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### **Supplemental Material**

#### **Fine Particulate Matter Exposure and Cancer Incidence: Analysis of SEER Cancer Registry Data from 1992-2016**

Nathan C. Coleman, Richard T. Burnett, Majid Ezzati, Julian D. Marshall, Allen L. Robinson, and C. Arden Pope III

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Table S1. Description of 16 SEER registries that are used in the analysis.

Registry Name (Registry ID)	Region	State	Counties / Parishes included
San Francisco-Oakland (0000001501)	Pacific	California	Alameda, Contra Costa, Marin, San Francisco, San Mateo
San Jose-Monterey (0000001531)	Pacific	California	Monterey, San Benito, Santa Clara, Santa Cruz
Los Angeles (0000001535)	Pacific	California	Los Angeles
Greater California (0000001541) <sup>a</sup>	Pacific	California	All 48 remaining California counties excluding San Francisco, San Jose, and Los Angeles
Connecticut (0000001502)	Northeast	Connecticut	All 8 Connecticut counties
Metropolitan Atlanta (0000001527)	South	Georgia	Clayton, Cobb, De Kalb, Fulton, Gwinnett
Rural Georgia (0000001537)	South	Georgia	Glascock, Greene, Hancock, Jasper, Jefferson, Morgan, Putnam, Taliaferro, Warren, Washington
Greater Georgia (0000001547) <sup>a</sup>	South	Georgia	All 144 remaining Georgia counties excluding Metropolitan Atlanta and Rural Georgia
Iowa (0000001522)	Midwest	Iowa	All 99 Iowa counties
Kentucky (0000001542) <sup>a</sup>	South	Kentucky	All 120 Kentucky counties
Louisiana (0000001543) <sup>a</sup>	South	Louisiana	All 64 Louisiana parishes
Metropolitan Detroit (0000001520)	Midwest	Michigan	Macomb, Oakland, Wayne
New Mexico (0000001523)	West	New Mexico	All 33 New Mexico counties
New Jersey (0000001544) <sup>a</sup>	Northeast	New Jersey	All 21 New Jersey counties
Seattle (Puget Sound) (0000001525)	Pacific	Washington	Clallam, Grays Harbor, Island, Jefferson, King, Kitsap, Mason, Pierce, San Juan, Skagit, Snohomish, Thurston, Whatcom
Utah (0000001526)	West	Utah	All 29 Utah counties

<sup>a</sup> Cancer incidence data is only available from 2000-2016.

Table S2. Incident Rate Ratios and 95% confidence interval estimates for the association between cancer incidence and an increase of 10  $\mu\text{g}/\text{m}^3$   $\text{PM}_{2.5}$  exposure using the time varying model.

Cancer	$\text{PM}_{2.5}$ 1-year moving avg <sup>a</sup>	$\text{PM}_{2.5}$ 5-year moving avg <sup>b</sup>	$\text{PM}_{2.5}$ 10-year moving avg <sup>c</sup>	$\text{PM}_{2.5}$ 15-year moving avg <sup>d</sup>	$\text{PM}_{2.5}$ 15-year moving avg LOESS <sup>e</sup>
All Cancer	1.04 (1.00-1.07)	1.06 (1.02-1.09)	1.05 (1.02-1.09)	1.04 (1.01-1.08)	1.06 (1.03-1.10)
Digestive Tract					
Oral	1.02 (0.92-1.12)	1.12 (1.01-1.24)	1.15 (1.04-1.28)	1.14 (1.04-1.25)	1.14 (1.03-1.27)
Esophagus	0.99 (0.89-1.11)	1.00 (0.88-1.13)	1.00 (0.88-1.13)	0.98 (0.88-1.10)	0.91 (0.81-1.03)
Stomach	1.01 (0.91-1.12)	1.04 (0.93-1.17)	1.03 (0.93-1.15)	1.01 (0.92-1.12)	0.89 (0.80-1.00)
Small Intestine	0.85 (0.75-0.96)	0.80 (0.70-0.92)	0.82 (0.72-0.93)	0.84 (0.74-0.95)	0.82 (0.72-0.93)
Colon	1.04 (0.97-1.12)	1.08 (0.99-1.17)	1.10 (1.02-1.20)	1.09 (1.01-1.17)	1.09 (1.01-1.19)
Rectal	1.10 (1.00-1.20)	1.14 (1.03-1.26)	1.17 (1.06-1.29)	1.17 (1.06-1.28)	1.13 (1.02-1.26)
Liver	0.98 (0.89-1.09)	0.99 (0.89-1.11)	1.05 (0.95-1.17)	1.04 (0.95-1.15)	0.93 (0.83-1.04)
Pancreas	0.96 (0.87-1.06)	0.94 (0.85-1.05)	0.96 (0.86-1.06)	0.97 (0.88-1.07)	0.90 (0.81-1.00)
Respiratory					
Nose	0.75 (0.62-0.89)	0.64 (0.51-0.80)	0.63 (0.51-0.79)	0.68 (0.55-0.84)	0.66 (0.55-0.80)
Larynx	0.97 (0.86-1.10)	0.99 (0.87-1.12)	1.04 (0.91-1.17)	1.03 (0.92-1.15)	0.94 (0.83-1.06)
Lung	1.08 (1.01-1.15)	1.11 (1.04-1.19)	1.16 (1.08-1.24)	1.16 (1.08-1.23)	1.16 (1.08-1.24)
Bone/Tissue					
Bone	0.96 (0.88-1.05)	1.02 (0.93-1.12)	1.02 (0.93-1.11)	1.02 (0.94-1.10)	0.99 (0.90-1.09)
Skin	1.19 (1.09-1.30)	1.21 (1.10-1.33)	1.22 (1.11-1.34)	1.21 (1.11-1.33)	1.20 (1.08-1.32)
Soft Tissue	0.91 (0.81-1.01)	0.88 (0.78-0.99)	0.88 (0.78-0.99)	0.91 (0.82-1.02)	0.89 (0.79-1.00)
Sex-Specific					
Breast	1.01 (0.95-1.07)	1.06 (1.00-1.13)	1.05 (0.99-1.12)	1.05 (0.99-1.11)	1.11 (1.04-1.19)
Cervix	1.03 (0.92-1.15)	1.05 (0.93-1.19)	1.04 (0.93-1.18)	1.03 (0.92-1.15)	0.96 (0.85-1.08)
Uterine	0.91 (0.83-1.01)	0.89 (0.80-0.99)	0.90 (0.81-1.00)	0.90 (0.82-0.99)	0.91 (0.81-1.02)
Ovarian	0.93 (0.83-1.03)	1.00 (0.89-1.12)	1.03 (0.92-1.15)	1.04 (0.94-1.15)	1.01 (0.91-1.14)
Prostate	0.99 (0.92-1.06)	0.96 (0.89-1.03)	0.93 (0.87-1.00)	0.94 (0.88-1.01)	0.94 (0.88-1.01)
Other Male	1.00 (0.88-1.13)	0.91 (0.79-1.04)	0.98 (0.86-1.11)	0.98 (0.86-1.10)	0.85 (0.76-0.96)
Urinary Tract					
Kidney	1.05 (0.96-1.16)	1.07 (0.97-1.18)	1.08 (0.98-1.19)	1.05 (0.96-1.15)	1.05 (0.95-1.17)
Bladder	0.92 (0.84-1.00)	0.96 (0.87-1.06)	0.97 (0.88-1.06)	0.96 (0.89-1.05)	0.97 (0.88-1.07)
Other					
Brain	1.02 (0.93-1.14)	1.00 (0.90-1.12)	1.03 (0.93-1.15)	1.02 (0.93-1.13)	1.05 (0.94-1.17)
Endocrine	0.97 (0.88-1.08)	0.99 (0.88-1.10)	1.09 (0.98-1.22)	1.08 (0.97-1.19)	1.08 (0.96-1.21)
Ill Defined	1.06 (0.98-1.16)	1.09 (1.00-1.20)	1.12 (1.02-1.23)	1.08 (0.99-1.18)	1.06 (0.97-1.17)

Note: Adjusted for percent of the county in various age buckets; percent male; percent white, black, Hispanic, and other; percent that did not graduate high school, graduated high school, or obtained more education than high school; median income, rent, and home value; percent below 150% poverty; percent working class; percent unemployed; percent that live in a rural area; percent smokers; percent alcohol consumption; percent that are physically active; and percent of individuals in a county who are obese as well as indicator variables for urban/rural, state, and year. Only SEER counties from 2002-2011 were used.

<sup>a</sup> Linear yearly estimates for all covariates was used with a 1-year moving average estimate for  $\text{PM}_{2.5}$  exposure.

<sup>b</sup> Linear yearly estimates for all covariates was used with a 5-year moving average lagged estimate for  $\text{PM}_{2.5}$  exposure.

<sup>c</sup> Linear yearly estimates for all covariates was used with a 10-year moving average lagged estimate for  $\text{PM}_{2.5}$  exposure.

<sup>d</sup> Linear yearly estimates for all covariates was used with a 15-year moving average lagged estimate for  $\text{PM}_{2.5}$  exposure.

<sup>e</sup> A locally weighted smoothing model with 3 degrees of freedom for all covariates with a 15-year moving average lagged estimate for  $\text{PM}_{2.5}$  exposure.

Table S3. Incident Rate Ratios and 95% confidence interval estimates for the association between cancer incidence and an increase of 10 µg/m<sup>3</sup> PM<sub>2.5</sub> exposure from 1988-2015 using a variety of different models.

Cancer	LOESS (Cross Validation) <sup>a</sup>	SPLINE (Cross Validation) <sup>b</sup>	LOESS (No Spatial Control) <sup>c</sup>	LOESS (Region Control) <sup>d</sup>	LOESS (Registry Control) <sup>e</sup>	Linear (Poisson Distribution) <sup>f</sup>	Linear (Sandwich) <sup>g</sup>	PM <sub>2.5</sub> 1999-2015 <sup>h</sup>	PM <sub>2.5</sub> 1988-2007 <sup>i</sup>
All Cancer	1.07 (1.02-1.12)	1.07 (1.02-1.12)	1.07 (1.03-1.10)	1.04 (0.99-1.08)	1.09 (1.03-1.15)	1.05 (1.02-1.09)	1.06 (1.00-1.12)	1.11 (1.05-1.17)	1.06 (1.01-1.11)
Digestive Tract									
Oral	1.19 (1.04-1.36)	1.15 (1.01-1.31)	1.18 (1.08-1.30)	1.15 (1.02-1.30)	1.19 (1.03-1.38)	1.23 (0.97-1.55)	1.19 (1.02-1.38)	1.19 (1.01-1.39)	1.14 (0.97-1.33)
Esophagus	1.05 (0.86-1.28)	1.09 (0.89-1.33)	1.21 (1.06-1.39)	1.21 (1.01-1.44)	1.09 (0.88-1.35)	1.17 (0.80-1.71)	1.09 (0.90-1.32)	1.12 (0.89-1.41)	0.97 (0.74-1.26)
Stomach	0.99 (0.82-1.19)	1.06 (0.88-1.27)	0.87 (0.77-0.99)	0.86 (0.73-1.02)	0.95 (0.78-1.16)	0.97 (0.72-1.31)	1.00 (0.83-1.19)	0.95 (0.77-1.18)	0.93 (0.74-1.17)
Small Intestine	1.01 (0.79-1.29)	1.03 (0.80-1.33)	1.18 (1.00-1.40)	1.08 (0.86-1.36)	1.17 (0.89-1.54)	0.95 (0.56-1.61)	0.97 (0.77-1.22)	1.13 (0.84-1.52)	0.90 (0.68-1.20)
Colon	1.00 (0.92-1.09)	1.03 (0.95-1.13)	1.06 (1.00-1.14)	0.97 (0.89-1.06)	1.04 (0.94-1.14)	1.00 (0.87-1.15)	1.01 (0.92-1.11)	1.09 (0.99-1.22)	1.14 (1.02-1.27)
Rectal	1.13 (1.01-1.27)	1.05 (0.94-1.18)	1.08 (1.00-1.18)	1.04 (0.93-1.16)	1.14 (1.00-1.30)	1.04 (0.85-1.27)	1.04 (0.92-1.18)	1.14 (1.00-1.31)	1.14 (0.97-1.34)
Liver	1.31 (1.11-1.55)	1.32 (1.13-1.55)	1.04 (0.93-1.17)	1.07 (0.92-1.24)	1.39 (1.16-1.66)	1.43 (1.10-1.86)	1.45 (1.17-1.80)	1.43 (1.18-1.74)	1.26 (1.03-1.53)
Pancreas	1.00 (0.87-1.14)	1.02 (0.89-1.15)	0.94 (0.86-1.03)	0.93 (0.83-1.05)	0.99 (0.85-1.14)	0.98 (0.77-1.25)	0.98 (0.87-1.10)	1.02 (0.87-1.19)	0.98 (0.83-1.16)
Respiratory									
Nose	0.59 (0.43-0.82)	0.44 (0.29-0.67)	0.79 (0.58-1.08)	0.74 (0.49-1.10)	0.54 (0.33-0.89)	0.86 (0.35-2.13)	1.08 (0.76-1.53)	0.57 (0.33-0.99)	0.80 (0.47-1.35)
Larynx	1.14 (0.94-1.39)	-- <sup>j</sup>	1.15 (1.01-1.32)	1.13 (0.95-1.35)	1.20 (0.97-1.48)	1.08 (0.73-1.61)	1.10 (0.92-1.31)	1.20 (0.95-1.50)	1.03 (0.82-1.31)
Lung	1.20 (1.10-1.31)	1.17 (1.09-1.27)	1.35 (1.27-1.43)	1.21 (1.12-1.31)	1.20 (1.09-1.31)	1.18 (1.07-1.31)	1.19 (1.06-1.34)	1.16 (1.05-1.28)	1.14 (1.04-1.25)
Bone/Tissue									
Bone	0.96 (0.86-1.07)	0.98 (0.88-1.10)	1.07 (0.99-1.16)	1.01 (0.91-1.12)	1.03 (0.91-1.17)	0.98 (0.84-1.14)	0.99 (0.89-1.11)	1.09 (0.96-1.25)	0.92 (0.82-1.04)
Skin	1.18 (1.03-1.36)	1.11 (0.97-1.27)	1.21 (1.10-1.33)	1.25 (1.10-1.42)	1.23 (1.06-1.43)	1.22 (1.06-1.41)	1.30 (1.12-1.52)	1.26 (1.07-1.48)	1.27 (1.09-1.49)
Soft Tissue	1.01 (0.83-1.22)	0.86 (0.81-0.91)	1.09 (0.96-1.24)	1.03 (0.87-1.23)	1.05 (0.86-1.30)	0.97 (0.66-1.44)	0.99 (0.83-1.17)	0.95 (0.76-1.18)	0.84 (0.65-1.08)
Sex-Specific									
Breast	1.07 (1.00-1.15)	1.04 (0.97-1.11)	1.14 (1.09-1.20)	1.07 (1.01-1.15)	1.07 (0.99-1.16)	1.03 (0.93-1.13)	1.03 (0.97-1.10)	1.08 (1.00-1.18)	1.05 (0.96-1.15)
Cervix	1.26 (1.01-1.57)	1.31 (1.05-1.63)	1.01 (0.87-1.17)	1.07 (0.88-1.30)	1.13 (0.89-1.42)	1.17 (0.78-1.76)	1.21 (0.99-1.47)	1.28 (1.00-1.64)	1.09 (0.83-1.44)
Uterine	0.93 (0.80-1.08)	1.03 (0.90-1.18)	1.05 (0.94-1.17)	1.08 (0.94-1.24)	0.96 (0.82-1.13)	0.97 (0.77-1.22)	0.94 (0.82-1.07)	0.98 (0.82-1.16)	1.11 (0.93-1.33)
Ovarian	0.96 (0.81-1.14)	0.98 (0.83-1.15)	1.00 (0.89-1.13)	1.09 (0.93-1.27)	0.95 (0.79-1.15)	1.00 (0.73-1.38)	0.98 (0.85-1.14)	0.97 (0.79-1.18)	0.86 (0.67-1.10)
Prostate	0.95 (0.87-1.04)	0.95 (0.87-1.04)	0.84 (0.79-0.90)	0.86 (0.79-0.94)	0.97 (0.87-1.07)	0.92 (0.83-1.02)	0.94 (0.86-1.03)	0.99 (0.89-1.11)	0.91 (0.81-1.01)
Other Male	1.08 (0.85-1.38)	1.08 (0.85-1.37)	0.96 (0.82-1.13)	0.92 (0.75-1.15)	1.13 (0.87-1.46)	0.99 (0.64-1.54)	0.99 (0.77-1.27)	1.09 (0.83-1.44)	1.15 (0.85-1.55)
Urinary Tract									
Kidney	1.23 (1.08-1.39)	1.10 (0.98-1.23)	1.09 (0.99-1.20)	0.98 (0.86-1.11)	1.22 (1.06-1.41)	1.09 (0.89-1.35)	1.12 (0.98-1.29)	1.24 (1.07-1.45)	1.10 (0.95-1.28)
Bladder	1.10 (0.97-1.24)	1.05 (0.93-1.17)	1.08 (0.99-1.17)	1.00 (0.90-1.12)	1.07 (0.94-1.21)	0.96 (0.80-1.16)	1.01 (0.89-1.15)	1.06 (0.92-1.21)	1.03 (0.89-1.19)
Other									
Brain	1.11 (0.96-1.28)	1.06 (0.91-1.23)	0.99 (0.89-1.11)	0.97 (0.84-1.12)	1.12 (0.94-1.32)	1.06 (0.79-1.44)	1.08 (0.93-1.24)	1.14 (0.95-1.37)	1.08 (0.89-1.32)
Endocrine	1.21 (1.01-1.45)	1.28 (1.06-1.54)	1.02 (0.90-1.16)	0.95 (0.80-1.12)	1.21 (1.00-1.48)	1.25 (1.00-1.57)	1.22 (1.02-1.45)	1.30 (1.05-1.60)	1.16 (0.93-1.44)
Ill Defined	1.01 (0.91-1.13)	0.96 (0.88-1.05)	1.01 (0.94-1.09)	0.99 (0.90-1.09)	1.05 (0.93-1.17)	1.04 (0.88-1.22)	1.04 (0.92-1.17)	1.08 (0.95-1.22)	1.03 (0.90-1.17)

Note: Adjusted for percent of the county in various age buckets; percent male; percent White, Black, Hispanic, and other; percent that did not graduate high school, graduated high school, or obtained more education than high school; median income, rent, and home value; percent below 150% poverty; percent working class; percent unemployed; percent that live in a rural area; percent smokers; percent that consume alcohol; percent that are physically active; and percent of individuals in a county who are obese as well as indicator variables for urban/rural and state. All models use average incidence rate from 1992-2016 (primary time independent model) unless indicated otherwise.

<sup>a</sup> A cross validated locally weighted smoothing model was used for all covariates.

<sup>b</sup> A cross validated SPLINE method was used for all covariates.

<sup>c</sup> A locally weighted smoothing model with 3 degrees of freedom for all covariates was used. State was removed from the model.

<sup>d</sup> A locally weighted smoothing model with 3 degrees of freedom for all covariates was used. State was removed from the model and replaced with a region control.

<sup>e</sup> A locally weighted smoothing model with 3 degrees of freedom for all covariates was used. State was removed from the model and replaced with a region control.

<sup>f</sup> A linear regression was used with only linear terms for the covariates, assuming a Poisson distribution.

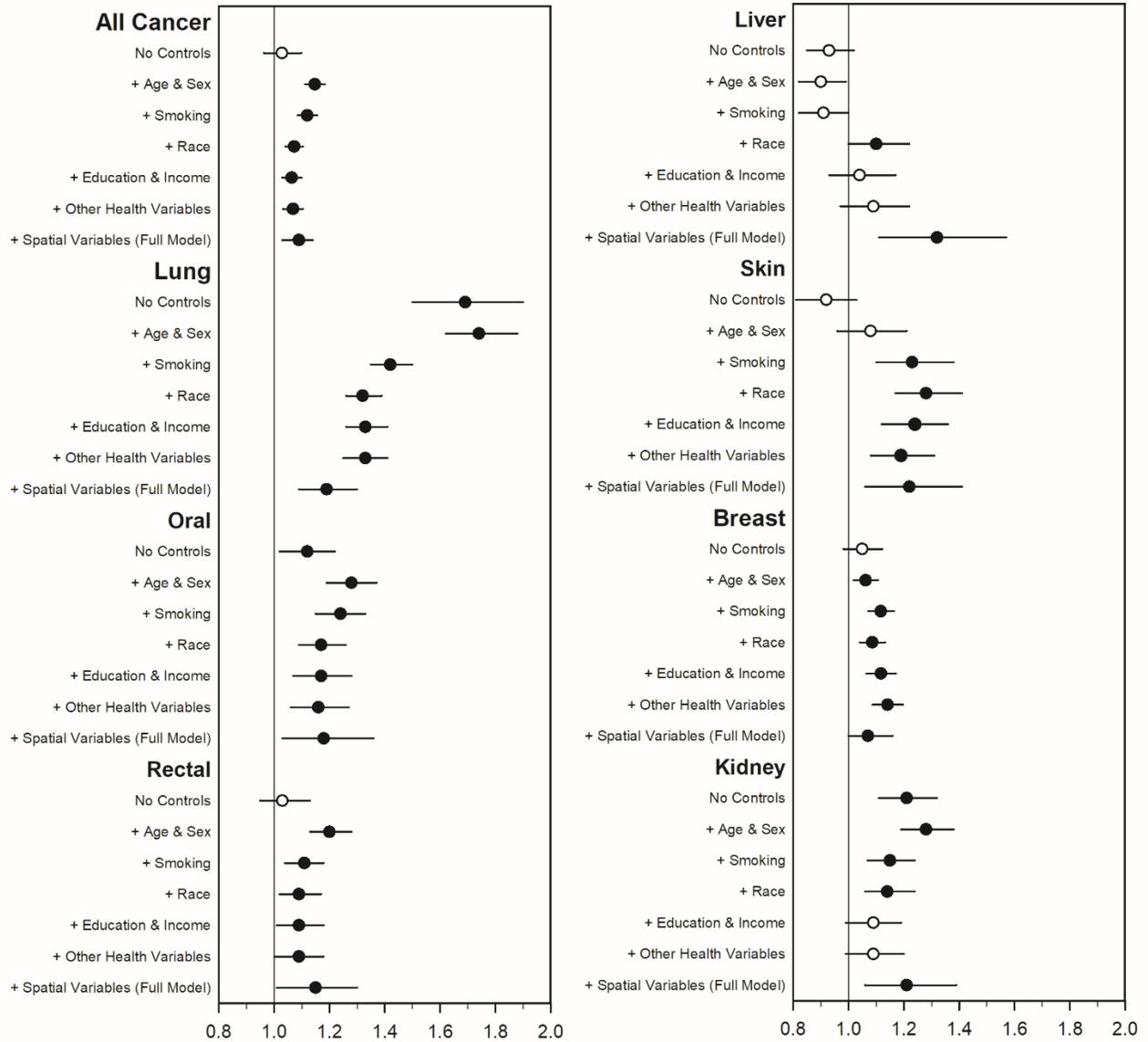
<sup>g</sup> A linear regression was used with only linear terms for the covariates. The sandwich method was used to estimate standard errors.

<sup>h</sup> A locally weighted smoothing model with 3 degrees of freedom for all covariates was used with mean PM<sub>2.5</sub> exposure from 1999-2015.

<sup>i</sup> A locally weighted smoothing model with 3 degrees of freedom for all covariates with indicator variables for urban/rural and state was used with mean PM<sub>2.5</sub> exposure from 1988-2007 on SEER counties from 2008-2016.

<sup>j</sup> Insufficient degrees of freedom due to limited cases.

Figure S1. Incident Rate Ratios and 95% confidence interval estimates for the association between average cancer incidence for SEER counties from 1992-2016 and an increase of 10  $\mu\text{g}/\text{m}^3$   $\text{PM}_{2.5}$  exposure from 1988-2015 for a controlled stepwise, model sensitivity analysis with control variables progressively added to the model.



Note: A LOESS model with 3 degrees of freedom is used for all covariates included in the model. Age and sex controls include all age bucket variables and % male; smoking includes % of the county that smokes; race includes % white, black, Hispanic, and other; education & income includes % of a county to not graduate high school, graduate high school, and to graduate more than high school as well as median income, median home value, median rent, % below 150% poverty, % unemployed, and % working class; other health variables include % of a county that consumes alcohol, is obese, and is physically active; and spatial variables include % of individuals who live in a rural area in the county as well as indicator variables for urban/rural and state.

Figure S2. Estimated response relationship between oral, rectal, liver, skin, kidney, and all cancer incidence and smoking (upper) and PM<sub>2.5</sub> (lower). Smoking is estimated as the average percent of the county that identify as smokers from 1996-2012. PM<sub>2.5</sub> is measured as the population-weighted average concentration in a county from 1988-2015.

