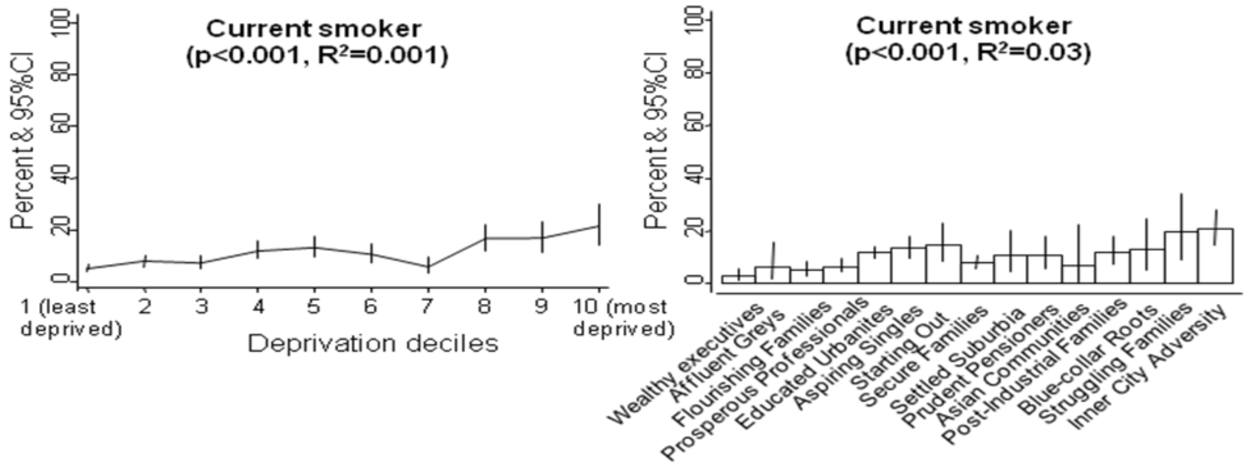


Figure 6 continued



p-values from tests for heterogeneity. ‘Burdened Singles’ and ‘High-Rise Hardship’ ACORN categories excluded as only 10 Whitehall II cohort members were in each group.