Appendix: The Impact of Lead Water Pollution on Birth Outcomes: A Natural Experiment in Scotland

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1 Further Robustness Checks

We carry out further robustness checks on our results in this appendix.

1.1 Alternative Difference-in-Differences Estimators

Our first check is using an alternative difference-in-difference estimation method. We use standard two-way fixed effects, the Calloway and Sant'Anna (2021) and Sun and Abraham (2021) methods. Henceforth, we call these TWFE, CS and SA respectively. We use TWFE as it was the standard baseline. We use the others because they are "sub-group" style estimators rather than an "imputation" style estimator, following the Harmon (2023) typology (another imputation style estimator is the Borusyak et al (2024) estimator which can be shown to be equivalent to the two-way Mundlak (Wooldridge, 2021). As discussed in section 4, to use these methods to estimate the effect on deaths, we cannot incorporate the CPRTS assumption, so cannot use logit. We must instead use the CCTS assumption with linear regression. We stress that both these assumptions cannot be true at the same time.

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We present overall averages for each estimator in table A.1. In columns 1 and 3 we present our estimates for the effect on birthweights. Column 1 shows the effect of treatment 1, while column 3 shows the effect for treatment 2. In column 1 all point estimates are small and the confidence intervals wide. In column 3 the estimates for CS and SA are negative but not significant, while for TWFE it is positive but not significant. Overall, we again see no evidence for an effect on birthweights even with these alternative methods.

In columns 2 and 4 we show the estimates for the effect on deaths. Column 2 shows the effect of treatment 1, while column 4 shows the effect for treatment 2. In column 2 the TWFE estimate is negative and significant. The CS and SA estimates are both negative and not significant. In column 4 the TWFE estimate is a precise null. The CS and SA estimates are again negative but not significant. Overall, we conclude the alternative estimators do not show any strong support for an effect on deaths.

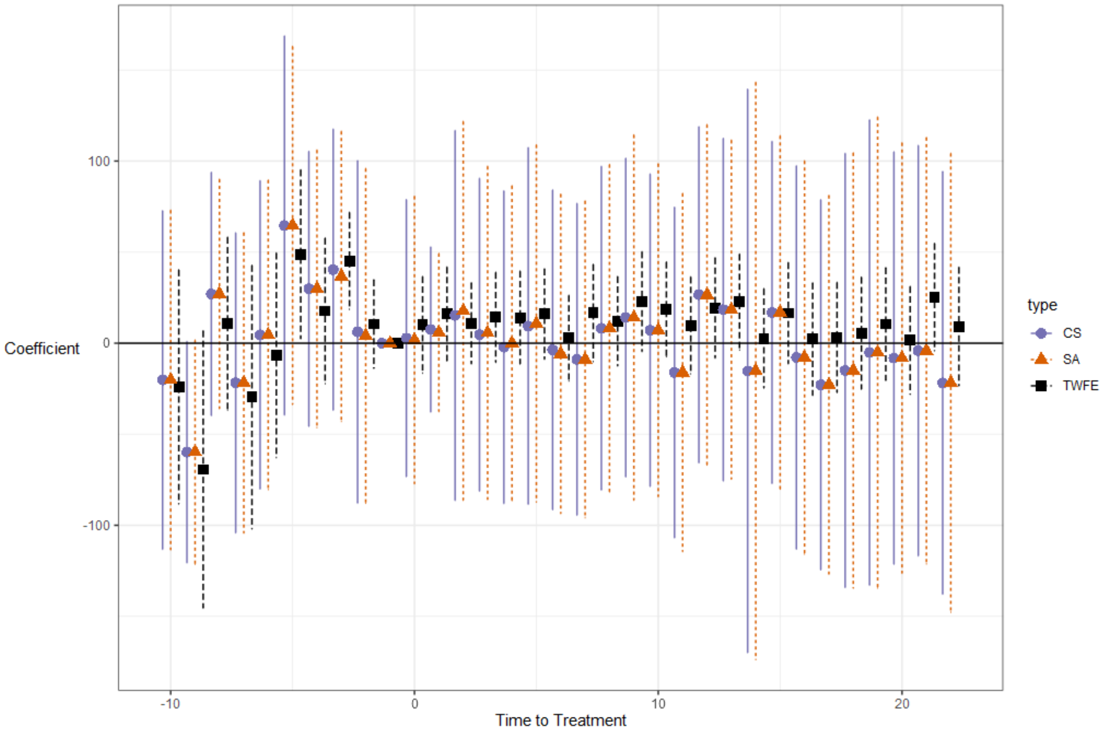
We also use alternative difference-in-difference estimators with event studies. These can be seen in figures 16-19. In figure A.1, we show all alternative estimators and their estimates of treatment 1 on birthweights, while in figure A.2 we show the effect of treatment 2 on birthweights. In both cases we observe no clear trend after treatment, and the 95% confidence intervals almost always cover zero. Similarly, when we look at deaths in figures A.3 and A.4, although the majority of point estimates are negative, there is no clear effect post-treatment, and most confidence intervals cover zero.

Table A.1 - Effect of Lead Reductions (Alternative Estimators)

Dependent Variable	Birthweights, Treatment 1 (1)		Under-5 Mortality, Treatment 1 (2)		Birthweights, Treatment 2 (3)		Under-5 Mortality, Treatment 2 (4)	
	ATT	SE	*ATT*	SE	*ATT*	SE	*ATT*	SE
TWFE	-3.5	(7.00)	-0.0017	(0.0009)	3.4	(4.1)	0.0000	(0.0007)
CS	0.3	(47.8)	-0.0020	(0.0021)	-11.6	(15.4)	-0.0031	(0.0017)
SA	0.4	(46.4)	-0.0019	(0.0021)	-13.0	(13.5)	-0.0030	(0.0016)
Observations	612,483		612,483		287,326		359,071	
Clusters	398		398		391		391	
Covariates	*Yes*		*Yes*		*Yes*		*Yes*	

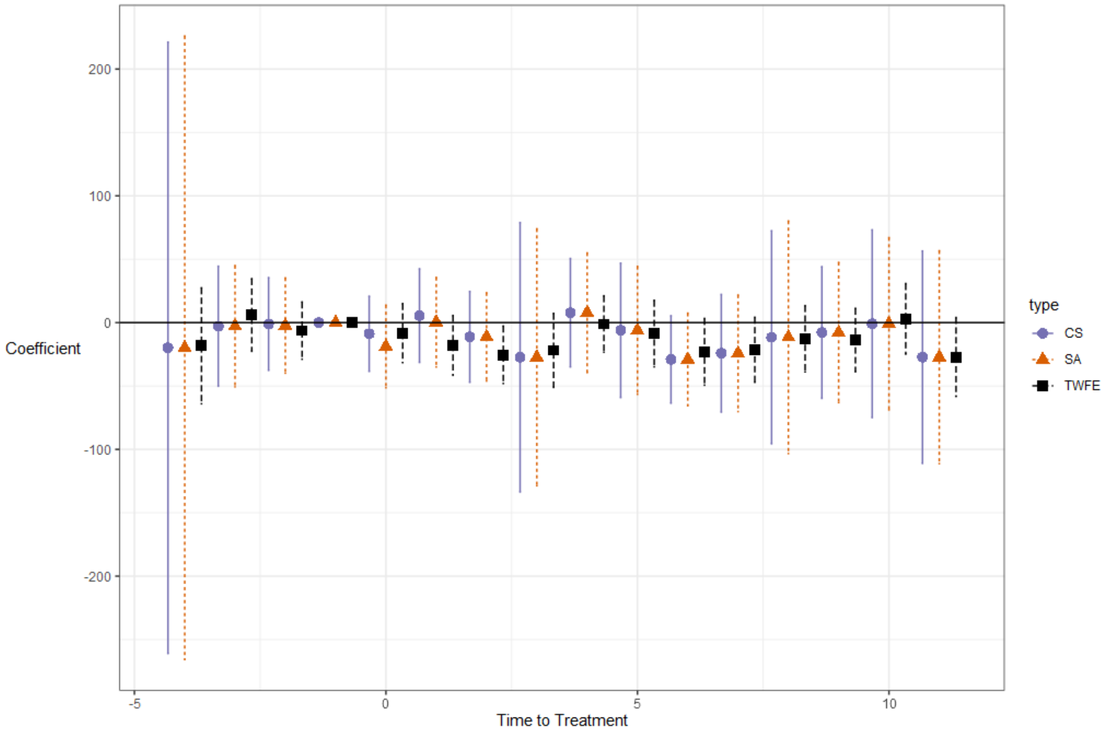
Notes: Table shows estimated treatment effects with different estimation methods. TWFE = Two-way fixed effects. CS = Calloway and Sant'Anna (2021). SA = Sun and Abraham (2021). We use robust standard errors, clustered by postcode sector. ATT = Average Treatment on the Treated estimate. Birthweights is the birthweight of the child in grams. Under-5 Mortality is the probability of all deaths and recorded non-viable pregnancies, including stillbirths. and spontaneous abortion. Birthweight regression estimates are rounded to 1 decimal place, mortality estimates are rounded to 3 decimal places. Treatment 1 = lime dosing in 70s and 80s, treatment 2 is orthophosphate dosing in late 80s and 90s.

Figure A.1 - Effect of Treatment 1 on Birthweights (Event Study with Alternative Estimators)



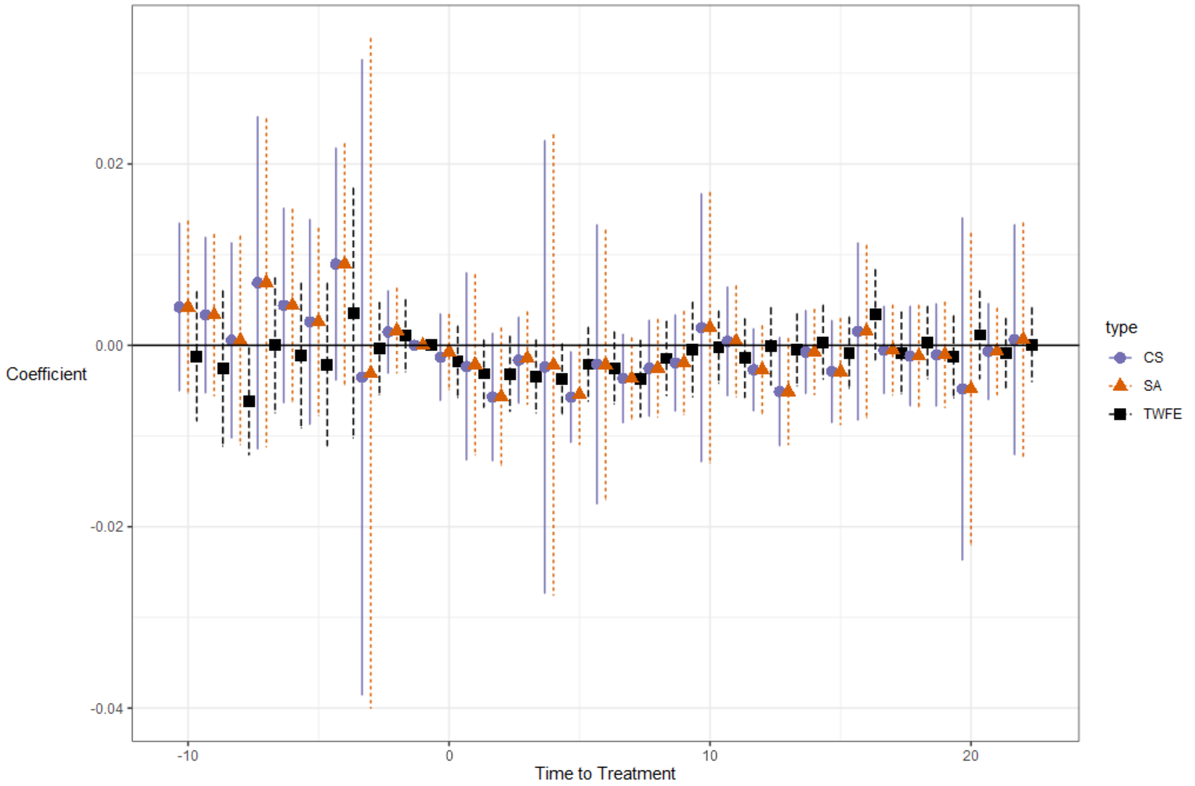
Notes: Table shows estimated treatment effects with different estimation methods of lead reduction due to lime-dosing in Glasgow and Edinburgh compared to a never-treated control group. TWFE = Two-way fixed effects. CS = Calloway and Sant'Anna (2021). SA = Sun and Abraham (2021). We use robust standard errors, clustered by postcode sector. In all cases the estimates are of the overall Average Treatment on the Treated (ATTs) for that year. Birthweights is the birthweight of the child in grams. Mortality is the probability of all deaths and recorded non-viable pregnancies, including stillbirths and spontaneous abortion.

Figure A.2 - Effect of Treatment 2 on Birthweights (Event Study with Alternative Estimators)



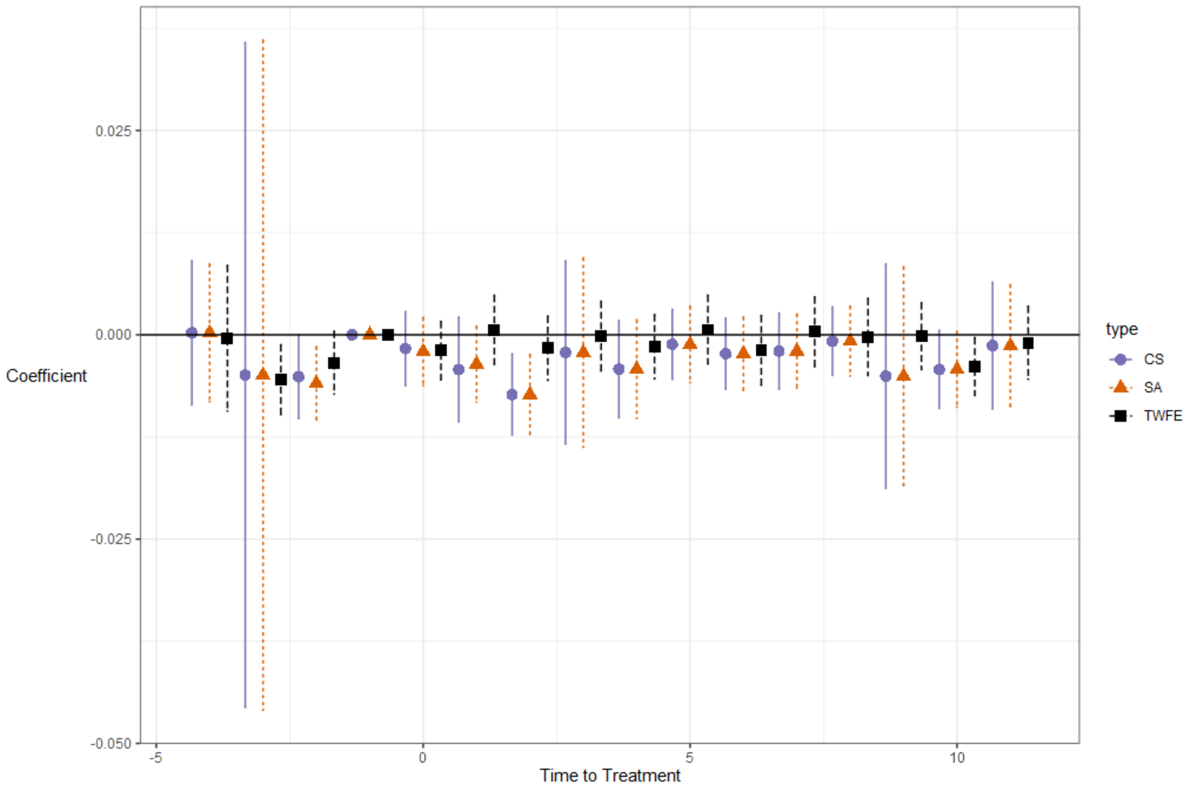
Notes: Table shows estimated treatment effects with different estimation methods of lead reduction due to orthophosphate dosing in Glasgow and Edinburgh compared to a never-treated control group. TWFE = Two-way fixed effects. CS = Calloway and Sant'Anna (2021). SA = Sun and Abraham (2021). We use robust standard errors, clustered by postcode sector. In all cases the estimates are of the overall Average Treatment on the Treated (ATTs) for that year. Birthweights is the birthweight of the child in grams. Mortality is the probability of all deaths and recorded non-viable pregnancies, including stillbirths and spontaneous abortion.

Figure A.3 - Effect of Treatment 1 on Under-5 Mortality (Event Study with Alternative Estimators)



Notes: Table shows estimated treatment effects with different estimation methods of lead reduction due to lime-dosing in Glasgow and Edinburgh compared to a never-treated control group. TWFE = Two-way fixed effects. CS = Calloway and Sant'Anna (2021). SA = Sun and Abraham (2021). We use robust standard errors, clustered by postcode sector. In all cases the estimates are of the overall Average Treatment on the Treated (ATTs) for that year. Mortality is the probability of all for all deaths and recorded non-viable pregnancies, including stillbirths and spontaneous abortion.

Figure A.4 - Effect of Treatment 2 on Under-5 Mortality (Event Study with Alternative Estimators)



Notes: Table shows estimated treatment effects with different estimation methods of lead reduction due to orthophosphate dosing in Glasgow and Edinburgh compared to a never-treated control group. TWFE = Two-way fixed effects. CS = Calloway and Sant'Anna (2021). SA = Sun and Abraham (2021). We use robust standard errors, clustered by postcode sector. In all cases the estimates are of the overall Average Treatment on the Treated for that year. Mortality is the probability of all for all deaths and recorded non-viable pregnancies, including stillbirths and spontaneous abortion.

1.2 Two-Way Mundlak Robustness Checks

In our main results the area in Edinburgh served with water by both the Edinburgh NE and Edinburgh SW plants, i.e. the "joint" area in figure 4, is included in the Edinburgh SW cohort. This is due to households in the area having an average water pH above 8, much closer to the Edinburgh SW pH, in 1985 (see figure 2). However, including this group may mean our Edinburgh SW results are not identified, as they do not receive identical treatments. We therefore exclude them from the two-way Mundlak regressions to see the effect on the results.

Table A.2 shows the effect on birthweight with and without covariates. Both averages are small and negative. Implying the treatment reduced birthweights. Table A.3 shows the results for deaths. Without covariates they show a small increase in deaths after treatment, but this is not statistically significant. With covariates we obtain a precise null effect for all years. These results are qualitatively similar to those when we include the joint water treatment area. In summary, we believe this shows it is not the inclusion of the joint treatment area in the Edinburgh SW cohort that leads to no effect being found for Edinburgh SW.

Table A.2 - Edinburgh SW Birthweight Results Excluding Joint Water Supply Area, Average Treatment on the Treated

Year	**Birthweight, No Covariates**	**Std Error**	**Birthweight, Covariates**	**Std Error**
1978	12.4	(33)	42.8	(25.3)
1979	10.6	(25.1)	-6.1	(18.2)
1980	3.9	(36.8)	-31.3	(25.7)
1981	-26.8	(32.1)	-60.4	(24)
1982	30.5	(49.8)	-37.9	(38.2)
1983	-62.5	(19.2)	-68.8	(19.4)
1984	-25.6	(39.7)	-20.0	(32.2)
1985	-7.9	(46.2)	-75.7	(44.)
1986	-25.6	(20.6)	-79.6	(11.5)
1987	-69.3	(47.7)	-123.4	(45.1)
1988	31.8	(28.8)	-4.2	(15.4)
1989	-9.2	(30.6)	-51.2	(19.1)
1990	36.8	(50.1)	1.5	(34.6)
1991	23.1	(50.5)	-42.5	(26.6)
1992	-8.9	(50.9)	-113.5	(17.1)
1993	-66.4	(23.6)	-78.8	(22.2)
1994	-5.9	(48.5)	17.4	(45.5)
1995	26.0	(38.6)	-46.2	(21.9)
1996	84.7	(30.4)	54.1	(15.8)
1997	-21.8	(41.1)	-90.7	(18.5)
1998	-66.1	(41)	-104.0	(47.6)
1999	11.8	(36.1)	11.5	(29.2)
2000	18.8	(58.5)	-27.0	(49)
Average	**-4.6**	**(8)**	**-40.6**	**(10.1)**

Notes: Table shows cohort specific treatment effects from two-way Mundlak regressions with and without covariates included in the regression. Sample is set to exclude all observations jointly served water by the Edinburgh SW and Edinburgh NE plant. Each year has an estimated treatment effect, and the bottom row is the mean of these. Robust standard errors, clustered by postcode sector, are in brackets.

Table A.3 - Edinburgh SW Deaths Before Age 5 Results Excluding Joint Water Supply Area, Average Partial Effect

Year	Deaths, No Covariates	Std Error	Deaths, Covariates	Std Error
1978	0.003	(0.007)	0.000	(0.000)
1979	0.002	(0.004)	0.000	(0.000)
1980	-0.006	(0.002)	0.000	(0.000)
1981	0.008	(0.007)	0.000	(0.000)
1982	-0.005	(0.002)	0.000	(0.000)
1983	0.006	(0.008)	0.000	(0.000)
1984	0.013	(0.01)	0.000	(0.000)
1985	-0.006	(0.002)	0.000	(0.000)
1986	0.013	(0.006)	0.000	(0.000)
1987	0.014	(0.011)	0.000	(0.000)
1988	0.003	(0.004)	0.000	(0.000)
1989	-0.001	(0.005)	0.001	(0.002)
1990	-0.002	(0.002)	0.000	(0.000)
1991	0.005	(0.004)	0.000	(0.000)
1992	0.003	(0.004)	0.002	(0.002)
1993	0.007	(0.006)	0.000	(0.000)
1994	-0.005	(0.002)	0.000	(0.000)
1995	0.000	(0.006)	0.000	(0.000)
1996	-0.001	(0.003)	0.000	(0.000)
1997	-0.001	(0.004)	0.000	(0.000)
1998	0.007	(0.007)	0.000	(0.000)
1999	0.009	(0.005)	0.000	(0.000)
2000	0.003	(0.004)	0.000	(0.000)
Average APE	0.003	(0.002)	0.000	(0.000)

Notes: Table shows cohort specific Average Partial Effects (APE). Sample is set to exclude all observations jointly served water by the Edinburgh SW and Edinburgh NE plant. These are calculated from logistic pooled quasi-maximum likelihood regressions using the two-way Mundlak method, with and without covariates. The relevant cohort and year indicators are set to 1, the relevant covariates indicators are set to1, continuous covariate variables are set to the cohort mean value for that covariate, and the difference with and without the cohort specific treatment indicator is taken. Each year has an estimated APE, and the bottom row is the mean of these. Standard errors of the APEs are bootstrapped.

Next we examine the treatment 2 intervention in isolation. That is, we only regress on outcomes that happen after all pH interventions are over. This means the treatment baseline is when all treated units have their pH raised to acceptable levels (after 1985). Therefore, the treatment of orthophosphate can be examined independently of the pH level increases. The Edinburgh group can be treated as one cohort as they all receive orthophosphate treatment at the same time, and the pH treatments have already happened.

Table A.4 and A.5, examine the regressions when we only look at the years 1986-2000, and therefore only at treatment 2, for the birthweight outcome with and without covariates. Table A.3, column 1 shows the treatment effects for Glasgow. The overall average is positive, but small and not significant. The biggest effects seem to be towards the end of the sample, but the 95% confidence intervals also cover zero. Table A.5, column 1 shows the effect for Glasgow with covariates. The results are much the same with the overall average positive but small and not significant. Column 2 shows the results for Edinburgh. Table A.4, without covariates, shows an overall average that is negative, but small and not significant. Table A.5 is qualitatively similar, with a small and insignificant average treatment effect.

Table A.4 - Average Effect of Treatment-on-the-Treated on Birthweights Orthophosphate Treatment Only, No Covariates

Year	Glasgow	Std Error	Edinburgh	Std Error
1989	-2.4	(12)	-	-
1990	-3.4	(12.5)	-	-
1991	8.4	(11.3)	15.7	(19.1)
1992	-8.5	(13.2)	-9.0	(19.7)
1993	14.8	(11.6)	-52.1	(13.8)
1994	-8.4	(13.9)	-18.1	(24.7)
1995	-4.7	(14.6)	2.8	(16.9)
1996	-6.7	(15.)	26.0	(18.2)
1997	6.3	(13.3)	-3.3	(20.)
1998	13.2	(13.5)	4.6	(20.4)
1999	20.5	(13.9)	-4.1	(20.1)
2000	15.8	(14.2)	23.8	(23.2)
Average	**3.7**	**(3.1)**	**-1.4**	**(7.2)**

Notes: Table shows cohort specific treatment effects from two-way Mundlak regressions without covariates included in the regression. Sample is restricted to 1985-2000. Each year has an estimated treatment effect, and the bottom row is the mean of these. Robust standard errors, clustered by postcode sector, are in brackets.

Table A.5 - Average Effect of Treatment-on-the-Treated on Birthweights Orthophosphate Treatment Only, Covariates Included

Year	Glasgow	Std Error	Edinburgh	Std Error
1989	-10.3	(12)	-	-
1990	10.1	(13.3)	-	-
1991	11.2	(12.9)	13.6	(17.1)
1992	-7.5	(12.7)	-21.4	(18.1)
1993	14.9	(12.1)	-50.8	(14.3)
1994	-10.0	(14.4)	-24.7	(26.4)
1995	-3.4	(13.8)	-17.7	(17)
1996	-9.0	(15.8)	10.6	(17.5)
1997	6.2	(13.3)	-16.8	(19.7)
1998	17.8	(14.8)	-9.5	(19.8)
1999	3.1	(15.5)	-16.4	(20.)
2000	9.8	(14.5)	10.7	(23.5)
Average	**2.7**	**(3)**	**-12.3**	**(6.2)**

Notes: Table shows cohort specific treatment effects from two-way Mundlak regressions with covariates included in the regression. Sample is restricted to 1985-2000. Each year has an estimated treatment effect, and the bottom row is the mean of these. Robust standard errors, clustered by postcode sector, are in brackets.

We repeat the logistic regression on deaths for Edinburgh and Glasgow using only the 1986-2000 sample. Table A.6, column 1 shows the APEs for the Glasgow treatment 2 without covariates in the regression. Most point estimate APEs are negative as expected, the overall average point estimate is negative but close to zero. The 95% interval implies an effect from decreasing deaths by 0.1 percentage points to increasing them by 0.06 percentage points. When we include covariates (table A.7), the overall APE becomes larger in magnitude but are still not significant. For Edinburgh, the two point estimate overall APEs have the opposite sign from expected, implying treatment increased deaths. Without covariates it implies an increase from 0.06-0.3 percentage points. When covariates are included (Table A.7) this is no longer statistically significant, with the 95% range being from decreasing deaths by 0.02 to increasing deaths by 0.03 percentage points. In summary, when examining only treatment 2, we find no evidence for an effect.

Table A.6 - Average Partial Effect of Treatment on Under-5 Mortality, Orthophosphate Treatment Only, No Covariates

Year	Glasgow	Std Error	Edinburgh	Std Error
1989	-0.001	(0.002)	-	-
1990	0.000	(0.001)	-	-
1991	-0.001	(0.001)	0.001	(0.002)
1992	0.002	(0.002)	0.005	(0.002)
1993	-0.003	(0.002)	-0.001	(0.002)
1994	0.005	(0.002)	0.005	(0.001)
1995	-0.002	(0.001)	0.001	(0.002)
1996	0.000	(0.002)	0.000	(0.002)
1997	-0.004	(0.001)	-0.001	(0.001)
1998	-0.001	(0.002)	0.001	(0.001)
1999	-0.001	(0.002)	0.007	(0.001)
2000	0.000	(0.002)	0.002	(0.001)
Average	**0.000**	**(0.000)**	**0.002**	**(0.001)**

Notes: Table shows cohort specific Average Partial Effects (APE). Sample is restricted to 1985-2000. These are calculated from logistic pooled quasi-maximum likelihood regressions using the two-way Mundlak method, without covariates. The relevant cohort and year indicators are set to 1, and the difference with and without the cohort specific treatment indicator is taken. Each year has an estimated APE, and the bottom row is the mean of these. Standard errors of the APEs are bootstrapped.

Table A.7 - Average Partial Effect of Treatment on Under-5 Mortality, Orthophosphate Treatment Only, Covariates Included

Year	Glasgow	Std Error	Edinburgh	Std Error
1989	-0.005	(0.002)	-	-
1990	-0.003	(0.002)	-	-
1991	-0.003	(0.002)	0.000	(0.002)
1992	0.003	(0.002)	0.005	(0.002)
1993	-0.003	(0.002)	-0.002	(0.003)
1994	0.003	(0.002)	0.002	(0.004)
1995	-0.002	(0.002)	-0.004	(0.001)
1996	0.000	(0.002)	0.000	(0.002)
1997	-0.004	(0.001)	-0.001	(0.001)
1998	-0.002	(0.002)	0.001	(0.002)
1999	0.000	(0.001)	0.004	(0.002)
2000	0.001	(0.001)	0.000	(0.002)
Average	**-0.001**	**(0.001)**	**0.000**	**(0.001)**

Notes: Table shows cohort specific Average Partial Effects (APE). Sample is restricted to 1985-2000. These are calculated from logistic pooled quasi-maximum likelihood regressions using the two-way Mundlak method and including covariates. The relevant cohort and year indicators are set to 1, the relevant covariates indicators are set to1, continuous covariate variables are set to the cohort mean value for that covariate, and the difference with and without the cohort specific treatment indicator is taken. Each year has an estimated APE, and the bottom row is the mean of these. Standard errors of the APEs are bootstrapped.

Next, we examine if the prevalence of lead piping in Glasgow affected the strength of the relationship with our outcomes and the lead reducing treatment. Different treatment dosage levels, such as we have when some areas have high lead pipe prevalence, and others have low lead pipe prevalence, can lead the treatment effect estimates being biased if there is selection into or out of the different dosage groups (see Callaway et al., 2021). To remove this threat to identification, Callaway et al., (2021) suggest regressing on each dosage group separately.

Therefore, we perform separate two-way Mundlak regressions, first removing the low lead pipe prevalence areas from the sample, then removing the high lead pipe areas (see figure 3). One issue is that there are far fewer births in the high lead areas, and especially few death occurrences, with only 1 or 2 in some years. Nevertheless, we include the estimation here as a robustness check.

The results for birthweights are in table A.8. They are similar to our main results for both the high and low lead areas, with small negative effects for both areas. The under-5 mortality results are in table A.9. For high lead areas, we see the majority of years have negative APEs, but the effects are relatively small and the overall APE is a precise null. For low lead areas, the year estimates of the APE are predominately negative. The overall APE is also negative and statistically significant.

Table A.8 - Glasgow High and Low Lead Areas Only, Average Effect of Treatment-on-the-Treated on Birthweights, Covariates Included

Year	**High Lead Areas**	**Std Error**	**Low Lead Areas**	**Std Error**
1978	-63.4	(26.5)	-10.6	12
1979	-46.5	(21.9)	7.1	11.7
1980	-90.3	(30.5)	-14.2	10.3
1981	-12.3	(24.0)	-5.9	12.3
1982	-17.9	(34.5)	-7.4	13
1983	-32.3	(32.5)	2.8	13.1
1984	-60.7	(32.6)	-19.3	13.5
1985	-50.0	(41.4)	6.9	12.5
1986	-30.5	(22.9)	9.7	11.9
1987	-10.2	(24.7)	13.2	13.5
1988	-37.5	(29.2)	5	13.7
1989	-60.5	(31.7)	-8.4	14.8
1990	-10.4	(23.9)	-11.1	13.6
1991	-25.1	(36.5)	-1.5	13.4
1992	-39.6	(32.9)	-17.9	13.6
1993	12.7	(26.6)	-0.6	14.8
1994	-55.3	(46.4)	-6.8	14.7
1995	-66.6	(31.2)	-19.2	15.8
1996	-70.9	(31.5)	-12.2	16.1
1997	-28.6	(28.1)	-10.8	15.6
1998	-87.5	(28.5)	-7.9	14.8
1999	-50.7	(19.8)	14.7	15.5
2000	-82.1	(33.3)	-14.0	17.2
Average	**-44.2**	**(5.6)**	**-4.7**	**(2.2)**

Notes: Table shows cohort specific treatment effects from two-way Mundlak regressions with covariates included in the regression. Column 1 and 3 are separate regressions, columns 2 and 4 are the standard errors. Column 1 is a regression excluding the areas with low prevalence of lead piping in Glasgow. Column 3 excludes the areas of high lead pipe prevalence in Glasgow. Each year has an estimated treatment effect, and the bottom row is the mean of these. Robust standard errors, clustered by postcode sector, are in brackets.

Table A.9 - Glasgow High and Low Lead Areas Only, Average Partial Effect of Treatment on Under-5 Mortality, Orthophosphate Treatment Only, Covariates Included

Year	**High Lead Areas**	**Std Error**	**Low Lead Areas**	**Std Error**
1978	-0.004	(0.001)	-0.003	(0.002)
1979	0.002	(0.003)	-0.006	(0.000)
1980	-0.002	(0.005)	-0.006	(0.004)
1981	0.004	(0.000)	-0.008	(0.003)
1982	0.000	(0.001)	-0.006	(0.002)
1983	-0.006	(0.001)	-0.004	(0.002)
1984	0.000	(0.004)	-0.008	(0.001)
1985	-0.005	(0.001)	-0.009	(0.002)
1986	-0.006	(0.000)	-0.003	(0.001)
1987	0.002	(0.001)	-0.005	(0.002)
1988	-0.001	(0.001)	-0.001	(0.004)
1989	-0.005	(0.000)	-0.004	(0.002)
1990	-0.001	(0.003)	-0.001	(0.003)
1991	0.001	(0.001)	-0.002	(0.003)
1992	0.002	(0.004)	-0.003	(0.002)
1993	0.001	(0.002)	-0.003	(0.004)
1994	0.005	(0.000)	0.001	(0.000)
1995	0.001	(0.001)	-0.004	(0.001)
1996	0.001	(0.002)	0.000	(0.000)
1997	-0.004	(0.002)	-0.002	(0.002)
1998	0.008	(0.002)	-0.002	(0.002)
1999	0.001	(0.002)	-0.003	(0.001)
2000	-0.001	(0.001)	-0.001	(0.002)
Average	**0.000**	**(0.001)**	**-0.004**	**(0.002)**

Notes: Table shows cohort specific Average Partial Effects (APE). These are calculated from logistic pooled quasi-maximum likelihood regressions using the two-way Mundlak method and including covariates. The relevant cohort and year indicators are set to 1, the relevant covariates indicators are set to1, continuous covariate variables are set to the cohort mean value for that covariate, and the difference with and without the cohort specific treatment indicator is taken. Each year has an estimated APE, and the bottom row is the mean of these. Standard errors of the APEs are bootstrapped. Columns 1 and 3 are separate regressions, columns 2 and 4 are the standard errors. Column 1 is a regression excluding the areas with low prevalence of lead piping in Glasgow. Column 3 excludes the areas of high lead pipe prevalence in Glasgow.