The Cost of Premature Birth from Preventable Air Pollution in California

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Preterm Birth Impacts a Child's Health

Preterm birth—defined as infants born at less than 37 weeks of gestational age—is the leading cause of perinatal mortality and morbidity in developed countries, accounting for up to two-thirds of mortality and more than half of morbidity in early childhood.[1 2] Advances in medical care have greatly improved the chances of survival for babies born prematurely, but the condition can still pose lifelong challenges.

Babies born prematurely may experience multiple poor health outcomes that can continue to impact the child into adulthood, including acute and chronic respiratory illness, gastrointestinal and immunological disease, cardiovascular issues, hearing and vision problems, and developmental delays that can lead to poor psychological, behavioral, and educational outcomes.[3 4 5 6] The frequency and severity of adverse health outcomes increases with decreasing gestational age and lower access to healthcare.[7]

Preterm Birth Continues to be a Serious Public Health Issue

Trends in preterm birth
The preterm birth rate in the United States remains high in comparison to other developed countries. Preterm birth rates had been declining in the U.S. since 2008. However, the rate has increased for two consecutive years, and now stands at 9.8%, short of the March of Dimes goal of 8.1% by 2020.[8]

Using methods from the March of Dimes and data from the National Center for Health Statistics, the preterm birth rate in California (8.6%) is lower than the U.S. average (9.8%), but still falls short of the March of Dimes 2020 goal of 8.1%.[9]

Etiology of preterm birth
The etiology of preterm birth is multifaceted and complex. Known risk factors for preterm birth include maternal age, race, previous history of preterm birth, multiple gestations, socioeconomic factors, healthcare access, prenatal care, smoking, stress, infection, and environmental exposures.

Research focused on the individual risk factors for preterm birth has yet to yield a full explanation of its causes, nor led to interventions to successfully decrease racial disparities in preterm birth.[6 10] Increasingly, researchers have focused on the role of a mother's social and physical environment in preterm birth risks, including chronic stress.[6 10 11 12 13 14 15 16]

Disparities in preterm birth
There are large racial disparities in the preterm birth rate. In California, the preterm birth rate among black women is 44% higher than the rate among all other women, and 85% higher than the rate among white women.[17] There are multiple factors that contribute to this disparity, and

research suggests that inequitable exposure to air pollution is responsible for a portion of this racial disparity.[18]

PTB risks are also elevated for younger and older mothers, as well as mothers who have experienced previous preterm or low-weight births, are pregnant with more than one child, lack prenatal care, or are socioeconomically disadvantaged.[1, 6, 19, 20]

Environmental contributions to preterm birth
Historically, many epidemiological studies focused on tobacco smoking as the main environmental risk factor for preterm birth.[21] However, over the past decade, increasing research has found significant relationships between air pollution and preterm birth.[22, 23, 24, 25, 26, 27, 28]

Particulate Matter Pollution & Preterm Birth

Particulate matter air pollution
Particulate matter pollution is a mix of chemical particles found in the air that can be inhaled and harm health. Particulate matter that is 2.5 micrometers and smaller ($PM_{2.5}$) is of particular concern because the small particles can be inhaled deep into the lungs, and some $PM_{2.5}$ is small enough to enter the bloodstream.[29] Much of $PM_{2.5}$ is generated by the combustion of gasoline, oil, diesel, and wood. Common sources of $PM_{2.5}$ include cars and trucks, residential heating, power plants, and industrial activities.

Research shows an important relationship between air pollution and preterm birth, and greater risks for those living closest to $PM_{2.5}$ pollution. Mothers living in areas with high levels of PM from industrial emissions and vehicular traffic are more likely to have preterm births than mothers living further from these pollution sources.[19, 30, 31, 32] Exposure to air pollution may interfere with placental development and subsequent nutrient and oxygen delivery to the fetus; it may also disrupt the endocrine system, promote inflammation, lead to increased maternal susceptibility to infections, and trigger premature contractions and/or membrane ruptures, resulting in preterm birth.[1, 33, 34]

Understanding the impacts of particulate matter air pollution on preterm birth
Multiple complex factors are associated with preterm birth. Air pollution, however, is a hazard closely linked to preterm birth that is also preventable using existing policy tools. Yet, the human and economic benefits of preventing preterm births are rarely considered when developing policies and programs to reduce exposure to air pollution, despite the condition's lifelong impacts on the child and the economy. By better understanding the human and economic burden of preterm birth attributable to preventable particulate matter air pollution, policymakers can make more informed decisions on the social and economic benefits of pollution prevention efforts.

Calculating Preterm Birth Attributable to $PM_{2.5}$ Pollution

Overall approach

Utilizing methods from Trasande, Malecha, and Attina (2016), we estimate the proportion of preterm birth attributable to $PM_{2.5}$ in each California county. A base odds ratio for preterm birth of 1.15 per 10-µg/m3 increase in $PM_{2.5}$ concentration was used following the methods of Trasande et al. and the meta-analysis by Sapkota et al. (2012).[35] The base odds ratio and $PM_{2.5}$ monitor data were used to calculate the proportion of preterm births attributable to preventable air hazards in excess of a $PM_{2.5}$ reference level of 8.8 µg/m3. We then calculated the direct and indirect costs associated with each case of preterm birth to estimate the annual human and economic burden of $PM_{2.5}$-attributable preterm birth in California.

Preterm birth data

Preterm birth data were derived from the California Department of Public Health, Center for Health Statistics and Information Birth Statistical Master Files for 2013. A preterm birth (PTB) is defined as a baby born prior to 37 completed weeks of pregnancy. Birth records of multiple births (twins, triplets, etc.) were excluded from the calculation. Only records for singleton births were included (births to a single child). Counties with fewer than 12 singleton preterm births in 2013 were excluded due to small numbers.

Particulate matter data

Daily average $PM_{2.5}$ concentrations (µg/m3) for each county were obtained for 2012 (all days from January 1 – December 31) from the California Air Resources Board Air Monitoring Network (AQMIS).[36] Counties missing more than 50% of days of $PM_{2.5}$ daily averages were excluded from the analysis. Daily average $PM_{2.5}$ concentrations within each county were then ranked as deciles of $PM_{2.5}$ exposure. Births were assumed to be evenly distributed throughout the entire year, and that 10% of a county's total preterm births were exposed pregnancy-wide to $PM_{2.5}$ at the lowest level of the 90^{th} decile, 10% exposed at the lowest level of the 80^{th} decile, and so forth through the 10^{th} decile. The lowest decile was assumed to have no attributable PTB or $PM_{2.5}$ exposure above the reference level.

Thirteen of California's 58 counties were excluded from subsequent calculations due to small numbers of PTB and/or limited $PM_{2.5}$ data. The remaining 45 counties included in the analysis account for 98.5% (n=459,093) of total singleton births statewide, and 98.6% of preterm births (n=32,989).

Air quality reference levels (RL) and base PTB odds ratios (OR)

Some amount of existing $PM_{2.5}$ concentration is assumed to come from naturally occurring conditions and that it cannot be prevented through existing air control regulations (such as some wildfire smoke, organic and inorganic particulates from erosion, gas seeps, and other sources).[37] We used a reference level (RL) of 8.8 µg/m3 $PM_{2.5}$ from the 2010 Global Burden of Disease Study estimate of $PM_{2.5}$-attributable disease burden, and in alignment with the analysis by Trasande et al.[38] A lower RL of 5.8 µg/m3 was also used during sensitivity analyses (this lower RL was also used in the Global Burden of Disease Study). Health effects may occur below these reference levels, and research has shown a relationship between $PM_{2.5}$ and all-cause mortality with no threshold signal down to 5 µg/m3.[39]

An estimated base odds ratio (OR) for preterm birth of 1.15 per 10 µg/m3 $PM_{2.5}$ for pregnancy-wide exposure was used following the methods of Trasande et al. A meta-analysis by Sapkota et al. (2012) identified an OR of 1.15 for pregnancy-wide exposure and 1.07 for third-trimester exposure. A study by Stieb et al. (2012) found an OR of 1.16 for pregnancy-wide exposure.[28] The OR was varied from 1.07 to 1.16 during sensitivity analyses.

Calculating the $PM_{2.5}$-attributable fraction of preterm births

Attributable fractions were estimated for each county using the following steps.

1. **Calculate the corresponding OR for each decile of exposure above the lowest decile using the following formula:**

$$OR_{\text{county-decile}} = OR_{\text{meta-analysis}}^{(\text{decile of county-averaged PM2.5} - \text{RL})/10\ \mu g/m3}$$

The meta-analysis OR from Sapkota et al. of 1.15 per 10-µg/m3 increase in $PM_{2.5}$ was used as the base case. The exponent is the increment in a county-specific average $PM_{2.5}$ above the RL of 8.8 µg/m3. For example, in Alameda County, 16 µg/m3 is the $PM_{2.5}$ concentration at the highest percentile.

$$OR_{\text{alameda90th decile}} = 1.15^{(16\text{-}8.8)/10\ \mu g/m3} = 1.1059$$

2. **Calculate risk ratios (RR) from the ORs and PTB rate for each decile using the following formula from Zheng & Yu (1998)[57]:**

$$RR_{\text{county-decile}} = OR_{\text{county-decile}} / [(1\text{-PTB rate}) + (\text{PTB rate}*OR_{\text{county-decile}})]$$

Continuing the Alameda County example:

$$RR_{\text{Alameda90th decile}} = 1.1059/ [(1 - .07) + (.07 \times 1.1059)] = 1.098$$

3. **Calculate the decile specific attributable fraction (AF) using the following formula from Levin (1953) and assuming 10% of births were exposed at each decile of $PM_{2.5}$:**

$$AF_{\text{PM2.5, county-decile}} = \text{Prevalence}_{\text{PM2.5exposure}} \times (RR_{\text{county-decile}} - 1)/ [1 + \text{Prevalence}_{\text{PM2.5 exposure}} \times (RR_{\text{county-decile}} - 1)]$$

Continuing with the Alameda County example:

$$AF_{\text{Alameda90th decile}} = .10 \times (1.098\text{-}1)/[1\text{+}.10 \times (1.098\text{-}1)]= 0.00997$$

4. **Calculate the overall AF by repeating steps 1-3 for each decile then summing all of the decile-specific AFs:**

Sum the AFs for each decile:

Overall $AF = \sum AF_{Alameda90th\ decile}, AF_{Alameda80th\ decile} \ldots\ldots\ldots\ AF_{Alameda10th\ decile} = 0.02028$

5. **Multiply the overall AF by the total number of PTBs for each county to estimate the number of $PM_{2.5}$-attributable preterm births.**

Overall $AF_{Alameda}$ **x** $PTB_{Alameda}$

0.02028 x 1214 = 24.62

Using the calculations above, it is estimated that approximately 25 preterm births in Alameda County could be prevented by eliminating exposure to $PM_{2.5}$ concentrations above the RL of 8.8 µg/m3.

Repeating these steps, the $PM_{2.5}$-attributable fraction of preterm birth was calculated for each county, estimating the proportion of preterm birth that could be avoided by reducing preventable air pollution in each county and, cumulatively, statewide.

Calculating the Economic Burden of Preterm Birth

Economic burden of preterm birth

The economic burden of preterm birth includes both direct and indirect costs. Direct costs include medical care and intervention services for preterm infants, therapeutic services that may continue into early childhood, and special education services for those children needing them. Indirect costs include the lost economic productivity that results from reduced cognitive potential and subsequent decreases in lifetime wages.

Because of a lack of reliable data, figures are not included for the cost of medical care beyond infancy; the cost of other financial and emotional impacts on the child's family; the cost of additional caretaker services that may be needed; or the cost for other services that may extend into adulthood. For these reasons, the estimated economic burden calculated here most likely underestimates the true cost of preterm birth.

Cost estimates are made for the cohort of children born preterm in 2013 (the most recent data available). All costs are expressed in 2013 US$ unless otherwise noted. Costs beyond the first year of life were discounted at a 3 percent rate. Studies of healthcare utilization and service costs are typically population-specific (often by institution, healthcare provider, or geographic area), and may not be representative of other populations. Because of this, California data have been used when feasible.

Direct costs of preterm birth

Medical expenditures and therapeutic service costs in early childhood
Direct medical expenditures included costs from neonatal intensive care unit (NICU) services, excess maternal delivery costs, and additional child medical services up to 5 years of age. Direct costs resulting from early-intervention therapeutic services are calculated and include physical therapy, speech therapy, and developmental therapy for non-institutionalized children in the first three years of life. Direct costs estimated here are *in excess* of the average service utilization costs associated with term birth infants (born between 37-40 weeks of gestation).

Direct cost estimates are based on average expenses and service utilization, though there is variability based on a child's gestation time. Extremely preterm births (<28 weeks of gestation) account for only 6% of all preterm births, but these births account for more than one-third of total medical costs associated with preterm birth.[6] Very preterm births (28 – 31 weeks of gestation) and moderately preterm births (32 – 36 weeks of gestation) account for the majority of preterm birth and its economic burden.

On average, preterm birth costs an estimated $50,099 per case in medical costs and early intervention services. The cost figures shown in Table 1 are based on the 2007 report from the Institute of Medicine, and are the same costs used by Trasande et al.

Table 1. Direct medical costs and therapeutic service costs for preterm birth, per case (2013 US$)

Expense	Cost per case preterm birth (2013 US$)	Definition
Early life medical care costs*	$43,671	Direct medical care associated with PTB up to age 5, including NICU care and extended hospital stays
Maternal delivery costs	$4,998	Maternal delivery costs for PTB infants in excess of a term birth
Early-intervention therapeutic services*	$1,430	Includes physical therapy, speech therapy, and developmental therapy for first 3 years of life
Sum of medical costs and early intervention services	$50,099	Annual economic burden per preterm birth in excess of term birth costs

**Costs beyond the first year of life are discounted at a 3% rate back to the year of birth.*

Special education costs
Special education costs occur due to increases in the prevalence of four developmental disabilities associated with preterm birth, including cerebral palsy (especially spastic diplegia), mental retardation, hearing loss, and vision problems (retinopathy of prematurity). These

developmental disabilities may range from mild to severe, but special education costs are calculated as a per-child average.

The estimated prevalence of developmental disabilities due to preterm birth was based on data from the CDC's Metropolitan Atlanta Developmental Disability Surveillance Program (MADDSP). An estimated 3.1% of all children born preterm may incur one of the four developmental disabilities noted above, and these children are assumed to utilize special education services.

Special education costs are from a 2013 report by the California's Legislative Analyst's Office. Costs were inflated to 2016 dollars (based on the assumption that the first year of special education for the cohort of PTB children born in 2013 would begin at age 3) and discounted at a 3 percent rate for fifteen years (until the child is age 18). Using this approach, the incremental costs of special education services for children born in 2013 are estimated to be $171,463 (2016 US$); adjusted to 2013 US$ (for comparison purposes), the cost is estimated to be $166,660 (Table 2). Assuming that 3.1% of all children born preterm utilize special education services, special education services on a per-case of preterm birth basis would average $5,166.

Federal law requires states to provide special education for children with developmental disabilities through age 22, or until the students graduate high school, whichever comes first. Because costs were only calculated to age 18, this estimate may be conservative.

Table 2. Incremental costs of special education services in California expressed as per use case and as per case of preterm birth (2013 US$)

Expense	Cost per student for special education (2013 US$)	Definition
Special education costs over the lifetime, per use case*	$166,660	Incremental costs of special education services for a child born in 2013 and utilizing services from age 3-18
Special education costs over the lifetime, averaged per PTB child	$5,166	Incremental special education services calculated on a per-case of PTB assuming that 3.1% of PTB infants have one of four conditions: cerebral palsy, mental retardation, vision impairment, or hearing loss

**Costs beyond the first year of life discounted at a 3 percent rate back to the year of birth.*

Indirect costs of preterm birth

Lost lifetime economic productivity

Preterm birth is associated with reduced cognitive potential, which can decrease future economic productivity and lifetime earnings. On average, preterm birth is associated with an estimated 11.9 point IQ reduction (95% CI: 10.5, 13.4) based on a systematic review of 27 published studies.[40] Using research from Grosse et al. (2002), each IQ point is estimated to increase worker productivity by 2% (range: 1.76-2.38%).[41] Decreases in lifetime earning potential were estimated by multiplying average IQ loss by the change in worker productivity associated with a per-point reduction in IQ and average potential lifetime earnings for children born in 2013 (Table 3). Estimated potential lifetime earnings ($1,343,341) are from Grosse et al. (2009). Estimated lost lifetime earnings include a 3% discount rate and assume future productivity growth of 1% per year.

Table 3. Lost lifetime economic productivity associated with preterm birth (2013 US$)

	Preterm children born in 2013
Estimated potential lifetime earnings, 2013$*	$1,343,341
Average IQ loss associated with PTB	11.9 (95% CI: 10.5, 13.4)
Change in worker productivity per IQ point	2.0% (1.76 – 2.38%)
% Decrease in lifetime earning potential*	23.8% (20.9% - 28.3%)
Estimated lost lifetime earnings for PTB infants, 2013$*	$319,715 ($294,389 - $355,140)

**Costs beyond the first year of life discounted at a 3 percent rate back to the year of birth.*

Sensitivity analysis

We performed a sensitivity analysis to assess the impact of a range of odds ratios describing the relationship between PM2.5 and PTB. We used the range of ORs (Table 4) identified in the literature (Sapkota et al., 2012; Stieb et al., 2012) for pregnancy wide exposure and third-trimester exposure (1.07-1.16). Additionally, we examined how a RL of 5.8 would affect the results (Table 5).

Table 4. Range of estimated costs of $PM_{2.5}$-attributable preterm births using a low and high odds ratio scenario

	Low OR scenario*	**Base OR scenario***	High OR scenario*
Attributable fraction	4.30%	**9.20%**	9.80%
Attributable PTBs	1435	**3062**	3265
Attributable indirect costs of preterm birth	$458,922,417	**$979,266,577**	$1,043,936,496
Attributable direct costs of preterm birth	$79,328,453	**$169,274,150**	$180,452,869
Total attributable costs of preterm birth	$538,250,870	**$1,148,540,728**	$1,224,389,365

*Base scenario OR of 1.15; low scenario OR of 1.07; high scenario OR of 1.16.

Table 5. Range of estimated costs of $PM_{2.5}$-attributable preterm births using a low and base reference level scenario

	Base RL Scenario*	Low RL scenario*
Attributable fraction	**9.20%**	12.60%
Attributable PTBs	**3062**	4210
Attributable indirect costs of preterm birth	**$979,266,577**	$1,346,199,161
Attributable direct costs of preterm birth	**$169,274,150**	$232,701,416
Total attributable costs of preterm birth	**$1,148,540,728**	$1,578,900,577

*Base scenario estimates used a RL of 8.8 μg/m3; low scenario used a RL of 5.8 μg/m3.

Costs of $PM_{2.5}$-attributable preterm birth by county

Complete results for the estimated number of $PM_{2.5}$-attributable preterm births and the direct and indirect costs of $PM_{2.5}$-attributable preterm birth by county are shown in Table 6.

Table 6. The estimated number of $PM_{2.5}$-attributable preterm births and associated direct and indirect costs of $PM_{2.5}$-attributable preterm birth, by county, 2013

County*	Estimated number of attributable preterm births**	Attributable direct costs of preterm birth	Attributable indirect costs of preterm birth	Total attributable costs of preterm birth
Alameda	25.9	$ 1,430,777	$ 8,277,179	$ 9,707,956
Butte	8.3	$ 457,368	$ 2,645,918	$ 3,103,286
Calaveras	<1	$ 3,020	$ 17,468	$ 20,488
Colusa	<1	$ 54,701	$ 316,452	$ 371,153
Contra Costa	4.7	$ 261,000	$ 1,509,908	$ 1,770,908
Fresno	107.5	$ 5,943,279	$ 34,382,418	$ 40,325,697
Glenn	<1	$ 35,673	$ 206,372	$ 242,045
Humboldt	<1	$ 39,931	$ 231,005	$ 270,936
Imperial	24.8	$ 1,371,144	$ 7,932,197	$ 9,303,342
Inyo	<1	$ 3,579	$ 20,707	$ 24,286
Kern	120.5	$ 6,656,672	$ 38,509,459	$ 45,166,131
Kings	11.0	$ 606,219	$ 3,507,034	$ 4,113,254
Los Angeles	1,417.3	$ 78,330,462	$ 453,148,951	$ 531,479,413
Madera	11.3	$ 624,651	$ 3,613,664	$ 4,238,315
Marin	1.4	$ 78,255	$ 452,710	$ 530,965
Mariposa	<1	$ 7,871	$ 45,533	$ 53,404
Mendocino	<1	$ 18,222	$ 105,418	$ 123,640
Merced	8.6	$ 476,770	$ 2,758,161	$ 3,234,931
Monterey	1.6	$ 88,650	$ 512,848	$ 601,498
Napa	2.1	$ 118,511	$ 685,599	$ 804,110
Nevada	1.8	$ 99,850	$ 577,644	$ 677,495
Orange	145.0	$ 8,015,324	$ 46,369,391	$ 54,384,716
Placer	10.5	$ 580,543	$ 3,358,496	$ 3,939,039
Plumas	1.8	$ 98,715	$ 571,076	$ 669,791
Riverside	351.9	$ 19,446,256	$ 112,498,384	$ 131,944,640
Sacramento	40.7	$ 2,250,990	$ 13,022,187	$ 15,273,177
San Benito	<1	$ 2,215	$ 12,811	$ 15,026
San Bernardino	278.9	$ 15,413,942	$ 89,171,076	$ 104,585,018
San Diego	245.1	$ 13,545,985	$ 78,364,775	$ 91,910,760
San Francisco	7.2	$ 395,592	$ 2,288,533	$ 2,684,125
San Joaquin	41.8	$ 2,312,496	$ 13,378,001	$ 15,690,496
San Luis Obispo	4.4	$ 242,291	$ 1,401,673	$ 1,643,964
San Mateo	7.8	$ 429,352	$ 2,483,841	$ 2,913,193

Santa Barbara	7.9	$ 437,161	$ 2,529,018	$ 2,966,179
Santa Clara	37.9	$ 2,092,643	$ 12,106,130	$ 14,198,772
Santa Cruz	<1	$ 6,092	$ 35,245	$ 41,337
Solano	5.9	$ 327,443	$ 1,894,289	$ 2,221,732
Sonoma	3.6	$ 196,275	$ 1,135,468	$ 1,331,743
Stanislaus	35.7	$ 1,973,057	$ 11,414,317	$ 13,387,374
Sutter	1.9	$ 102,007	$ 590,118	$ 692,124
Tehama	<1	$ 28,352	$ 164,019	$ 192,371
Trinity	1.0	$ 57,068	$ 330,146	$ 387,214
Tulare	50.0	$ 2,762,022	$ 15,978,549	$ 18,740,571
Ventura	31.1	$ 1,716,882	$ 9,932,318	$ 11,649,200
Yolo	2.4	$ 134,842	$ 780,071	$ 914,912
California	3,062.9	$ 169,274,150	$ 979,266,577	$ 1,148,540,728

*13 counties were excluded from the analysis because of a lack of PM2.5 data or because of too few preterm births to be included in the analysis: Alpine, Amador, Del Norte, El Dorado, Lake, Lassen, Modoc, Mono, Shasta, Sierra, Siskiyou, Tuolumne, and Yuba Counties.
** When the calculated estimated number of attributable preterm births is a fraction of 1 birth, it is shown as simply <1, and cost calculations are carried out with the estimated fraction of a birth.

The Human and Economic Burden of $PM_{2.5}$-Attributable Preterm Birth in California

Of the 466,009 children born (singleton births only) in California in 2013, 33,449 children were born preterm (7.2% of all births, with substantial variation by county). Statewide, an estimated 9.2% of preterm births among singleton births in 2013 were attributable to exposure to preventable $PM_{2.5}$ air pollution. This figure excludes 13 counties with limited data, but the 45 counties included in the analysis account for 98.5% of all singleton births statewide.

Statewide, for all preterm children born in 2013, direct medical and educational costs associated with $PM_{2.5}$-attributable preterm birth are estimated to be $169,274,000, and lifetime costs are estimated to total $979,266,000.

Limitations
There are limitations to consider when interpreting these findings.

The findings presented here are based on the relationship between $PM_{2.5}$ and preterm birth found in one of the most recent meta-analyses in peer-reviewed literature (Sapkota 2012). Another meta-analysis from the same year published very similar results. The actual relationship between $PM_{2.5}$ and preterm birth may be stronger or weaker than these estimates. The results shown here do not take into account the potential impact of $PM_{2.5}$ concentrations less than 8.8 μg/m3. (A lower reference level of 5.8 μg/m3 was explored in the sensitivity analysis.)

Data on $PM_{2.5}$ concentrations were from daily averages, by county, measured by the California Air Resources Board Air Monitoring Network. These measurements assume even distribution of $PM_{2.5}$ across the county. The reported daily average for a given county is from the monitor with the highest average concentration for that day in counties with multiple air monitors, potentially leading to an overestimation of $PM_{2.5}$ concentrations for a given day. Births were assumed to be spread evenly throughout the year, and evenly split among 10 deciles of $PM_{2.5}$ concentrations; this may lead to misclassification of exposure.

Finally, cost estimates are limited to those for which data are available, and all costs are averaged over all cases of preterm birth. However, it is known that the severity of preterm birth can impact the economic costs. The financial costs presented here exclude the emotional toll that preterm birth can take on a family.

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