Supplementary Information for

Fine Particulate Matter Damages and Value Added in the United States Economy

Peter Tschofen*, Inês L. Azevedo, Nicholas Z. Muller

*corresponding author

Email: ptschofen@cmu.edu

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1. Data Sources

1.1. NEI Data Treatment

Emissions data were downloaded from EPA's website (1–3) in July 2018 and reflect the most recent version of the NEI available (for 2014, this is version 2) at time of publication. See the repository for the paper (https://github.com/ptschofen/PNAS_SectoralMortality) with links to obtain original data files of larger sizes. We then filtered for the pollutants of interest and aggregated all point sources and area sources into separate files. Sources from tribal lands, as well as all non-contiguous territories of the U.S. were excluded. Mobile sources, i.e. sources that do not have a FIPS county code assigned to them, were allocated to their respective state based on the relative shares of NOx emissions from area sources for each county within that state.

1.2. BEA Data

All economic data were extracted directly from spreadsheets downloaded from the Bureau of Economic Analysis (BEA) website (4).

1.3. CDC Data

Center for Disease Control and Prevention (CDC) data on baseline mortality rates for age groups in 5-year intervals are used for marginal damage calculations in the AP3 model. They were downloaded from CDC's WONDER database (5) in August 2018. CDC does not publish mortality rates for certain counties and age groups, so a fraction of rates had to be imputed based on state, regional or national averages.

1.4. Population Data

Population data was obtained from the intercensal county population totals (6) for 2008 and population estimates on the Census Fact Finder website (7) for 2011 and 2014.

1.5. Effective Heights Calculations

It is crucial to match all emissions in the country with their respective marginal damage not just by location (i.e. county) but also to account for the release height of these emissions (marginal damage estimates within a county vary by a factor of 2 to 3, depending on whether the emissions occur at ground level or through smokestacks). Different IAMs provide marginal damage estimates for different effective heights of release: (1) AP3: ground level, low stacks (<250m), medium stacks (250m < x < 500m) and tall stacks (>500m); (2) EASIUR: ground level release, release at 150m effective height, release at 300m effective height; (3) InMAP: ground level, point sources

To achieve the best possible match for marginal damage estimate and emission, we therefore calculated the effective height of emissions for all point sources where data was available and then used the effective height estimates to match with the best available marginal damage estimate for each model. For this, we used the Smoke FLAT files available on EPA's FTP server (8) for stack parameters, wind maps from NREL for average wind speeds at 80m elevation, and weather data from NOAA.

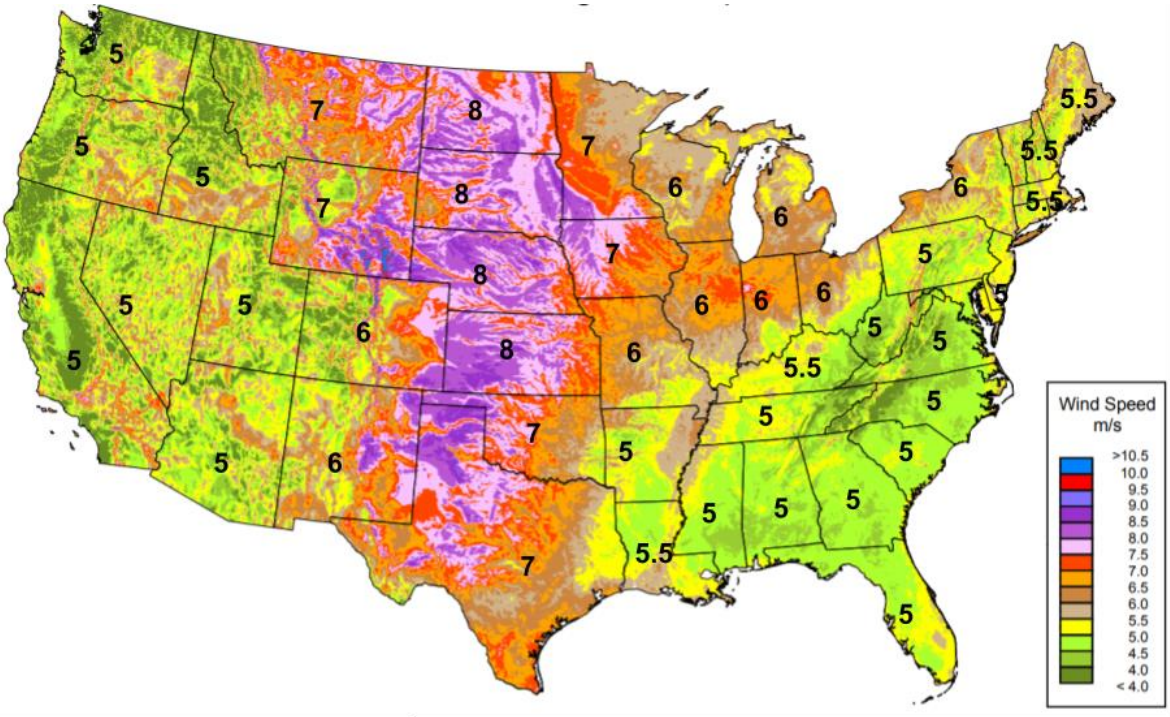

Fig. S 1: Average annual wind speed asssignment for effective height of emissions calculations

Fig. S 1 shows a wind map from NREL and the state average annual wind speed we assigned based on the map. We then used equations from Turner (9) to compute effective heights. A table with our computed effective heights and marginal damage assignments for all facilities for the three IAM's will be made available. Among the ~70,000 facilities in 2014, we were able to compute effective heights for approximately 50% of them.

1.6. IAM Data

For AP3, we provide all the data inputs as well as the code in Matlab to run the model in our repository.

The marginal damages from EASIUR and the population adjustment factors for them were obtained on the model's website (10), and then adjusted according to the method suggested by the authors.

Marginal damages for InMAP were downloaded in $2000 units from the CACES website (11).

2. AP3 Model Description

The AP3 model is an adaptation of the more commonly known previous version, AP2 (12, 13). The newer version, AP3, uses an updated formula to deal with the relationship of ammonium, nitrates and sulfates, but other than that remains unchanged from AP2 except for the calibration coefficients to align model predictions with monitor data. This updated relationship uses a regression to model the formation of $PM_{2.5}$ from nitric acid and ammonia that includes an interaction term of these two precursors. The primary model output are marginal damage estimates for all contiguous counties in the United States for the aforementioned categories (area sources, low stacks, medium stacks and tall stacks).

2.1. AP3 Performance Metrics from Sergi et al.

Model calibration of AP3 follows the two-step method employed by Sergi et al. (14). The first step of the process is a calibration based on EPA monitor data, performance metrics of which are provided in Table S1.

Table S1: Performance Metrics of AP3 reported by Sergi et al. (14)

(Pollutant)/Year	COR	MFE	MFB	Obs
(Total PM2.5)				
2008	0.560	0.314	-0.118	584
2011	0.524	0.313	-0.110	547
2014	0.558	0.318	-0.129	592
(Sulfate)				
2008	0.856	0.495	-0.136	314
2011	0.830	0.483	-0.217	310
2014	0.850	0.457	-0.216	302
(Nitrate)				
2008	0.643	0.502	-0.048	307
2011	0.636	0.498	0.099	306
2014	0.579	0.535	-0.033	299
(VOCs)				
2008	0.662	0.359	0.119	154
2011	0.605	0.447	0.313	151
2014	0.653	0.417	0.268	146
(Ammonium)				
2008	0.492	0.457	-0.135	186
2011	0.477	0.456	0.222	182
2014	0.342	0.480	0.222	177

In the second step, the top 1% of outliers in terms of MFE in monitor vs. predicted data are corrected.

3. Additional Informationon Model Comparison

After adjusting marginal damages from EASIUR and InMAP to make sure they use the same value of mortality risk (VMR), we compare how they differ with the AP3 model. Because all three models report marginal damages for different heights by source location, the assignment of emissions is different for each three. As a consequence, it is perhaps illustrative to compare marginal damages weighted by emissions. We do so for all counties nationwide in Table S 2.

Table S 2: Average national marginal damages weighted by attributed emissions ($2018 per metric ton)

Model	Year	Pollutant				
		NH3	NOx	PM2.5	SO2	VOC
AP3	2008	58,000	19,000	110,000	36,000	7,900
	2011	54,000	19,000	110,000	36,000	6,600
	2014	63,000	21,000	130,000	42,000	6,700
EASIUR	2008	48,000	8,700	110,000	22,000	7,900*
	2011	47,000	8,400	110,000	22,000	6,600*
	2014	46,000	8,600	110,000	22,000	6,700*
InMAP	2008	41,000	11,000	86,000	23,000	7,400
	2011	37,000	11,000	77,000	21,000	6,300
	2014	45,000	11,000	84,000	22,000	6,100

* EASIUR does not report marginal damages for VOC, which is why AP3 damages were used

Based on this table, we computed relative differences in national average marginal damages.

Table S 3: Relative differences in national average marginal damages weighted by emissions

	NH3	NOx	PM2.5	SO2	VOC
AP3/EASIUR	20%	117%	-2%	66%	0%
	14%	125%	2%	66%	0%
	37%	148%	12%	87%	0%
EASIUR/InMAP	18%	-21%	30%	-4%	8%
	27%	-25%	42%	1%	5%
	3%	-23%	35%	2%	10%
InMAP/AP3	-30%	-41%	-21%	-37%	-7%
	-31%	-41%	-31%	-41%	-5%
	-29%	-47%	-34%	-48%	-9%

	NH3	NOx	PM2.5	SO2	VOC
AP3/InMAP	42%	70%	27%	58%	8%
	44%	69%	45%	68%	5%
	41%	90%	52%	91%	10%
InMAP/EASIUR	-15%	27%	-23%	5%	-7%
	-21%	32%	-30%	-1%	-5%
	-3%	30%	-26%	-2%	-9%
EASIUR/AP3	-17%	-54%	2%	-40%	0%
	-12%	-55%	-2%	-40%	0%
	-27%	-60%	-11%	-47%	0%

Based on Table S 3, we then compared marginal damages in $2018 per metric ton of emissions between AP3 and EASIUR for NO_x and between AP3 and InMAP for SO2.

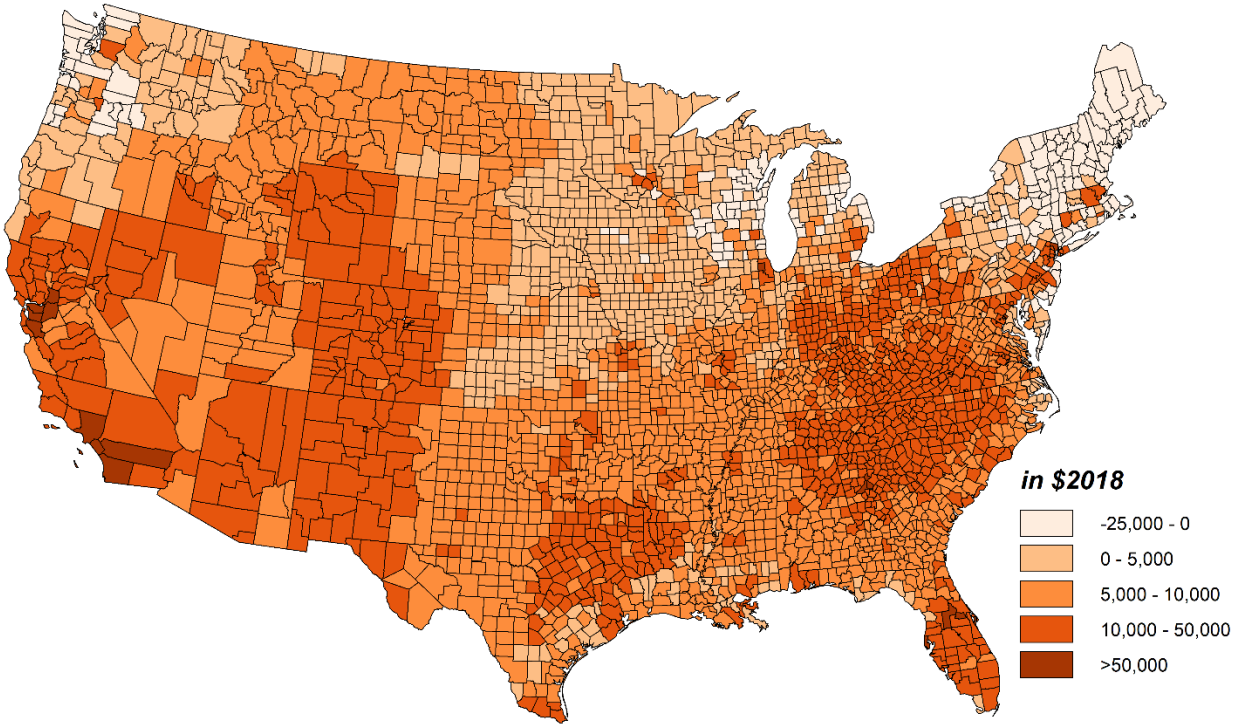

Fig. S 2: Absolute difference in $2018 in emission-weighted marginal NOx damage (AP3 minus EASIUR)

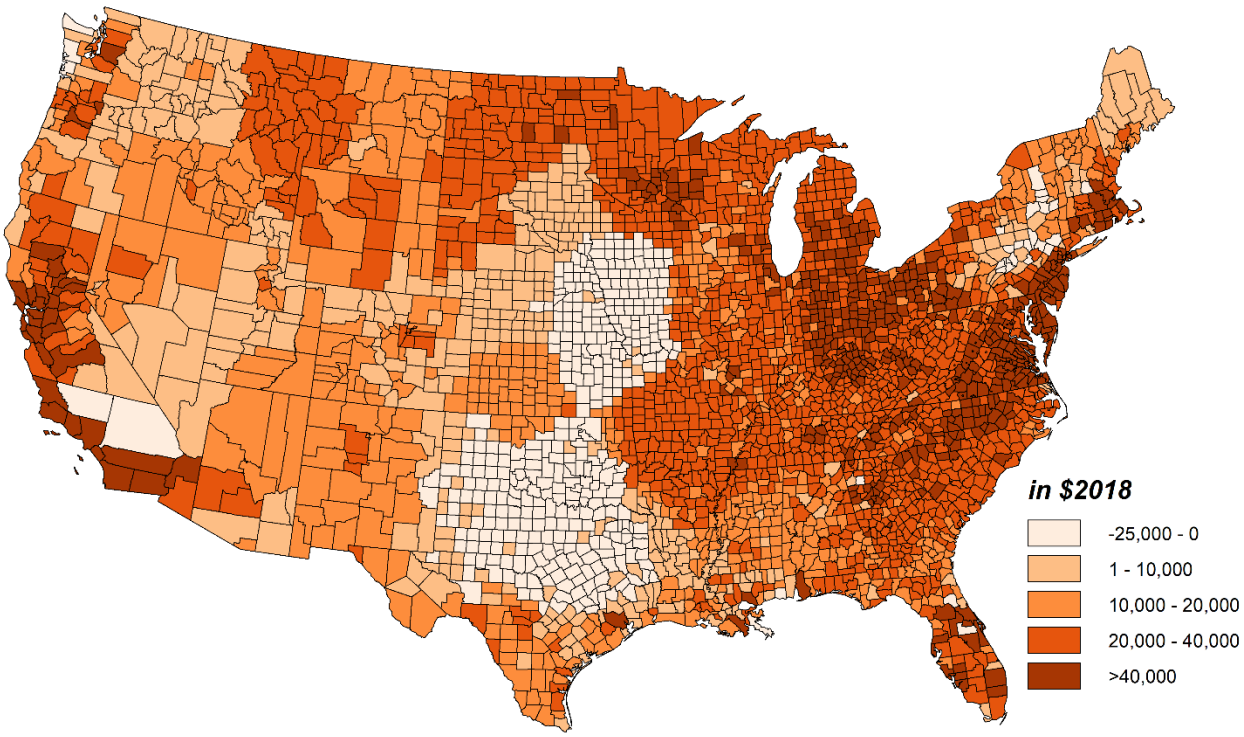

Fig. S 3: Absolute difference in $2018 in emission-weighted marginal SO2 damage (AP3 minus InMAP)

Emission-weighted marginal damages are larger in AP3 for a majority of counties nationwide for both SO_2 and NO_x, and the largest differences are visible in a select few counties in California. Because the exposure to fine particulate matter is especially large in California this can have a large impact on results. We will further analyze this in future work.

4. Detailed Description of Method for GED calculations

Emissions are matched with marginal damages by location and stack height and then aggregated by industry, industry group, subsector and sector. The attribution of area source emissions to economic units is a crucial part of this exercise, and we provide the a table with our mapping in the repository for this paper (https://github.com/ptschofen/PNAS_SectoralMortality). The table contains our exact mapping for all available source classification codes (SCC) from EPA (15). We have mapped codes only in instances where the attribution was clear, but are exploring options to attribute more emissions at a more granular level of the economic accounts with additional data sources. For point sources, the attribution to economic units is straightforward, since they are reported along with their NAICS code by EPA.

Table S 4: Number of deaths (attributed and non-attributed) estimated with three IAMs used for this paper

AP3	**2008**	**2011**	**2014**
Attributed to economic units	110,000	88,100	85,900
Not attributed to economic units	66,200	61,700	61,700
EASIUR	**2008**	**2011**	**2014**
Attributed to economic units	76,400	61,300	54,300
Not attributed to economic units	48,800	47,100	45,200
InMAP	**2008**	**2011**	**2014**
Attributed to economic units	84,200	64,400	59,800
Not attributed to economic units	62,300	57,600	52,800

In Table S5, we provide the results with GED estimates for all sectors of the economy, computed with the AP3 model, and adjusted for changes to per capita income in the United States.

Table S 5: Gross external damage in $2018 billion for all sectors of the economy (IAM used: AP3)

NAICS Sector	GED 2008	GED 2011	GED 2014
Agriculture, forestry, fishing, and hunting	240	230	230
Mining	22	25	26
Utilities	290	180	150
Construction	53	40	37
Manufacturing	120	95	96
Wholesale trade	1.3	0.7	0.71
Retail trade	4.8	3.2	2
Transportation and warehousing	170	150	120
Information	0.33	0.13	0.09
Finance and insurance	0.55	0.02	0.02
Real estate and rental and leasing	0.27	0.22	0.17
Professional and business services	0.29	0.25	1.6
Management of companies and enterprises	0.001	0.004	0.008
Administrative and waste management services	29	17	42
Educational services	2.5	2	1.4
Health care and social assistance	0.71	0.68	0.63
Arts, entertainment, and recreation	0.05	0.05	0.03
Accommodation and food services	0.06	0.07	0.06
Other services, except government	75	64	85
Government	3	2.2	2.2
No attribution	610	570	570

Lastly, in Table S6, we provide the results for GED in 2014 when computed with different combinations of the dose-response relationship parameter and VMR.

Table S 6: Sensitivity analysis for GED calculations. Reported numbers are expressed in 2018 $billion. Column S1 presents the results as reported in the paper, using a dose-response function from Krewski et al. 2009 (16) and the value of mortality risk (VMR) suggested by EPA. Column S2 presents GED estimates when using a dose-response function suggested by Lepeule et al. 2012 (17) and EPA's VMR. Columns S3 and S4 present versions of the first two columns but using the lower number for the VMR suggested by Taylor 2009 (18)

NAICS Sector	S1 Krewski + EPA	S2 Lepeule + EPA	S3 Krewski + Taylor	S4 Lepeule + Taylor
Agriculture, forestry, fishing, and hunting	230	470	76	160
Mining	26	53	8.5	18
Utilities	150	300	48	100
Construction	37	75	12	25
Manufacturing	96	200	32	66
Wholesale trade	0.7	1.4	0.2	0.5
Retail trade	2	4.1	0.7	1.4
Transportation and warehousing	120	250	40	83
Information	0.09	0.2	0.03	0.06
Finance and insurance	0.02	0.03	0.005	0.01
Real estate and rental and leasing	0.2	0.3	0.06	0.1
Professional and business services	1.6	3.2	0.5	1.1
Management of companies and enterprises	0.008	0.02	0.003	0.005
Administrative and waste management services	42	84	14	28
Educational services	1.4	2.9	0.5	1.0
Health care and social assistance	0.63	1.3	0.2	0.43
Arts, entertainment, and recreation	0.03	0.06	0.01	0.02
Accommodation and food services	0.06	0.1	0.02	0.04
Other services, except government	85	170	28	58
Government	2.2	4.4	0.7	1.5
No attribution	570	1,200	190	390
Total attributable	**790**	**1,600**	**260**	**540**

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