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Investigating the relationship between air pollution, health and social deprivation in Leeds, UK

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Abstract

This study examines the relationship between air pollution, social deprivation and health in the city of Leeds, UK under a baseline and three distance-based road user charging (RUC) scenarios set at 2 pence, 10 pence and 20 pence/km. Through application of a series of linked models of traffic, emission and pollutant dispersion, air quality was modelled in response to RUC scenarios. The pollutant modelled were NO_2, PM_{10}, CO, benzene and 1,3-butadiene, though results of NO_2 are used in this study. The RUC scenarios were compared with the 'base' scenario, all set for the year 2005. The RUC initiatives result in the differences in ambient concentrations of NO_2. The study correlates NO_2 concentrations with derived indices of social deprivation and health. The study concludes that positive but weak relationship exists between air quality and social deprivation, and indicates that deprived population groups are disproportionately exposed to higher NO_2 levels. The relationship between air quality and health status of the population is weak. There is a strong relationship between social deprivation and health status of the population. The study concludes that RUC scenarios result in reducing disparity between affluent and deprived populations.

Keywords: Air quality; Social deprivation; Health; Road user charging; Environmental justice

1. Introduction

A great deal of interest has been expressed in the relationships between social deprivation and health (Charlton, 1993;Burr et al., 1997;Hawker et al., 2003), and air quality and health (Schwartz, 1994;Vedal, 1997;Walker & Barber, 1997;Samet et al., 1999; Yamazaki et al., 2005). These studies have shown that air quality and social factors impact upon health. In a number of studies of health and air pollution, social indicators were included as explanatory factors for poorer health. For example, overcrowding (defined as more than one person per room), or the presence of a smoker, was frequently cited as a contributing factor to poor respiratory health (Levy & Herzog, 1974;Levy & Herzog, 1978; Harris, 1999;Wong et al., 1999;Borghetti et al., 2004).

The relationship between air quality and social deprivation is also used to test the concept of environmental justice. The concept of environmental justice has gained greater recognition in recent years, as social goals (e.g. equity, fairness, and justice) have themselves gained greater prominence through almost universal efforts to promote sustainable development. The concept draws attention to the questions of whether certain socioeconomic groups, including the economically and politically disadvantaged, bear a disproportionate burden of environmental externalities, and whether policy and practice are equitable and fair (Wilkinson, 1998). Environmental injustice has multiple meanings to different people, but can be thought of simply as occurring when a particular social group is disproportionately burdened with environmental hazards (Pellow, 2000).

Environmental justice emerged initially in the US, where it is now an important part of environmental and public health policy assessment (Bass, 1998). There have been several environmental justice studies in USA addressing associations between emissions from industrial facilities and landfills with attributes of nearby populations (Cutter, 1995;Bowen, 2002). The environmental justice movement in the US emerged in a sphere only peripherally related to transportation. Its scope within the transportation sector, however, has grown enormously in recent years with the publication of several studies

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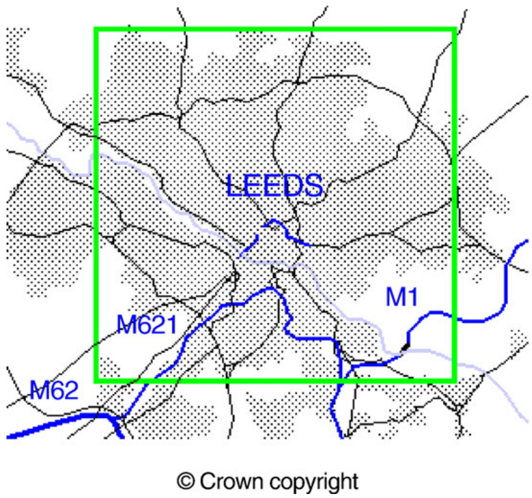

Fig. 1. City of Leeds showing study area boundary.

evaluating the environmental justice impacts of transport improvement projects (Chakraborty, 2006).

In Sweden, a study (Chaix et al., 2006) examined whether children of low socioeconomic status suffered greater exposure to outdoor nitrogen dioxide than more affluent ones, both at their place of residence and at school. Exposure to nitrogen dioxide regularly increased as the socioeconomic status of a child's neighbourhood of residence decreased. Thus the study found the evidence of environmental injustice even in a country noted for its egalitarian welfare state.

A nationwide environmental justice analysis was performed (Mitchell & Dorling, 2003) to estimate how one aspect of air pollution, nitrogen dioxide levels, affects different population groups differently across Britain. The study found evidence of environmental injustice in the distribution and production of poor air quality. It also found that the communities that have access to fewest cars tend to suffer from the highest levels of air pollution, whereas those in which car ownership is greatest enjoy the cleanest air. The links between sustainability and environmental justice are becoming clearer and more widely understood in the UK (Agyeman & Evans, 2004). For example, another study in Birmingham focused particularly on the environmental equity of air pollution (Brainard et al., 2002). The study found that there was a striking relationship between modelled emissions and poverty indicators and ethnicity. The effects were difficult to separate out but there was strong evidence to suggest that the two factors (poverty and ethnicity) operated in an independent manner.

Relationships between air pollution and health and deprivation, potentially result in the most cost to both the public and the government in terms of increased mortality and morbidity, hence establishing causal links between them is very important and can be justified.

The main aim of this study was to investigate the possibility of a relationship between local air quality and measures of health and deprivation. The supporting objectives were: (a) to establish if a positive correlation exists between areas with poor air quality and those which are socially deprived and/or experience poor health; and (b) to determine what impacts road user charging initiatives have on air quality, and consequently on deprivation and health in Leeds.

2. Air quality

Traffic assignment, pollutant emission and dispersion models were applied to a 12 × 12 km area of the city of Leeds city, as shown in Fig. 1, so as to assess the air quality impacts of five road user charging (RUC) schemes. This work has been described in detail elsewhere (Mitchell et al., 2005). This involved the application of a chain of dynamic simulation models of traffic flow (SATURN, SATTAX), pollutant emission (ROADFAC) and dispersion (ADMS-Urban), integrated within a geographic information system model TEMMS (Namdeo et al., 2002).

The possible impacts of road user charging on emission and air quality were assessed using cordon and distance charging. Cordon charging was selected as it is proven technologically (London, Singapore, Norway), and hence of most interest to local authorities. However, May and Milne (2000) found that cordon pricing was the least effective regime in terms of network performance (generalised cost, trip time and distance, total trips) under road pricing. They added that this is very sensitive to cordon location and concluded that, given concerns over added driver risk taken and the uncertain charge per trip associated with time and congestion charging, future road pricing work could usefully focus on distance-based charging. The inner cordon charge was set to £3. A second test split this fee over two cordons (£2 for inner cordon and £1 for the outer cordon). Distance-based charging scenarios were set at 2, 10 and 20p/km for travels within the outer cordon.

Schemes were evaluated with reference to: exceedance of air quality standards for six pollutants; emission of greenhouse gases; redistribution of pollution, and road network performance as traffic speed and trip distance. Results were compared to alternatives of do nothing or base scenario.

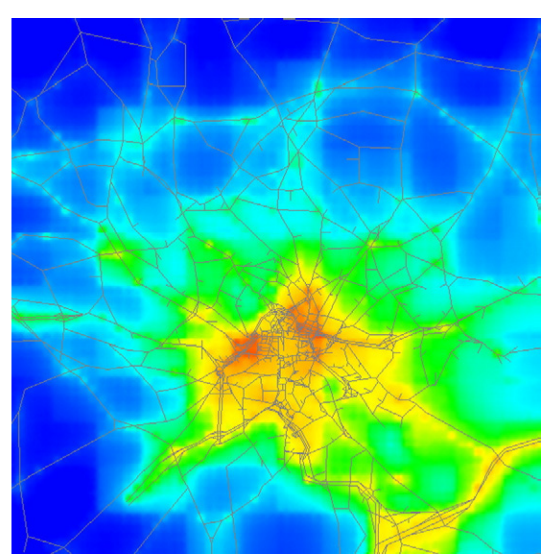

Fig. 2. NO_2 annual mean for the base scenario.

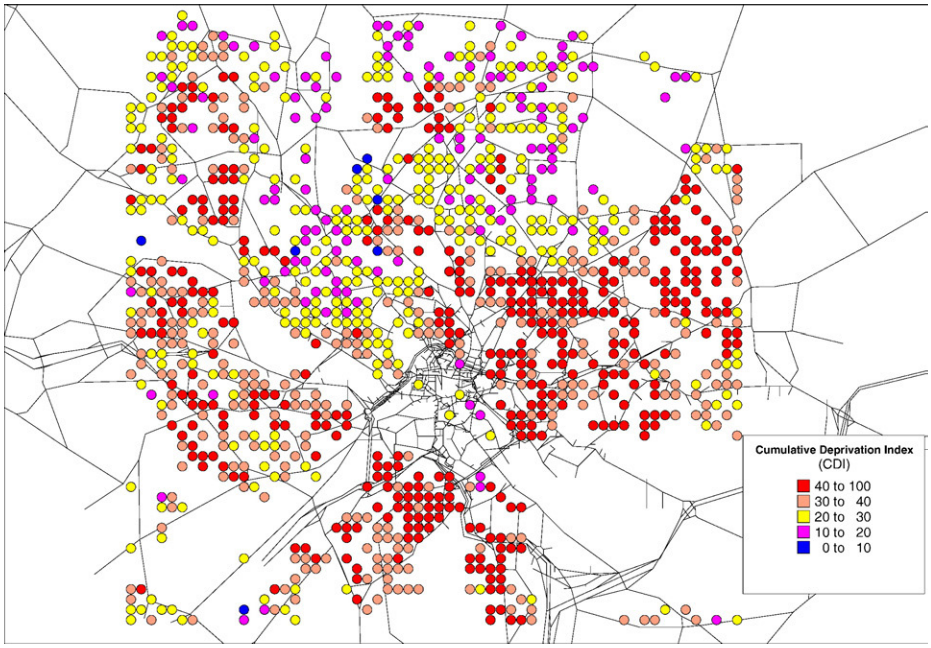

Fig. 3. Deprivation (CDI) in Leeds — Census 2001. (Note: 0 = Least deprived; 100 = Most deprived).

Out of the several scenarios selected in the original study, the base and three road user charging (RUC) scenarios have been selected for the current study to investigate the possibility of a relationship between local air quality and measures of health and deprivation. The three scenarios selected are road user charging set at three levels — 2 pence, 10 pence and 20 pence/km. Air quality response to the RUC scenarios was investigated for six pollutants in the original study, but only NO_2 has been selected in the current study as other environmental equity research in UK has also focused on this pollutant (Brainard et al., 2002; Mitchell & Dorling, 2003). Current NO_2 levels for the base and three RUC scenarios for the year 2005 have been predicted for 3600 cells of 200×200 m size in the study area. Annual mean NO_2 levels for the Base Scenario are shown in Fig. 2. Contribution of major radial and ring roads is clearly evident from this figure.

2.1. Social deprivation and health indices

The UK Census 2001 data (Office of National Statistics, 2001) have been used to derive indicators of health and deprivation levels of the population in the study area. Census has its

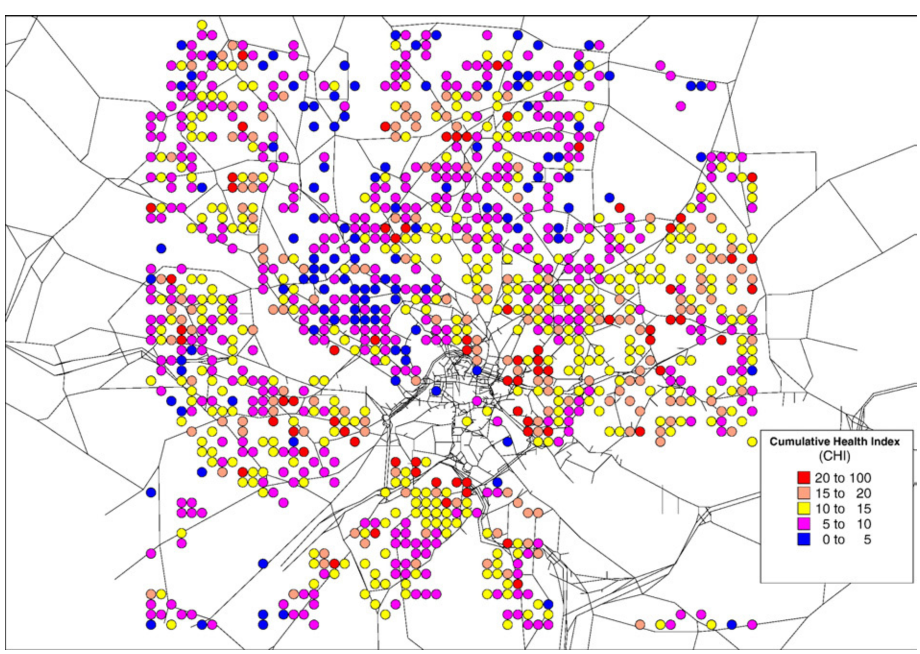

Fig. 4. Health status (CHI) in Leeds — Census 2001. (Note: 0 = Most healthy; 100 — Least healthy).

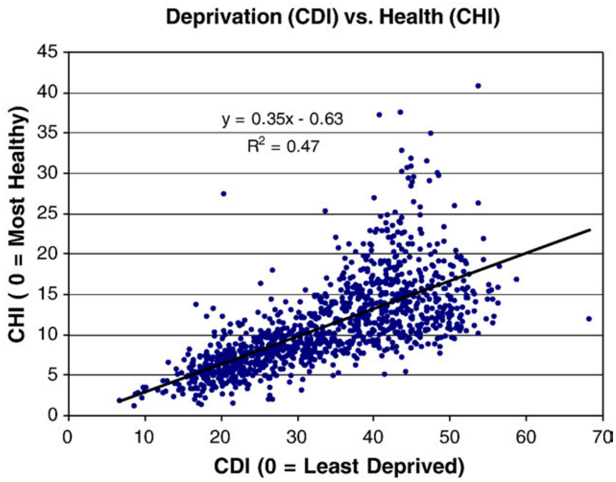

Fig. 5. Relationship between deprivation and health.

own measure of deprivation, which ranks the Census Output Area (COA) population as being deprived in terms of any number of four dimensions. It lists the number of households in the COA which were not deprived, as well as those deprived in one, two, three or all four dimensions. Similarly, for health, it lists the number of households which rated themselves as either having good health, fairly good health or not good health. Cumulative deprivation index (CDI) and Cumulative Health Index (CHI) for each COA were derived on a scale of 0 to 100, with 100 representing most deprived or least healthy areas.

CDI was derived by calculating what percentage of the total households in each COA was deprived to each degree, followed by weighting and scaling it to arrive at a score ranging from 0 to 100 with 0 representing least deprived and 100 representing most deprived. The first step was to work out what percentage of households were deprived in each number of dimensions. It was decided to give the degrees of deprivation a weighting between zero and four, with the least deprived being given the smallest weighting, and the most deprived the heaviest. Therefore, the number of households who weren't deprived in any dimension were given a weighting of 0, so were multiplied by 0/10 (as $1+2+3+4=10$), those deprived in one dimension were multiplied by 1/10 (0.1), those in two dimensions by 0.2, in three dimensions by 0.3 and so on. This resulted in a range of scores from 0 to 40, which was then scaled (multiplied by 2.5) to give an index (CDI) between 0 and 100.

A similar process was intended to devise a single index value for health (CHI), but with this data there were only three possible variations — good health, fairly good health and not good health. As these were quite vague, it was decided that the first two concerned only with people who were not of poor health. The third class was assumed to represent 'not healthy'. The percentage of people 'not healthy' has been used as cumulative health index (CHI) with 0 representing most healthy and 100 representing least healthy.

Fig. 3 shows the map of cumulative deprivation index of the study area. It shows that deprivation is highest in the southern and eastern parts of the city. Deprivation levels are lowest to the north of the city. Map of baseline health status using CHI (Fig. 4) shows that it follows a similar pattern of distribution of CDI. The areas in which poor health is more common are primarily adjacent to main radial routes into the city.

3. Analysis

3.1. Relationship between deprivation and health

In order to see if there was any relationship between health of the population and deprivation, a scatter plot of cumulative health and deprivation indices was plotted. Fig. 5 shows the scatter plot of cumulative health and deprivation indices along with the best-fit-line. It is evident from this plot that social deprivation and

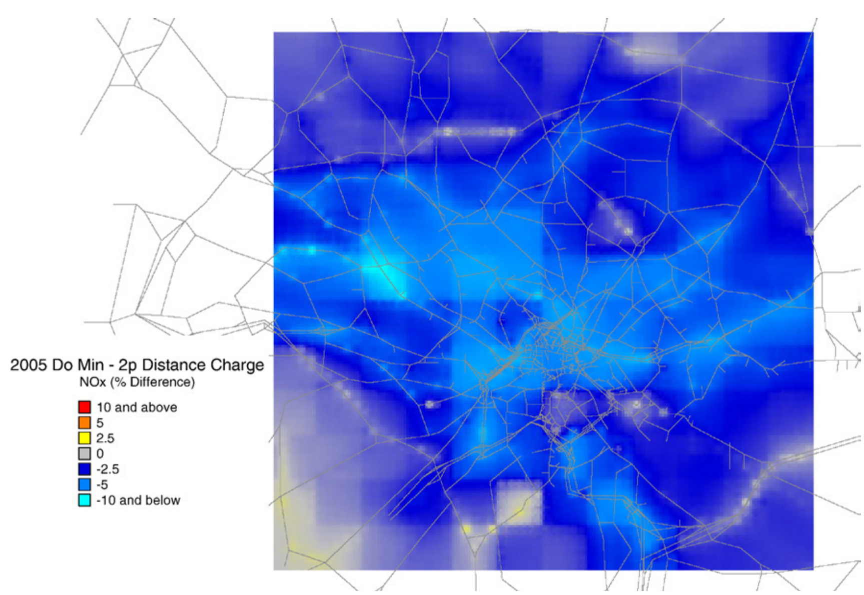

Fig. 6. Percentage change in NO_2 concentrations between No-Charge and 2p/km scenarios.

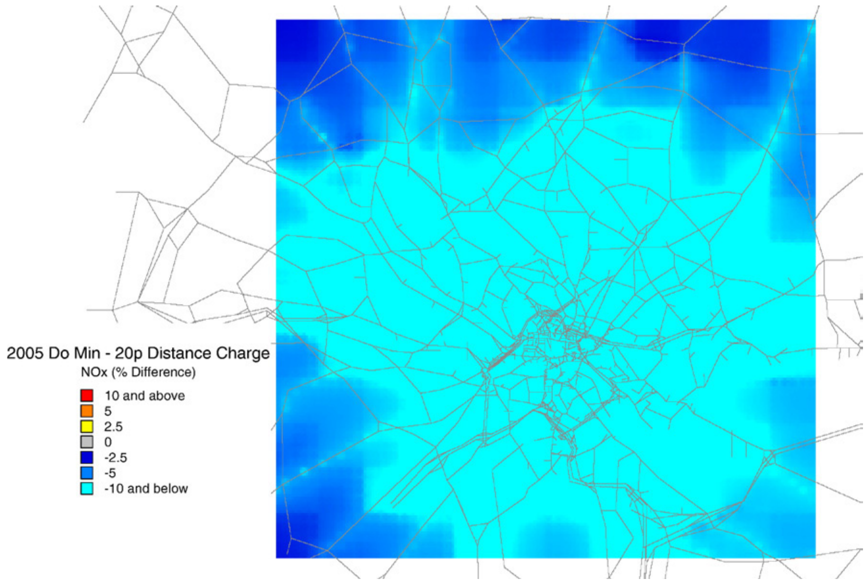

Fig. 7. Change in NO_2 concentrations between No-Charge and 20p/km charge (Jerrett et al., 2001).

health are strongly, and positively related, with a high correlation coefficient ($r=0.68$), and a trend-line gradient of 0.35. F statistics is 999.46 ($P<0.0001$). The trend line has lower and upper 95% confidence interval as 0.324 and 0.366 respectively. This quite clearly shows that social deprivation and health are strongly related in Leeds. This is similar to the findings established in other studies (Smith et al., 1998;Hawker et al., 2003).

Three RUC scenarios studied have different effects on the level and distribution of air pollutant concentrations, the general trend being that all distance-based road user charging regimes investigated produce a significant improvement in city wide air quality, a consequence of trip suppression and emission reduction. Figs. 6 and 7 show changes in NO_2 concentrations between the base, 2p/km and 20p/km charge scenarios. It is clear from these figures that 2p and 20p charge scenarios results in significant reduction in NO_2 concentrations, though 20p charging regime results in greater improvements which are distributed to a wider area.

Table 1
Regression statistics for NO_2 and CDI/CHI

	Correlation coefficient (r)	F statistics	Intercept	Slope	Slope 95% confidence interval	T statistics
CDI						
Base	0.247	71.100*	18.256	0.050	0.038–0.062	8.432
2p/km	0.250	75.962*	17.714	0.045	0.035–0.055	8.716
10p/km	0.232	65.058*	16.761	0.019	0.014–0.023	8.066
20p/km	0.218	56.996*	16.407	0.012	0.009–0.015	7.550
CHI						
Base	0.178	35.743*	19.159	0.071	0.048–0.095	5.799
2p/km	0.176	36.650*	18.541	0.063	0.043–0.083	6.054
10p/km	0.171	34.310*	17.089	0.027	0.018–0.036	5.858
20p/km	0.167	32.794*	16.615	0.019	0.120–0.025	5.727

*$P<0.0001$.

3.2. Relationship between air quality, deprivation and health

In the environmental justice analysis, air quality data for each 200 m grid cell was paired with social deprivation and health indices for corresponding COA. This analysis focuses on exposure to Nitrogen dioxide (NO_2). Nitrogen dioxide was selected as the study pollutant, as review and assessment exercise carried out, as a fulfilment to NAQS (National Air Quality Strategy) obligations by local authorities in UK, have indicated that NO_2 and PM_{10} are currently the principle pollutants of concern in UK urban areas (ENDS, 2002), and are thought to pose significant risks to health (Vedal, 1997). Secondly, our modelling work (Mitchell et al., 2005) has shown that in the case of Leeds, NO_2 is more sensitive to changes in transport emissions than PM_{10}, due to the large contribution to total particulate emission from point sources.

Two statistical tests were used in the environmental justice analysis. Firstly, for each scenario, an ordinary least squares

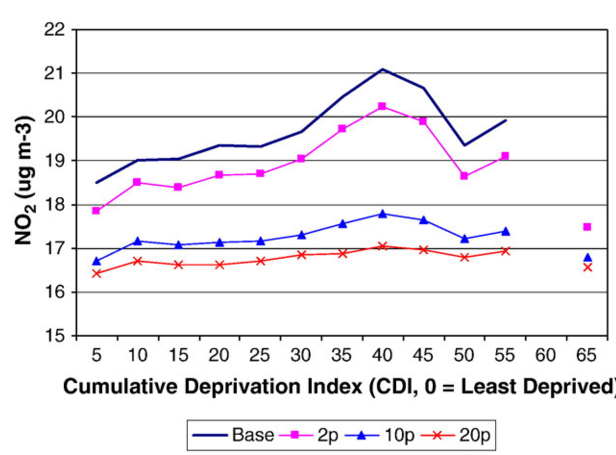

Fig. 8. Relationship of annual mean NO_2 and deciles of deprivation under base and road user charging scenarios.

Table 2
NO_2 and quartiles of CDI and CHI

Quartile	CDI	CHI	Average of corresponding NO_2 values (μg m^{-3}) (standard deviation in parenthesis)			
			Base	2p	10p	20p
First quartile (25th percentile) n=286	24.53	7.17	19.21 (2.06)	18.55 (1.75)	17.12 (0.71)	16.62 (0.49)
Second quartile (50th percentile) n=286	33.87	10.03	19.46 (1.80)	18.82 (1.53)	17.21 (0.75)	16.75 (0.65)
Third quartile (75th percentile) n=286	42.77	14.03	20.52 (2.55)	19.77 (2.20)	17.59 (1.02)	16.93 (0.67)

regression was conducted of annual mean NO_2 and the cumulative deprivation index. Regression is not used here to infer causality between these variables, but is used to test for an association between them. A steeper slope coefficient indicates greater inequality. This approach was adopted in environmental justice analysis of PM_{10} in Hamilton, Canada (Jerrett et al., 2001). Following the regression analysis, different tests were conducted which compared mean NO_2 concentration with deciles, and the upper and lower quartiles of the deprivation index.

Regression analysis shows that for all scenarios, the correlation in terms of the R value was quite low but slopes of the best-fit-lines were positive (Table 1) indicating that there is an association between air quality and deprivation. Table 1 also includes F and T regression statistics, and upper and lower 95% confidence intervals for each slope. The relationship between deciles of deprivation index and NO_2 under the modelled transport scenarios is illustrated in Fig. 8. For each scenario, the data (n=1143) have been presented as mean NO_2 against the deciles of CDI classes. For all scenarios, there is a strong positive association between deprivation and NO_2; however 20p and 10p charging regimes result in flatter slopes. This indicates that these scenarios results in reducing the disparity between deprivation and NO_2 exposure. To assess the statistical significance of the apparent inequalities, difference tests were conducted to compare mean NO_2 concentration in the upper and lower quartiles of the deprivation index. The results of these tests (Table 2) show that deprived group (first quartile of deprivation index) experience higher NO_2 concentrations in their residential location as compared to the affluent group

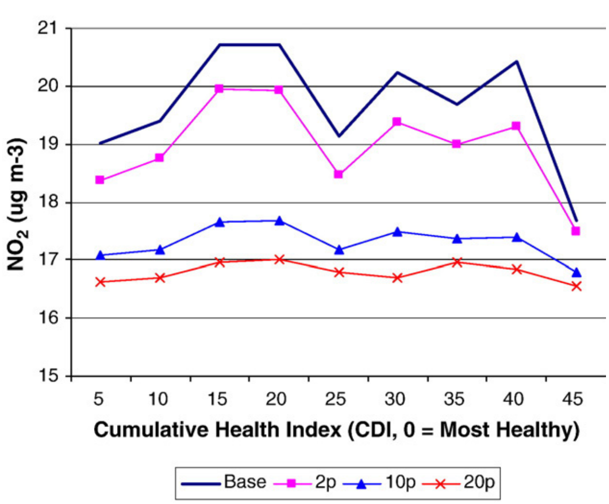

Fig. 9. Relationship of annual mean NO_2 and health under base and road user charging scenarios.

(third quartile of deprivation index). These findings are similar to those found by Mitchell and Dorling (2003) indicating inequalities in NO_2 exposure in Britain.

Correlation between health (deciles of CHI) and NO_2 is shown in Fig. 9. It is clear from this figure that there is no discernible association between them. This is also evident from the statistics in Table 1.

4. Conclusions

The outcome of this study has been that air quality (NO_2) impacts disproportionately on certain, more deprived areas of the city. The analysis shows that there is a significant welfare inequity in the distribution of urban air quality, with more deprived groups clearly experiencing higher atmospheric concentrations of NO_2 in their residential location. The analysis cannot be used to state categorically that deprived communities have a higher exposure, as other exposure specific factors including daily population movement and individual activity rate are neglected. Distance-based road user charging scenarios result in varying degree of reduction in NO_2 concentrations. Reduction in NO_2 concentrations in case of 10p and 20p per km charge scenarios are significant and in a wider area and consequently results in removing inequity in the distribution of urban air quality.

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