

Supplementary Online Content

Short-term exposure to low level ambient fine particulate matter and natural cause, cardiovascular, and respiratory morbidity among US adults with health insurance: case time series study

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eAppendix. Calculation of excess relative risk, excess events per million enrollees per day

Excess relative risk was defined as $(\text{relative risk} - 1) \times 100\%$.

To calculate the excess events, we first calculated the incidence rate of hospitalizations and emergency department (ED) visits per million enrollees per day using the total number of cause-specific hospitalizations/ED visits during 2010 to 2016 covered by the health insurance divided by the total person-days for the beneficiaries covered by the health plans, which we denoted as α .¹

We then calculated the excess events associated with each $10 \mu\text{g}/\text{m}^3$ increase of two-day moving average $\text{PM}_{2.5}$ as $\alpha \times (\text{relative risk} - 1)/\text{relative risk}$, and its standard error as $\text{se} = \alpha \times \exp(-\beta_{\text{PM}_{2.5}} \times 10) \times \text{se}(10 \times \beta_{\text{PM}_{2.5}})$ according to the delta method.²

Table S1. Codes to identify hospital admissions and emergency department (ED) visits

	Hospital admissions	ED visits
Current Procedure Terminology (CPT codes)	N/A	99281, 99282, 99283, 99284, 99285, 99288
Revenue codes	N/A	0450, 0451, 0452, 0453, 0454, 0455, 0456, 0457, 0458, 0459
Place of service codes	21, 51, 55, 56, 61	N/A

Table S2. The number of US counties included in the analyses

Disease	Hospital admissions No. (%)	Emergency department visits No. (%)
Natural cause	2939 (93.5%)	2939 (93.5%)
Cardiovascular	2935 (93.4%)	2937 (93.4%)
Respiratory	2938 (93.4%)	2936 (93.4%)

Table S3. Number of hospital admissions and emergency department (ED) visits for natural cause, cardiovascular and respiratory diseases by different characteristics in the adult population with health insurance from 2010 to 2016

	Hospital admissions			ED Visits		
	Natural Cause	Cardiovascular diseases	Respiratory diseases	Natural Cause	Cardiovascular diseases	Respiratory diseases
n	10,316,606	3,776,606	2,263,405	24,097,688	3,318,642	3,513,702
Age, year, %						
18-29	1,086,206 (10.5%)	58,465 (1.5%)	64,422 (2.8%)	4,111,577 (17.1%)	75,536 (2.3%)	537,433 (15.3%)
30-39	1,377,437 (13.4%)	96,905 (2.6%)	72,373 (3.2%)	3,475,573 (14.4%)	131,708 (4.0%)	423,927 (12.1%)
40-49	960,831 (9.3%)	226,546 (6.0%)	135,524 (6.0%)	3,556,436 (14.8%)	269,388 (8.1%)	435,025 (12.4%)
50-64	2,369,250 (23.0%)	910,556 (24.1%)	533,605 (23.6%)	5,421,001 (22.5%)	797,570 (24.0%)	762,879 (21.7%)
65-74	1,847,118 (17.9%)	914,520 (24.2%)	545,617 (24.1%)	3,168,870 (13.2%)	733,815 (22.1%)	545,373 (15.5%)
75+	2,675,764 (25.9%)	1,569,614 (41.6%)	911,864 (40.3%)	4,364,231 (18.1%)	1,310,625 (39.5%)	809,065 (23.0%)
Sex, %						
Male	4,088,336 (39.6%)	1,921,260 (50.9%)	1,095,573 (48.4%)	9,795,370 (40.6%)	1,632,648 (49.2%)	1,498,922 (42.7%)
Female	6,228,270 (60.4%)	1,855,346 (49.1%)	1,167,832 (51.6%)	14,302,318 (59.4%)	1,685,994 (50.8%)	2,014,780 (57.3%)
Insurance type, %						
Commercial	7,111,488 (68.9%)	2,080,915 (55.1%)	1,207,571 (53.4%)	18,390,500 (76.3%)	1,917,754 (57.8%)	2,467,421 (70.2%)
Medicare Advantage	3,205,118 (31.1%)	1,695,691 (44.9%)	1,055,834 (46.6%)	5,707,188 (23.7%)	1,400,888 (42.2%)	1,046,281 (29.8%)
NCA4 region, %						
Northeast	1,890,683 (18.3%)	781,004 (20.7%)	444,951 (19.7%)	3,954,262 (16.4%)	646,037 (19.5%)	578,500 (16.5%)
Northern great plains	164,686 (1.6%)	59,356 (1.6%)	35,933 (1.6%)	320,618 (1.3%)	46,996 (1.4%)	42,937 (1.2%)
Northwest	223,030 (2.2%)	67,000 (1.8%)	45,556 (2.0%)	486,842 (2.0%)	63,982 (1.9%)	59,840 (1.7%)
Midwest	2,637,200 (25.6%)	997,964 (26.4%)	581,669 (25.7%)	6,224,392 (25.8%)	852,707 (25.7%)	955,095 (27.2%)
Southeast	3,097,262 (30.0%)	1,211,376 (32.1%)	736,935 (32.6%)	7,496,185 (31.1%)	1,094,849 (33.0%)	1,112,254 (31.7%)

Southern great plains	1,208,654 (11.7%)	353,534 (9.4%)	215,825 (9.5%)	3,111,791 (12.9%)	330,549 (10.0%)	429,063 (12.2%)
Southwest	1,095,091 (10.6%)	306,372 (8.1%)	202,536 (8.9%)	2,503,598 (10.4%)	283,522 (8.5%)	336,013 (9.6%)

Abbreviations: NCA4 region= geographic regions as defined by the US Global Change Research Program's Fourth National Climate Assessment; ED=emergency department.

Table S4. Incidence rate of hospital admissions and emergency department (ED) visits per million enrollees per day by different characteristics during the study period from 2010 to 2016

	Hospital admissions			ED Visits		
	Natural Cause	Cardiovascular diseases	Respiratory diseases	Natural Cause	Cardiovascular diseases	Respiratory diseases
Overall	207.9	76.1	45.6	485.7	66.9	70.8
Age, years						
18-29	116.6	6.3	6.9	441.5	8.1	57.7
30-39	160.3	11.3	8.4	404.4	15.3	49.3
40-49	103.3	24.4	14.6	382.3	29.0	46.8
50-64	182.8	70.3	41.2	418.3	61.5	58.9
65-74	337.8	167.2	99.8	579.4	134.2	99.7
75+	672.7	394.6	229.2	1097.2	329.5	203.4
Sex						
Male	172.3	81.0	46.2	412.8	68.8	63.2
Female	240.6	71.7	45.1	552.5	65.1	77.8
Insurance type						
Commercial	162.2	47.5	27.5	419.5	43.7	56.3
Medicare Advantage	554.4	293.3	182.6	987.2	242.3	181.0
NCA4 region						
Northeast	225.4	93.1	53.0	471.3	77.0	69.0
Northern great plains	253.3	91.3	55.3	493.1	72.3	66.0
Northwest	181.4	54.5	37.0	395.9	52.0	48.7
Midwest	231.1	87.4	51.0	545.4	74.7	83.7
Southeast	227.5	89.0	54.1	550.5	80.4	81.7
Southern great plains	164.5	48.1	29.4	423.5	45.0	58.4
Southwest	157.1	44.0	29.1	359.2	40.7	48.2

Abbreviations: NCA4 = US Global Change Research Program's Fourth National Climate Assessment

Table S5. Excess relative risk (%) of hospital admissions and emergency department (ED) visits for natural cause, cardiovascular and respiratory diseases associated with each 10 µg/m³ increase in PM_{2.5}, stratified by age, sex, insurance type and NCA4 regions

	Hospital admissions			ED Visits		
	Natural Cause	Cardiovascular diseases	Respiratory diseases	Natural Cause	Cardiovascular diseases	Respiratory diseases
Overall	0.91 (0.55, 1.26)	1.39 (0.81, 1.98)	1.90 (1.15, 2.66)	0.20 (-0.03, 0.43)	0.43 (-0.18, 1.05)	1.34 (0.73, 1.94)
Age, years	P<0.001	P=0.06	P=0.80	P=0.007	P=0.19	P=0.35
18-29	0.36 (-0.72, 1.45)	2.46 (-2.13, 7.27)	3.40 (-1.02, 8.01)	0.45 (-0.10, 1.01)	2.51 (-1.53, 6.72)	1.95 (0.42, 3.50)
30-39	-0.61 (-1.56, 0.36)	3.07 (-0.54, 6.82)	2.57 (-1.56, 6.87)	0.09 (-0.52, 0.69)	1.89 (-1.18, 5.05)	1.91 (0.19, 3.65)
40-49	0.20 (-0.94, 1.35)	-0.25 (-2.55, 2.11)	2.35 (-0.68, 5.46)	-0.39 (-0.98, 0.20)	-1.44 (-3.52, 0.69)	2.57 (0.87, 4.30)
50-64	0.40 (-0.33, 1.14)	0.07 (-1.10, 1.24)	1.22 (-0.31, 2.76)	-0.27 (-0.75, 0.21)	-0.37 (-1.60, 0.88)	0.86 (-0.40, 2.15)
65-74	1.43 (0.60, 2.26)	1.71 (0.54, 2.89)	2.60 (1.09, 4.14)	0.46 (-0.17, 1.09)	0.75 (-0.54, 2.06)	1.03 (-0.45, 2.54)
75+	2.21 (1.52, 2.91)	2.08 (1.18, 2.99)	1.68 (0.51, 2.86)	0.93 (0.39, 1.46)	0.88 (-0.09, 1.86)	0.49 (-0.73, 1.73)
Sex	P=0.01	P=0.85	P=0.84	P=0.59	P=0.42	P=0.74
Male	1.48 (0.92, 2.05)	1.45 (0.63, 2.27)	1.82 (0.75, 2.91)	0.27 (-0.09, 0.63)	0.69 (-0.19, 1.57)	1.46 (0.54, 2.38)
Female	0.53 (0.07, 0.98)	1.34 (0.51, 2.17)	1.97 (0.93, 3.02)	0.14 (-0.15, 0.44)	0.18 (-0.67, 1.05)	1.25 (0.46, 2.04)
Insurance type	P=0.009	P=0.47	P=0.75	P=0.44	P=0.04	P=0.09
Commercial	0.58 (0.16, 1.01)	1.19 (0.40, 1.98)	2.02 (0.99, 3.07)	0.14 (-0.13, 0.40)	-0.12 (-0.93, 0.59)	1.66 (0.94, 2.38)
Medicare Advantage	1.60 (0.97, 2.23)	1.62 (0.77, 2.49)	1.78 (0.69, 2.87)	0.35 (-0.11, 0.81)	1.16 (0.23, 2.11)	0.52 (-0.55, 1.61)
NCA4 region	P<0.001	P=0.005	P=0.11	P<0.001	P=0.10	P<0.001
Northeast	2.81 (1.94, 3.68)	3.22 (1.89, 4.57)	2.00 (0.28, 3.75)	0.85 (0.26, 1.44)	1.50 (0.07, 2.95)	1.07 (-0.43, 2.59)
Northern great plains	1.48 (-1.43, 4.47)	5.56 (0.59, 10.78)	9.69 (3.11, 16.70)	2.37 (0.26, 4.53)	5.42 (-0.16, 11.32)	2.99 (-2.69, 8.99)
Northwest	-0.72 (-3.11, 1.73)	-2.61 (-6.82, 1.79)	1.64 (-3.60, 7.17)	-0.11 (-1.75, 1.56)	-4.18 (-8.43, 0.27)	3.15 (-1.51, 8.02)
Midwest	0.71 (0.00, 1.42)	1.31 (0.17, 2.46)	3.16 (1.66, 4.69)	-0.28 (-0.74, 0.17)	0.35 (-0.86, 1.57)	1.61 (0.46, 2.78)
Southeast	0.76	1.16	1.01	-0.21	0.12	0.08

	(0.13, 1.40)	(0.16, 2.18)	(-0.27, 2.30)	(-0.61, 0.20)	(-0.93, 1.17)	(-0.96, 1.13)
Southern great plains	0.11 (-0.97, 1.20)	0.54 (-1.43, 2.56)	2.32 (-0.23, 4.94)	1.39 (0.70, 2.07)	0.79 (-1.25, 2.88)	5.64 (3.77, 7.54)
Southwest	-0.02 (-1.22, 1.20)	-1.03 (-3.27, 1.27)	1.22 (-1.59, 4.12)	0.36 (-0.45, 1.16)	-0.73 (-3.08, 1.68)	0.63 (-1.56, 2.87)

Abbreviations: PM_{2.5} = fine particulate matter; NCA4 = US Global Change Research Program's Fourth National Climate Assessment

Table S6. Excess events per million enrollees per day of hospital admissions and emergency department (ED) visits for natural cause, cardiovascular and respiratory diseases associated with each 10 $\mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$, stratified by age, sex, insurance type and NCA4 regions

	Hospital admissions			ED Visits		
	Natural Cause	Cardiovascular diseases	Respiratory diseases	Natural Cause	Cardiovascular diseases	Respiratory diseases
Overall	1.87 (1.14, 2.59)	1.04 (0.61, 1.48)	0.85 (0.52, 1.18)	0.95 (-0.17, 2.07)	0.29 (-0.12, 0.69)	0.93 (0.52, 1.35)
Age, years						
18-29	0.41 (-0.84, 1.67)	0.15 (-0.13, 0.43)	0.23 (-0.07, 0.52)	2.00 (-0.44, 4.44)	0.20 (-0.12, 0.52)	1.10 (0.25, 1.96)
30-39	-0.98 (-2.53, 0.58)	0.34 (-0.05, 0.73)	0.21 (-0.13, 0.55)	0.35 (-2.09, 2.78)	0.28 (-0.18, 0.74)	0.92 (0.10, 1.74)
40-49	0.20 (-0.98, 1.38)	-0.06 (-0.63, 0.51)	0.33 (-0.09, 0.76)	-1.50 (-3.78, 0.79)	-0.42 (-1.05, 0.20)	1.17 (0.41, 1.93)
50-64	0.73 (-0.59, 2.06)	0.05 (-0.77, 0.87)	0.49 (-0.12, 1.11)	-1.14 (-3.17, 0.88)	-0.23 (-1.00, 0.54)	0.50 (-0.23, 1.24)
65-74	4.76 (2.04, 7.48)	2.81 (0.91, 4.71)	2.53 (1.08, 3.98)	2.64 (-0.95, 6.23)	1.00 (-0.71, 2.71)	1.02 (-0.44, 2.48)
75+	14.57 (10.09, 19.06)	8.04 (4.61, 11.47)	3.79 (1.18, 6.40)	10.06 (4.27, 15.86)	2.87 (-0.30, 6.03)	1.00 (-1.47, 3.48)
Sex						
Male	2.52 (1.58, 3.46)	1.15 (0.51, 1.80)	0.83 (0.35, 1.31)	1.12 (-0.36, 2.60)	0.47 (-0.13, 1.06)	0.91 (0.34, 1.47)
Female	1.26 (0.18, 2.34)	0.95 (0.37, 1.52)	0.87 (0.42, 1.33)	0.79 (-0.85, 2.44)	0.12 (-0.44, 0.68)	0.96 (0.36, 1.56)
Insurance type						
Commercial	0.94 (0.25, 1.63)	0.56 (0.19, 0.92)	0.55 (0.27, 0.82)	0.58 (-0.54, 1.69)	-0.05 (-0.41, 0.30)	0.92 (0.52, 1.31)
Medicare Advantage	8.71 (5.33, 12.09)	4.69 (2.24, 7.14)	3.19 (1.27, 5.11)	3.43 (-1.12, 7.99)	2.79 (0.56, 5.02)	0.94 (-0.99, 2.87)
NCA4 region						
Northeast	6.15 (4.30, 8.00)	2.91 (1.74, 4.08)	1.04 (0.15, 1.92)	3.97 (1.23, 6.70)	1.14 (0.06, 2.22)	0.73 (-0.29, 1.75)
Northern great plains	3.68 (-3.56, 10.93)	4.81 (0.64, 8.99)	4.88 (1.77, 8.00)	11.42 (1.38, 21.46)	3.72 (-0.02, 7.45)	1.91 (-1.72, 5.55)
Northwest	-1.32 (-5.77, 3.13)	-1.46 (-3.93, 1.01)	0.60 (-1.33, 2.53)	-0.43 (-6.99, 6.14)	-2.27 (-4.73, 0.19)	1.48 (-0.69, 3.66)
Midwest	1.62 (0.01, 3.23)	1.13 (0.15, 2.11)	1.56 (0.84, 2.29)	-1.54 (-4.03, 0.95)	0.26 (-0.64, 1.16)	1.33 (0.39, 2.27)
Southeast	1.72	1.02	0.54	-1.13	0.09	0.06

	(0.30, 3.14)	(0.14, 1.90)	(-0.14, 1.22)	(-3.37, 1.10)	(-0.75, 0.94)	(-0.78, 0.91)
Southern great plains	0.18 (-1.60, 1.96)	0.26 (-0.69, 1.21)	0.67 (-0.06, 1.39)	5.79 (2.97, 8.60)	0.35 (-0.56, 1.27)	3.12 (2.13, 4.10)
Southwest	-0.03 (-1.93, 1.87)	-0.46 (-1.48, 0.56)	0.35 (-0.46, 1.16)	1.27 (-1.60, 4.14)	-0.30 (-1.28, 0.69)	0.30 (-0.75, 1.36)

Abbreviations: PM_{2.5} = fine particulate matter; NCA4 = US Global Change Research Program's Fourth National Climate Assessment

Table S7. Excess relative risk (%) of hospital admissions and emergency department (ED) visits for natural cause, cardiovascular and respiratory diseases associated with each 10 $\mu\text{g}/\text{m}^3$ increase in two-day moving average $\text{PM}_{2.5}$, $\text{PM}_{2.5}$ on lag day 0 and $\text{PM}_{2.5}$ on lag day 1

Disease	Two-day moving average $\text{PM}_{2.5}$	$\text{PM}_{2.5}$ on lag day 0	$\text{PM}_{2.5}$ on lag day 1
Natural cause			
Hospital admissions	0.91 (0.55,1.26)	0.86 (0.52,1.19)	0.04 (-0.31, 0.38)
ED visits	0.20 (-0.03,0.43)	1.07 (0.85,1.29)	-0.90 (-1.12, -0.67)
Cardiovascular disease			
Hospital admissions	1.39 (0.81,1.98)	1.09 (0.54,1.64)	0.29 (-0.27,0.84)
ED visits	0.43 (-0.18,1.05)	0.91 (0.33,1.50)	-0.50 (-1.09,0.09)
Respiratory Disease			
Hospital admissions	1.90 (1.15,2.66)	0.86 (0.16,1.57)	1.03 (0.31,1.76)
ED visits	1.34 (0.73,1.94)	0.66 (0.09,1.23)	0.67 (0.09,1.25)

Table S8. Excess relative risk (%) of hospital admissions and emergency department (ED) visits for natural cause, cardiovascular and respiratory diseases associated with each 10 $\mu\text{g}/\text{m}^3$ increase in two-day moving average $\text{PM}_{2.5}$, results from main model compared with the model adjusted for daily maximum and minimum temperature

Disease	Main model (adjusted for daily mean temperature)	Sensitivity analysis (adjusted for daily maximum temperature)	Sensitivity analysis (adjusted for daily minimum temperature)
Natural cause			
Hospital admissions	0.91 (0.55,1.26)	0.74 (0.38, 1.11)	1.13 (0.79, 1.48)
ED visits	0.20 (-0.03,0.43)	0.04 (-0.20, 0.27)	0.65 (0.42, 0.88)
Cardiovascular disease			
Hospital admissions	1.39 (0.81,1.98)	1.21 (0.62, 1.80)	1.61 (1.04, 2.18)
ED visits	0.43 (-0.18,1.05)	0.20 (-0.43, 0.82)	0.77 (0.16, 1.37)
Respiratory Disease			
Hospital admissions	1.90 (1.15,2.66)	1.79 (1.03, 2.56)	2.01 (1.28, 2.76)
ED visits	1.34 (0.73,1.94)	1.30 (0.69, 1.92)	1.26 (0.67, 1.85)

Table S9. The excess relative risk (%) of hospital admissions and emergency department (ED) visits for natural cause, cardiovascular, and respiratory diseases associated with each 10 $\mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$, with considering the interaction of both temperature and relative humidity splines with NCA4 regions in the models

Disease	Main model (interact temperature splines with NCA4 regions)	Sensitivity analysis (interact both temperature and relative humidity splines with NCA4 regions)
Natural cause		
Hospital admissions	0.91 (0.55, 1.26)	0.94 (0.57, 1.30)
ED visits	0.20 (-0.03, 0.43)	0.23 (0.00, 0.47)
Cardiovascular disease		
Hospital admissions	1.39 (0.81, 1.98)	1.41 (0.82, 2.00)
ED visits	0.43 (-0.18, 1.05)	0.43 (-0.20, 1.05)
Respiratory Disease		
Hospital admissions	1.90 (1.15, 2.66)	2.01 (1.25, 2.78)
ED visits	1.34 (0.73, 1.94)	1.43 (0.82, 2.04)

Table S10. Results for analyses with and without filtered days with PM_{2.5} above 15 µg/m³.

Disease	Main model (restrict PM _{2.5} ≤ 15 µg/m ³)	Sensitivity analysis (unrestricted PM _{2.5})
Natural cause		
Hospital admissions	0.91 (0.55, 1.26)	0.86 (0.66, 1.06)
ED visits	0.20 (-0.03, 0.43)	0.06 (-0.07, 0.19)
Cardiovascular disease		
Hospital admissions	1.39 (0.81, 1.98)	1.11 (0.78, 1.43)
ED visits	0.43 (-0.18, 1.05)	0.60 (0.26, 0.95)
Respiratory Disease		
Hospital admissions	1.90 (1.15, 2.66)	1.04 (0.62, 1.46)
ED visits	1.34 (0.73, 1.94)	-0.03 (-0.36, 0.30)

Figure S1. Map for US Global Change Research Program's Fourth National Climate Assessment (NCA4) geographic regions



Figure S2. The probability density distribution of PM_{2.5} overall and by NCA4 regions

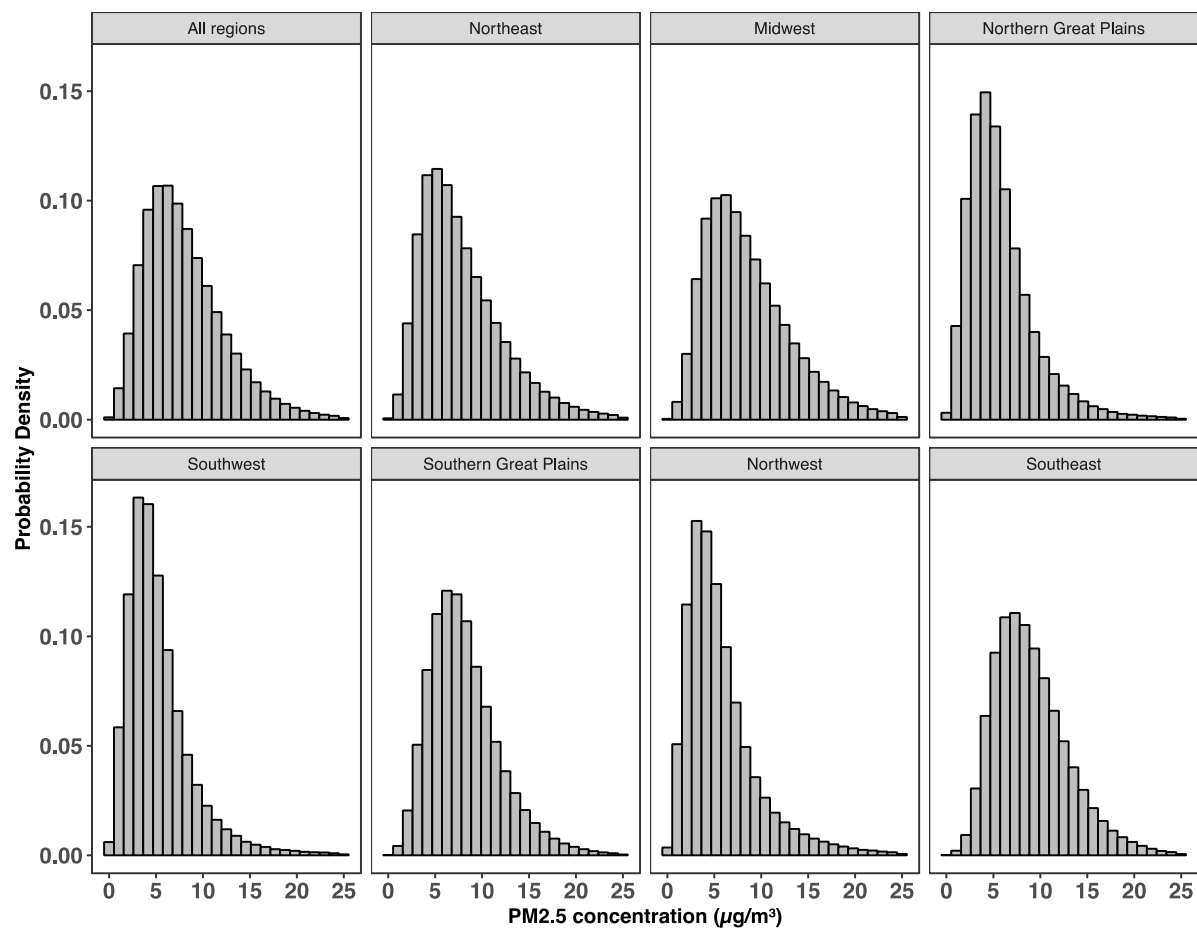
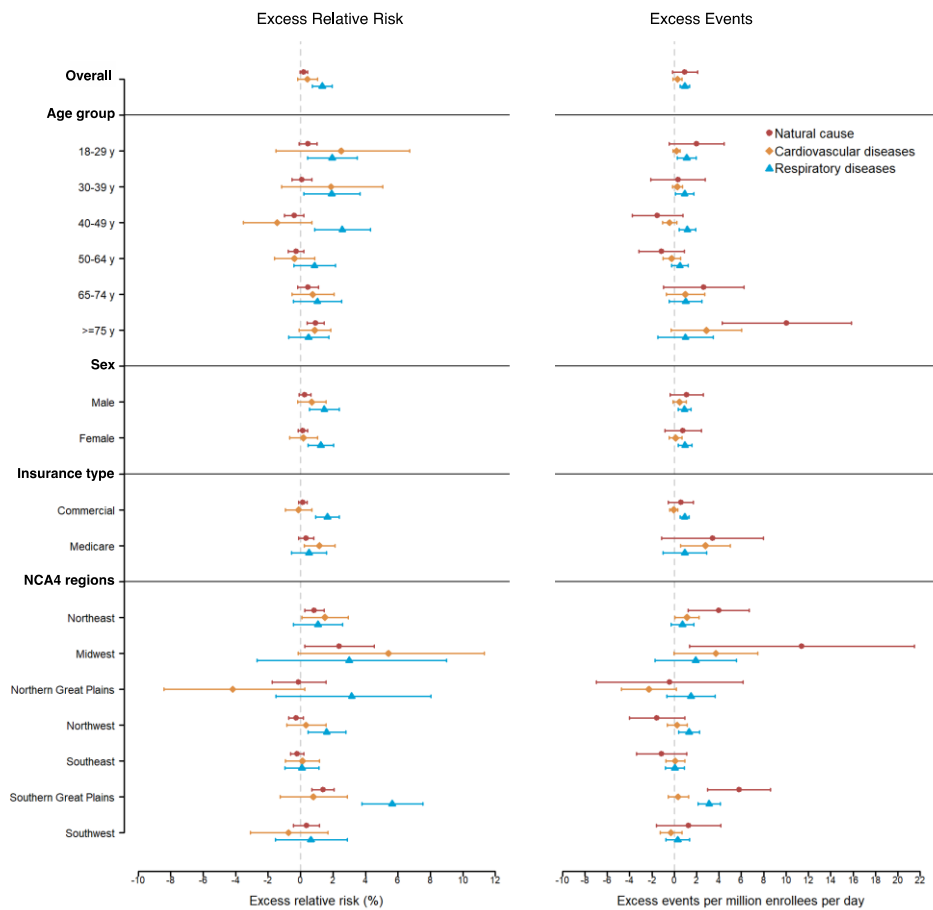


Figure S3. Excess relative risk (%) and excess events of emergency department (ED) visits for natural cause, cardiovascular and respiratory diseases associated with each 10 $\mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$, stratified by age, sex, insurance type and NCA4 regions



Supplemental references

1. Sun, S., Weinberger, K. R., Nori-Sarma, A., Spangler, K. R., Sun, Y., Dominici, F., & Wellenius, G. A. (2021). Ambient heat and risks of emergency department visits among adults in the United States: Time stratified case crossover study. *BMJ (Clinical Research Ed.)*, 375, e065653. <https://doi.org/10.1136/bmj-2021-065653>
2. Di, Q., Dai, L., Wang, Y., Zanobetti, A., Choirat, C., Schwartz, J. D., & Dominici, F. (2017). Association of Short-term Exposure to Air Pollution With Mortality in Older Adults. *JAMA*, 318(24), 2446–2456. <https://doi.org/10.1001/jama.2017.17923>