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Supplementary information

Lower test scores from wildfire smoke exposure

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Supplementary Information for

Lower test scores from wildfire smoke exposure

Jeff Wen and Marshall Burke

E-mail (corresponding author): jlwen@stanford.edu

Supplementary Note

Effect estimate comparison with average ambient air pollution. A recent paper leverages SEDA data and considers the effect of ambient air pollution on student test performance.[1] The authors discuss the impact in terms of an IQR change (2.8 $\mu g/m^3$) in 12 month average ambient air pollution in the year prior to the exam and find a 0.007 (95% CI: 0.005, 0.009) standard deviation lower average Math test score and a 0.004 (95% CI: 0.002, 0.005) standard deviation lower average ELA test score. Besides the difference of additional ambient $PM_{2.5}$ versus smoke $PM_{2.5}$, we are unable to compare directly with this estimate as the authors did not appear to provide the regression coefficient but rather provided an IQR change estimate. However, as the beta coefficient is linear in 12 month average ambient air pollution, we recalculate the effect size to better compare with our estimated effect. Specifically, we convert their estimate to the impact of an additional $\mu g/m^3$ of ambient $PM_{2.5}$ in the year prior to the exam and compare against the impact of an additional $\mu g/m^3$ of smoke $PM_{2.5}$ on school days in the year prior to the exam.

The IQR change of 2.8 $\mu g/m^3$ change in 12 month average ambient air pollution equates to 2.8 * 365 = 1022 $\mu g/m^3$ over the year. We then estimate the effect as 0.007/1022 = 0.0007% of a standard deviation for Math and 0.004/1022 = 0.0004% of a standard deviation for ELA test scores. We estimate that a $\mu g/m^3$ increase in smoke $PM_{2.5}$ decreased student test scores by 0.004% of a standard deviation on average. These estimates suggest that our effect sizes are an order of magnitude larger. However, as mentioned earlier, this comparison is not directly comparable as a $\mu g/m^3$ of smoke $PM_{2.5}$ is likely different from a $\mu g/m^3$ of ambient $PM_{2.5}$ and is potentially more harmful than sources of ambient PM2.5.[2] Another potential explanation for this difference is that total ambient PM2.5 may be correlated with other factors that affect student test performance in the opposite direction resulting in a downward biased estimate of the effect.[3]

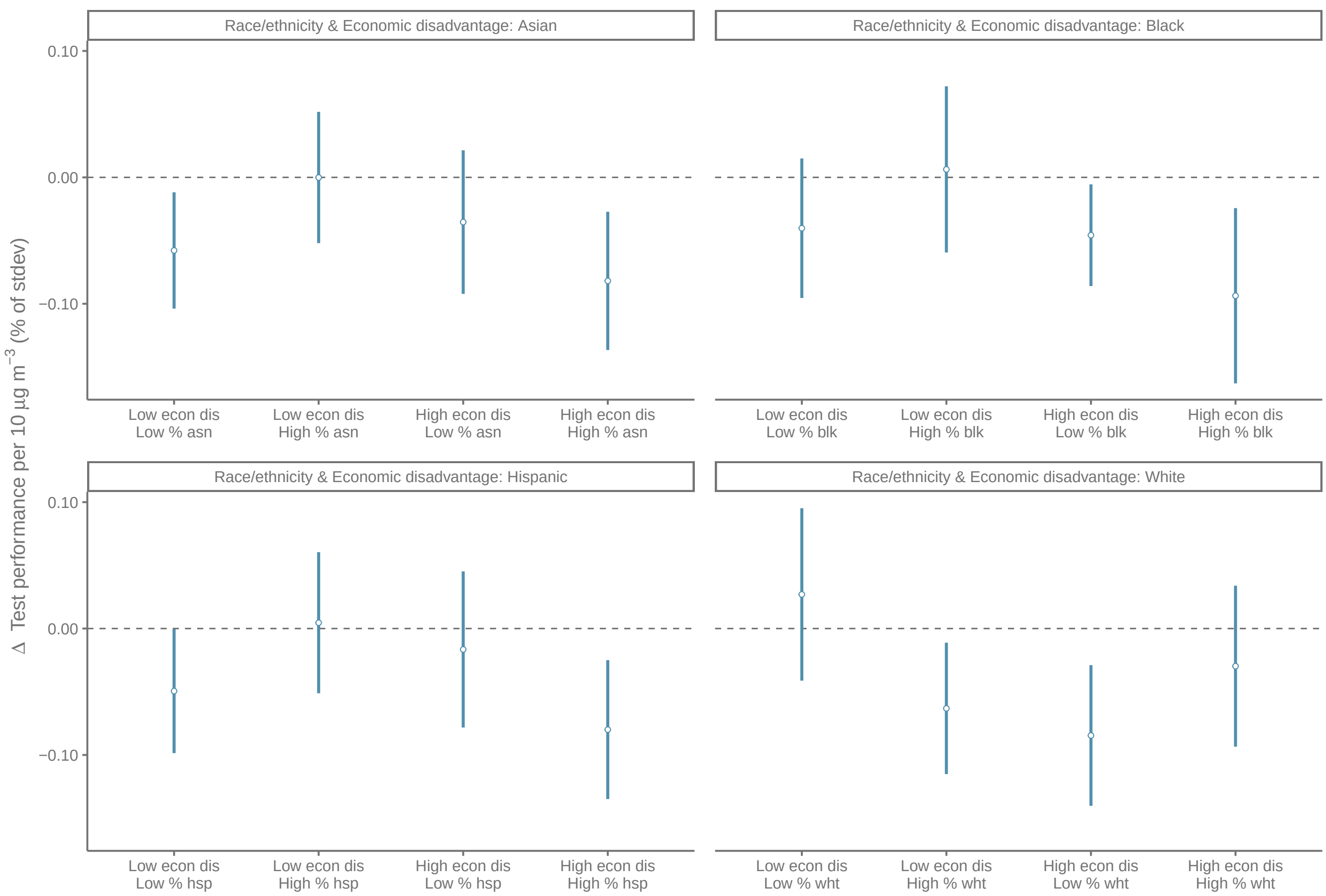

Fig. S1. Effect estimates of an additional 10μg/m^3 of cumulative school-day smoke $PM_{2.5}$ exposure across different racial-ethnic groups and levels of economic disadvantage. The bottom right panel shows effect estimates across across different levels of % White students while the right panel in Figure 3 of the main text shows the complement and subtracts the % of White students from *1*. Each panel displays results from a separate regression that considers the interaction between the specific racial-ethnic group, economic disadvantage, and smoke $PM_{2.5}$. As with the main specification, the regressions include district and year-grade fixed effects as well as temperature and precipitation controls. The circle markers represent the regression point estimates and the error bars show the 95% confidence intervals.

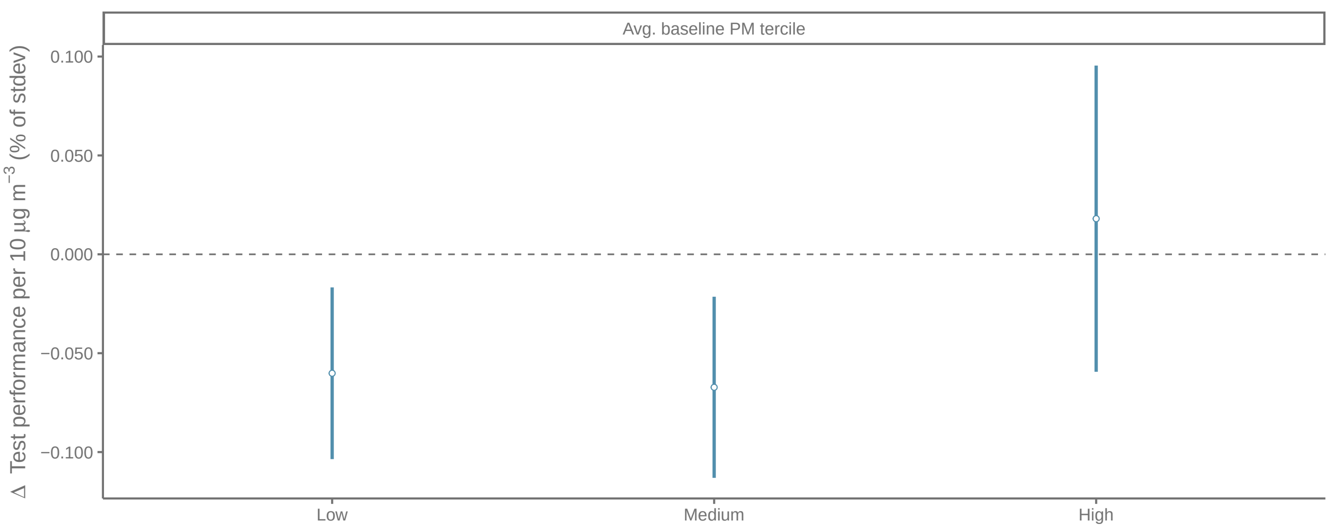

Fig. S2. Effect estimates of additional 10µg/m^3 of cumulative school-day smoke $PM_{2.5}$ exposure across different levels of baseline $PM_{2.5}$. The baseline $PM_{2.5}$ bins were determined by calculating the average total $PM_{2.5}$ for each district and separating into bins based on terciles across our data sample. The regression considers how the effect of smoke $PM_{2.5}$ differs across the different levels of baseline $PM_{2.5}$ bins and includes district and year-grade fixed effects as well as temperature and precipitation controls. The circle markers represent the regression point estimates and the error bars show the 95% confidence intervals.

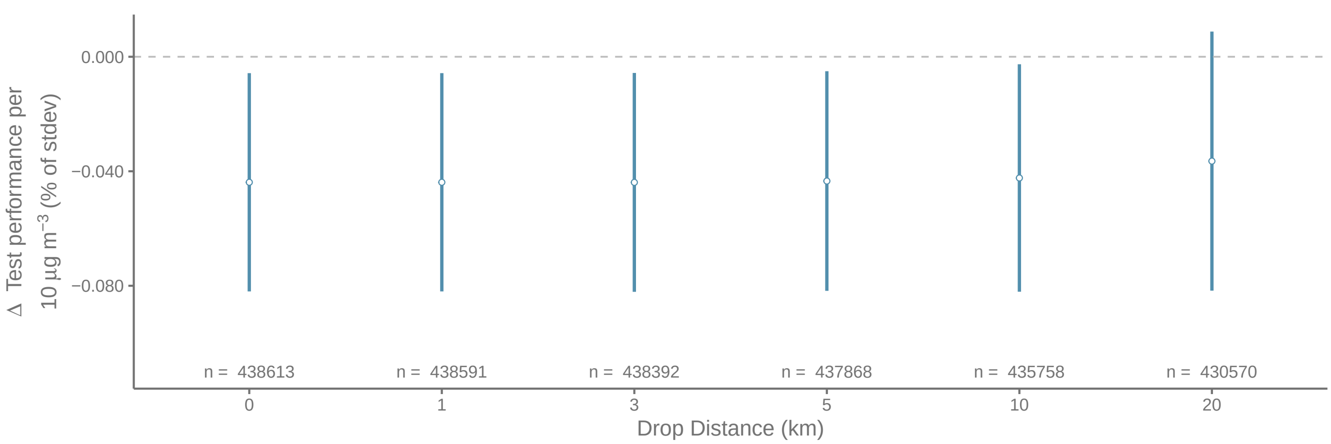

Fig. S3. Effect estimates of additional 10µg/m^3 of cumulative school-day smoke $PM_{2.5}$ exposure when dropping districts within a certain distance. To test that the identified effects are driven by exposure to wildfire-attributable smoke $PM_{2.5}$ rather than from the direct wildfire impacts, we drop school districts that within a certain distance to the nearest wildfire perimeter in that year. The estimated effects remain fairly stable even when dropping districts that are within 6.2 miles (10 kilometers) to the nearest fire perimeter. Each drop distance coefficient was estimated with a separate regression that excludes the dropped school districts. The regressions include district and year-grade fixed effects as well as temperature and precipitation controls. The circle markers represent the regression point estimates and the error bars show the 95% confidence intervals.

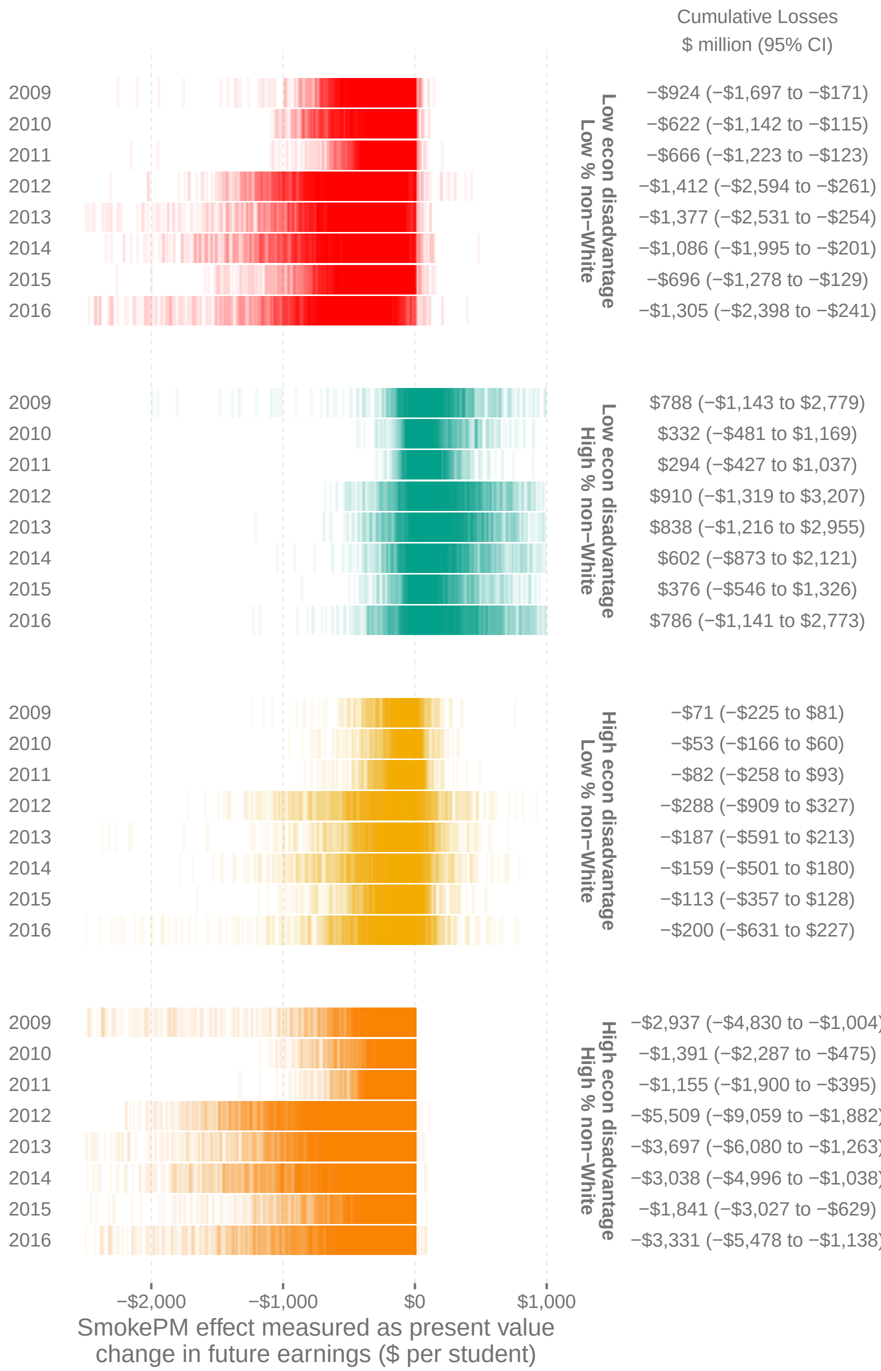

Fig. S4. Effect of total cumulative smoke $PM_{2.5}$ on the net present value of future earnings separated by year, economic disadvantage, and racial-ethnic subgroup. Figure differs from the Figure 4B in the main text as it uses estimates identified using total (school and non-school) day smoke $PM_{2.5}$ exposure rather than just school day smoke $PM_{2.5}$.

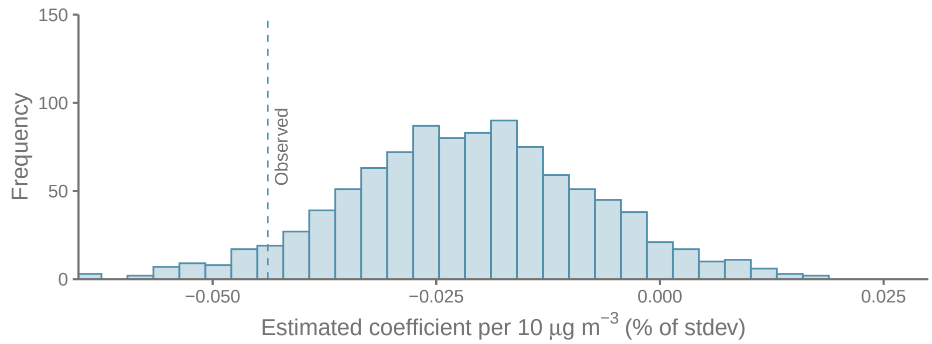

Fig. S5. Randomization inference test (1000 permutations) showing the estimated effect size of an additional 10µg/m^3 of smoke $PM_{2.5}$ on school days when district level smoke $PM_{2.5}$ time-series is randomly permuted across districts within the state. The observed result is at the 6th percentile of the resulting distribution. We note that some correlation across the state-level is expected as wildfire smoke plumes could cover large portions of a state. Each permutation of the randomization inference test was run with district and year-grade fixed-effects as well as temperature and precipitation controls as in the main specification.

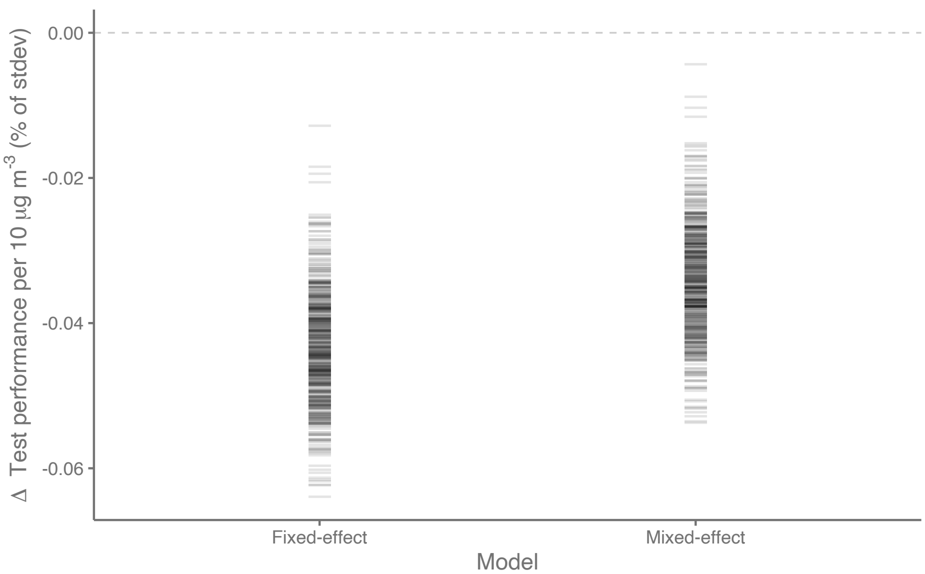

Fig. S6. Bootstrap simulation results showing the full distribution of coefficient estimates of an additional 10µg/m^3 of cumulative school-day smoke $PM_{2.5}$ from a fixed-effects (FE) model fit with the fixest package (0.8.4)[4] and a mixed-effects (ME) model fit with the lme4 package (1.1-29)[5] from 500 bootstrapped samples. In each sample, 10,000 districts were randomly selected. Both the FE and ME models were run with the same temperature and precipitation controls as in the main specification. The FE model included district and year-grade fixed-effects and the ME model had a district random-effect and year-grade fixed-effect.

Table S1. Median cumulative smoke $PM_{2.5}$ exposure by race/ethnicity on school and non-school days

	Asian		Black		Hispanic		Native Amer.		White	
Category	High	Low	High	Low	High	Low	High	Low	High	Low
Nonschool SmokePM	48.49	50.86	45.38	54.61	45.70	52.60	49.15	49.81	58.00	39.58
School SmokePM	19.96	20.16	18.26	22.20	19.79	20.28	19.97	20.13	23.11	16.80

Notes: Exposure to wildfire smoke $PM_{2.5}$ is noticeably greater on non-school days as this includes the summer period before school begins.

Table S2. Median cumulative smoke $PM_{2.5}$ exposure by economic disadvantage on school and non-school days

	% Economic Disadvantage	
Category	High	Low
Nonschool SmokePM	42.08	55.63
School SmokePM	17.41	22.45

Table S3. % of districts by subgroup within each average baseline $PM_{2.5}$ bin.

	Avg. baseline $PM_{2.5}$		
Econ disadvantage & racial-ethnic subgroup	Low	Medium	High
High econ dis & High % non-White	37.60	33.02	29.38
High econ dis & Low % non-White	47.47	27.83	24.70
Low econ dis & High % non-White	37.61	32.12	30.27
Low econ dis & Low % non-White	43.95	28.70	27.35

Notes: A district's baseline $PM_{2.5}$ is calculated as the average yearly $PM_{2.5}$ across the sample and bins are created by splitting the data into terciles.

Table S4. Lagged impacts of school day smoke $PM_{2.5}$ exposure

Model:	(1)	(2)	(3)
Variables			
Contemporaneous year school smoke PM2.5	-0.086	-0.092	-0.098
	(0.024)	(0.026)	(0.026)
1 year lagged school smoke PM2.5		-0.004	-0.005
		(0.003)	(0.003)
2 year lagged school smoke PM2.5			-0.007
			(0.003)
Fixed-effects			
District	✓	✓	✓
Year x Grade	✓	✓	✓
Controls			
Temperature	✓	✓	✓
Precipitation	✓	✓	✓
Observations	306,018	306,018	306,018

Notes: Contemporaneous and lagged effect estimates of an additional $10\mu g/m^3$ of cumulative school-day smoke $PM_{2.5}$ exposure on student test scores. Standard errors clustered by county are shown in parentheses. Effect estimates are represented as a percent of a standard deviation change in average test score.

References

[1] Wenxin Lu, Daniel A Hackman, and Joel Schwartz. Ambient air pollution associated with lower academic achievement among us children: a nationwide panel study of school districts. *Environmental Epidemiology*, 5(6), 2021.

[2] Rosana Aguilera, Thomas Corringham, Alexander Gershunov, and Tarik Benmarhnia. Wildfire smoke impacts respiratory health more than fine particles from other sources: observational evidence from southern california. *Nature communications*, 12(1):1–8, 2021.

[3] Tatyana Deryugina, Garth Heutel, Nolan H Miller, David Molitor, and Julian Reif. The mortality and medical costs of air pollution: Evidence from changes in wind direction. *American Economic Review*, 109(12):4178–4219, 2019.

[4] Laurent Bergé. Efficient estimation of maximum likelihood models with multiple fixed-effects: the R package FENmlm. *CREA Discussion Papers*, (13), 2018.

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