Supplementary material to *Estimating the health impact of air pollution in Scotland, and the resulting benefits of reducing concentrations in city centres*

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Introduction

This document contains supplementary analysis and results not included in the main paper. Section 1 motivates the need for a locally adaptive spatial autocorrelation model, while Section 2 illustrates the localised nature of the spatial autocorrelation in the respiratory hospitalisation data. Section 3 presents the estimated relative risks and 95% credible intervals quantifying the impact of the non-pollution covariates on disease risk, while Section 4 contains a sensitivity analysis, by presenting the estimated relative risks and 95% credible intervals quantifying the pollution-disease relationships from the simpler model where the spatial random effects are modelled by the globally smooth CAR prior proposed by Leroux et al. (2000). Finally, Section 5 presents the IZ level estimated reductions in respiratory hospitalisations from a $5\mu g\ m^{-3}$ decrease in NO_2 concentrations for Aberdeen and Dundee.

1. Residual spatial autocorrelation structure

Section 2.4 of the main paper illustrates that the residuals from applying an overdispersed quasi-Poisson log-linear model to each disease outcome exhibit spatial autocorrelation. However, these residuals visually exhibit local rather than global smoothness, because whilst most pairs of spatially neighbouring IZs exhibit similar residual values suggesting spatial autocorrelation, there are numerous examples of large step-changes between spatially neighbouring IZs suggesting independence. Figure 1 illustrates this, by presenting maps of the residuals from the model applied to respiratory hospitalisations in Edinburgh (top) and Glasgow (bottom). Theses cities are picked to illustrate the localised nature of the spatial autocorrelation, but the same phenomenon occurs throughout the study region. The figure shows numerous examples where two spatially neighbouring IZs exhibit very different residual values, suggesting there is a step-change in the residual surface. This in turn suggests that modelling this residual structure with a spatially smooth set of random effects would be inappropriate, because it would lead to an inflated random effects variance and poorer model fit due to trying to smooth over these step changes. A discussion of this issue is provided in Rushworth et al. (2017).

2. Localised spatial autocorrelation in the random effects

To illustrate the localised nature of the spatial autocorrelation in the random effects from the locally adaptive model, the estimated (posterior medians) random effects ϕ_k are mapped in Figure 2 for Edinburgh (top) and Glasgow (bottom). These cities are chosen to illustrate the localised

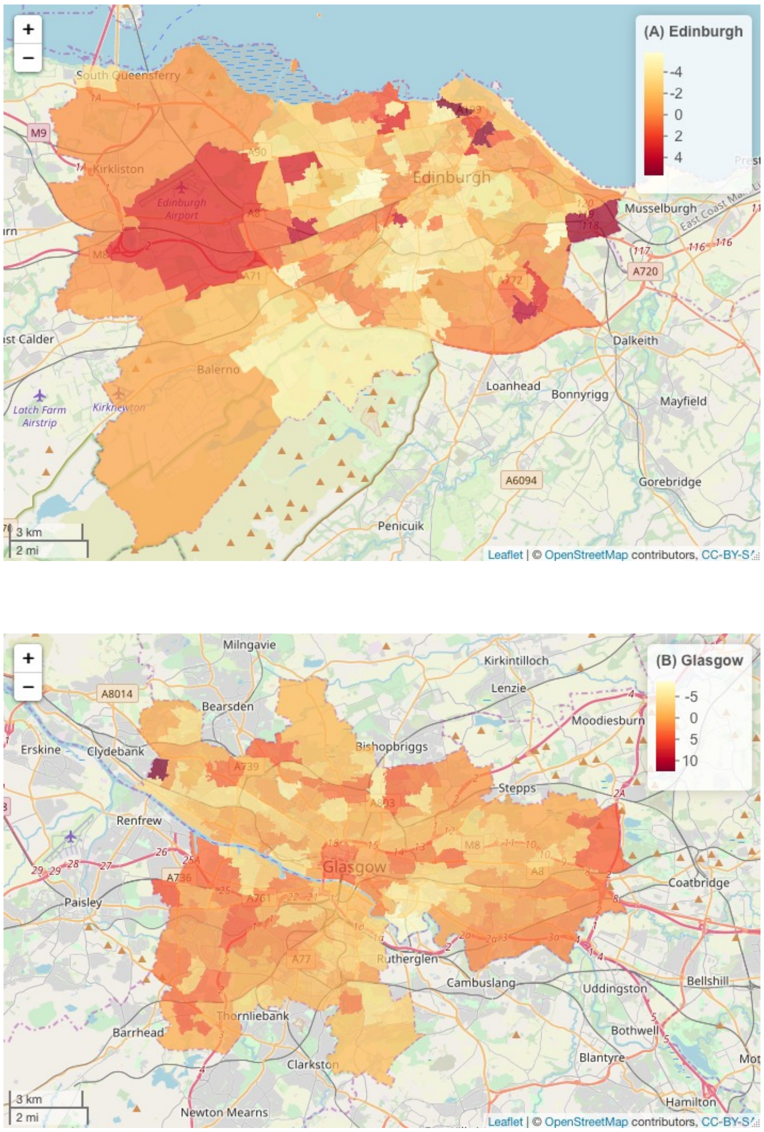

Figure 1: Maps of the residuals from a simple quasi-Poisson log-linear model for (A) Edinburgh and (B) Glasgow.

nature of the correlation, and a map of the whole country would be hard to visualise as a large number of units are squashed into the geographically small central belt containing Glasgow in the west and Edinburgh in the east. The blue dots on the figures denote boundaries where step changes occur (where $w_{ki} = w_{ik} = 0$), and visually correspond to pairs of IZs that exhibit different random effect values, suggesting a lack of spatial smoothness between these IZs.

3. Estimated relative risks for the non-pollution covariates

The estimated relative risks and 95% credible intervals for the non-pollution covariates are displayed in Table 1, and relate to an interquartile range (IQR) increase in each covariates value. The results relate to the locally adaptive model with $PM_{2.5}$ included as the pollutant, and the estimated effects from the other models are similar and are not shown for brevity. The table shows that the largest effects are for the income domain of SIMD across all five disease outcomes, with increased risks of between 18.2% and 40.5% as the level of income deprivation (percentage of working age people receiving benefits such as Job Seekers Allowance or tax credits) increases. An increase in housing deprivation (percentage of people who live in overcrowded or unheated homes) also leads to increased risks for all five diseases, with increases between 3.3% and 6.9%. The numbers of crimes has relatively little impact on disease risk, as the 95% credible intervals contain the null risk of 1 for all disease outcomes except respiratory hospitalisations. The remaining two variables suggest that urban areas generally have lower disease risks than rural areas (dwellings per hectare), and that within each of those environments

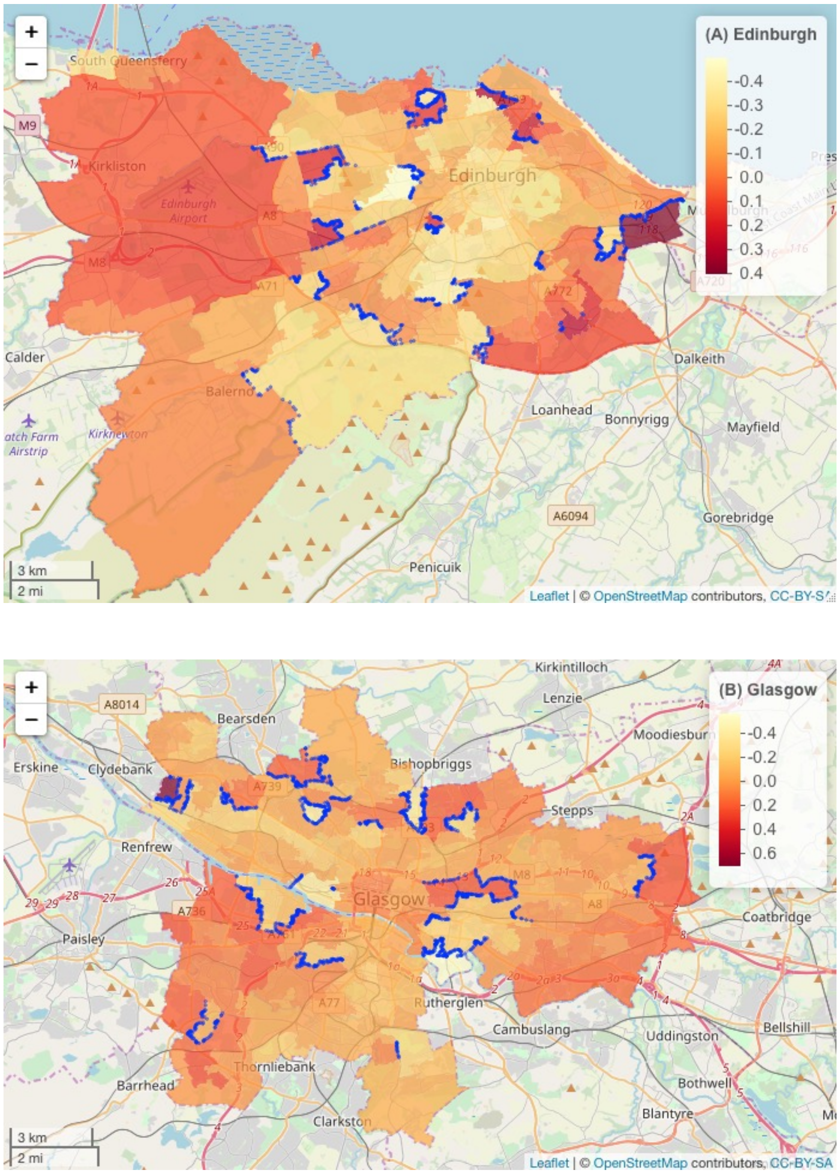

Figure 2: Maps of the estimated random effects surfaces from the locally adaptive smoothing model in (A) Edinburgh (top) and (B) Glasgow (bottom). The locations of the step changes for which $w_{ki} = w_{ik} = 0$ are displayed by blue dots.

the closer one is to local services then the higher the risk (access to services).

4. Estimated pollutant-disease relative risks from the model with the Leroux CAR prior

The estimated pollutant-disease relative risks from the model with the Leroux CAR prior are displayed in Table 2 for completeness, and show little change from those estimated with the locally adaptive model presented in the main paper, suggesting a robustness in our results to the choice of spatial autocorrelation structure.

5. Estimated reductions in respiratory hospital admissions in Aberdeen and Dundee

The estimated reductions in the numbers of respiratory hospitalisations resulting from a $5\mu g\ m^{-3}$ decrease in NO_2 concentrations and the estimated average NO_2 concentrations for Aberdeen (top) and Dundee (bottom) are displayed in Figure 3, which has the same format as Figure 3 (presenting Edinburgh and Glasgow) in the main paper. The figure presents the same message as for Edinburgh and Glasgow, namely that reducing pollution concentrations in the city centres where they are highest will likely have a low impact on public health in terms of reducing the numbers of respiratory related hospital admissions.

Table 1: Estimated relative risks and 95% credible intervals for the non-pollution covariates. The relative risks relate to an interquartile range (IQR) increase in each covariate as a meaningful increase.

Covariate	**Disease outcome**	**Risk**	**95% CI**
Dwellings per hectare	Cardiovascular hospitalisations	0.970	(0.955, 0.985)
(IQR = 16.9)	Cardiovascular mortality	0.970	(0.945, 0.996)
	Respiratory hospitalisations	0.960	(0.944, 0.975)
	Respiratory mortality	0.928	(0.892, 0.965)
	Total non-accidental mortality	0.956	(0.938, 0.974)
Access to services	Cardiovascular hospitalisations	0.980	(0.968, 0.992)
(IQR = 18.2)	Cardiovascular mortality	0.985	(0.964, 1.007)
	Respiratory hospitalisations	0.968	(0.955, 0.981)
	Respiratory mortality	0.954	(0.924, 0.986)
	Total non-accidental mortality	0.974	(0.959, 0.989)
Crime	Cardiovascular hospitalisations	0.993	(0.985, 1.000)
(IQR = 236.5)	Cardiovascular mortality	0.998	(0.983, 1.013)
	Respiratory hospitalisations	0.989	(0.981, 0.996)
	Respiratory mortality	0.986	(0.964, 1.008)
	Total non-accidental mortality	0.999	(0.990, 1.009)
Housing	Cardiovascular hospitalisations	1.038	(1.020, 1.056)
(IQR = 0.08)	Cardiovascular mortality	1.049	(1.022, 1.076)
	Respiratory hospitalisations	1.033	(1.014, 1.052)
	Respiratory mortality	1.069	(1.024, 1.115)
	Total non-accidental mortality	1.056	(1.035, 1.077)
Income	Cardiovascular hospitalisations	1.182	(1.162, 1.202)
(IQR = 10.7)	Cardiovascular mortality	1.222	(1.191, 1.254)
	Respiratory hospitalisations	1.405	(1.379, 1.432)
	Respiratory mortality	1.353	(1.298, 1.411)
	Total non-accidental mortality	1.246	(1.221, 1.270)

Table 2: Estimated relative risks and 95% credible intervals for the pollution-disease effects from the model with the Leroux CAR prior. The results for NO_2 and NO_x relate to a $5\mu g\ m^{-3}$ increase whilst those for $PM_{2.5}$ and PM_{10} relate to a $1\mu g\ m^{-3}$ increase. The significant results are shown in bold.

Disease outcome	**Pollutant**			
	NO_2	**NO_x**	**$PM_{2.5}$**	**PM_{10}**
Cardiovascular hospitalisations	1.013	1.006	1.014	1.003
	(0.993, 1.033)	(0.994, 1.018)	(0.990, 1.038)	(0.991, 1.015)
Cardiovascular mortality	0.988	0.993	0.994	0.997
	(0.970, 1.006)	(0.982, 1.005)	(0.974, 1.015)	(0.987, 1.008)
Respiratory hospitalisations	**1.025**	1.012	**1.060**	**1.027**
	(1.001, 1.049)	(0.998, 1.026)	**(1.031, 1.089)**	**(1.013, 1.041)**
Respiratory mortality	1.031	1.016	**1.045**	1.014
	(0.996, 1.067)	(0.995, 1.038)	**(1.002, 1.091)**	(0.992, 1.037)
Total non-accidental mortality	1.005	1.002	1.013	1.005
	(0.992, 1.019)	(0.994, 1.011)	(0.998, 1.029)	(0.997, 1.013)

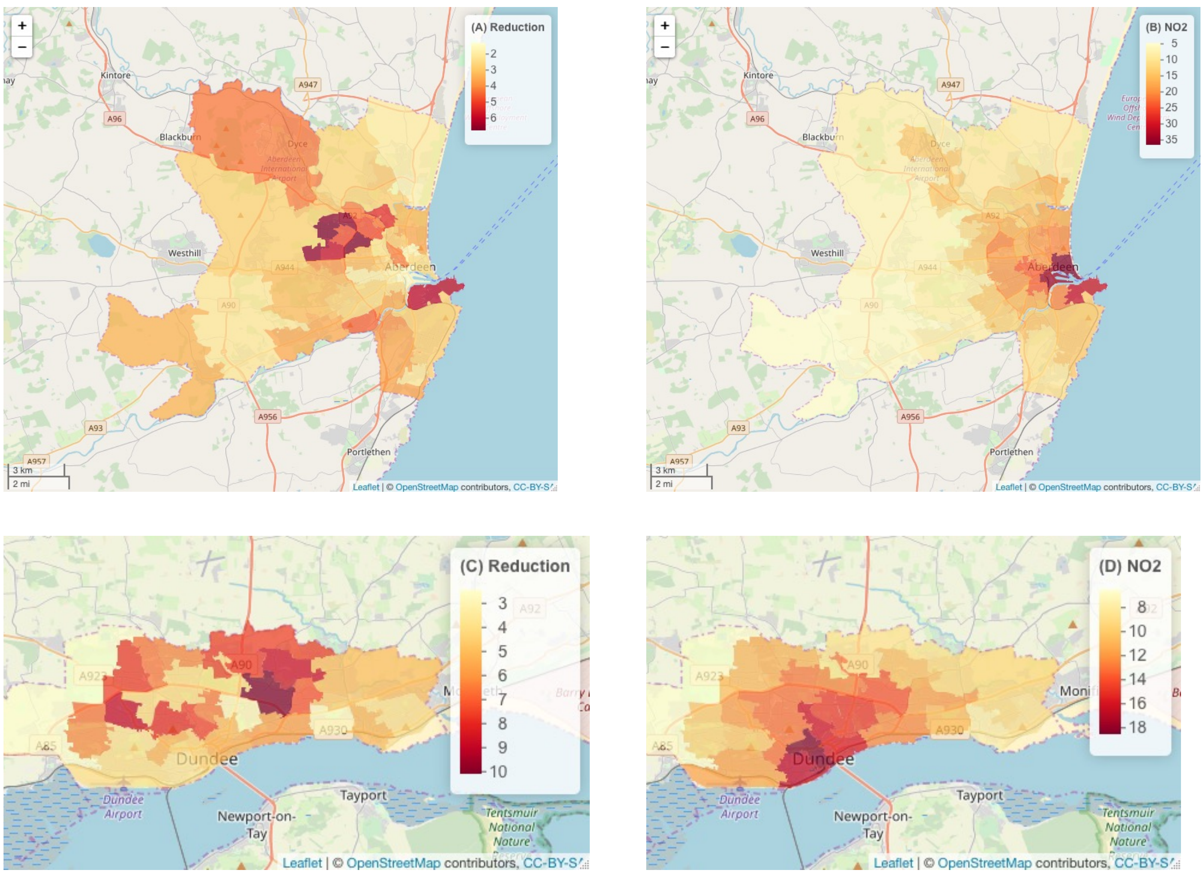

Figure 3: Maps of the estimated reductions in respiratory hospitalisations in each IZ due to a $5\mu g\ m^{-3}$ reduction in NO_2 concentrations (left), and the average NO_2 concentrations (right). The top row refers to Aberdeen and the bottom row refers to Dundee.

Bibliography

References

Leroux, B., Lei, X., Breslow, N., 2000. Estimation of Disease Rates in Small Areas: A New Mixed Model for Spatial Dependence. Springer-Verlag, New York, Ch. Statistical Models in Epidemiology, the Environment and Clinical Trials, Halloran, M and Berry, D (eds), pp. 135–178.

Rushworth, A., Lee, D., Sarran, C., 2017. An adaptive spatio-temporal model for estimating trends and step changes in disease risk. Journal of the Royal Statistical Society Series C 66, 141–157.