The Pollution–Productivity Curve: Non-Linear Effects and Adaptation in High-Pollution Environments

Matthew S. Brooks[1] and Faraz Usmani[2]

UC Davis NatuRE Lab
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[1]Department of Agricultural and Resource Economics; University of California, Davis
[2]Global Energy Alliance for People and Planet

Outline

1. Introduction

2. How to attach long-run measure to a person

3. What is right time window for past exposure

4. How to define acclimation

Research question

What is the marginal effect of PM2.5 exposure on labor productivity?

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Why does this matter?

- Over one-third of the global population is exposed to hazardous annual average PM2.5 levels ($> 35 \mu g/m^3$) (Rentschler and Leonova, 2023).
- Does a marginal increase in PM2.5 affect these people differently than people who are used to cleaner air?
  1. Non-linearities
  2. Adaptation

Research question

How does the marginal effect of *contemporaneous* PM2.5 exposure on labor productivity vary by *past* exposure to PM2.5?

What does this paper add?

- Demonstrates that workers build tolerance to particulate matter air pollution.

Performance data

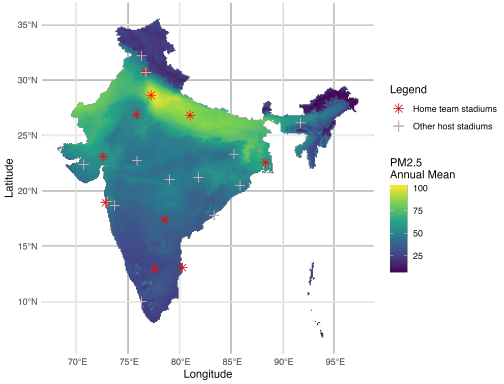
Figure 1: Outcome: run-scoring

Source: Wikipedia.

- Granular data on performance: 183,572 deliveries (throws)
- 619 individuals
- 14 years (2008-2022)
- 773 matches
- 20 stadiums

Air pollution data

Figure 2: PM2.5 in Cricket Stadiums



Notes. Annual mean PM2.5 in 2019.

- Rich air pollution data (daily PM2.5, 10km^2 gridded)
- Quasi-experimental variation in
  1. contemporaneous PM2.5 exposure
  2. past PM2.5 exposure
- **Key questions**
  - What is the right time window for past exposure?
  - How to attach a long-run measure to a person, not a place?
  - How to quantitatively define acclimation?

Main regression specification

$$R_{ij\ell t} = \beta_1 \text{PM2.5}_{\ell d} + \beta_2 \text{PM2.5}_{\ell d} \times \text{PM2.5}_{j0} + \beta_3 \text{PM2.5}_{j0} + \mathbf{X}'_{\ell d}\phi + \psi_j + \phi_i + \delta_{\ell y} + \theta_n + \eta_o + \Lambda_i + \Delta_j + \varepsilon_{ij\ell t} \quad (1)$$

$R_{ij\ell t}$: run scored (binary) on delivery t

$\text{PM2.5}_{\ell d}$: PM2.5 on day d of match at location ℓ (units: 10 $\mu g/m^3$)

PM2.5_{j0} : PM2.5 exposure history for bowler j (units: 10 $\mu g/m^3$)

$\psi_j(\phi_i)$: bowler (batter) fixed effects

$\delta_{\ell y}$: stadium-by-year fixed effects

θ_n, η_o : innings, over fixed effects

$\mathbf{X}_{\ell d}$: weather controls: temp, temp^2, humidity, precipitation, air pressure, radiation, wind

$\Lambda_j(\Delta_i)$: dummy for whether stadium is home for bowler (batter)

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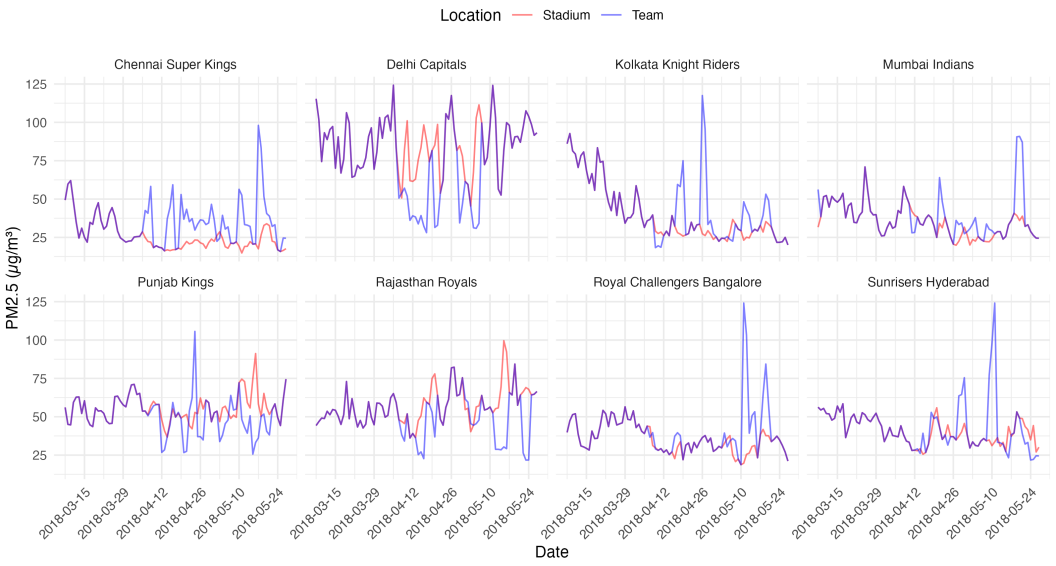
Figure 3: Team PM2.5 Exposure vs. Home Stadium PM2.5 Exposure in 2018



Notes. Figure compares the PM2.5 estimates assigned to teams (based on their travel itinerary) as opposed to the PM2.5 at their home stadium.

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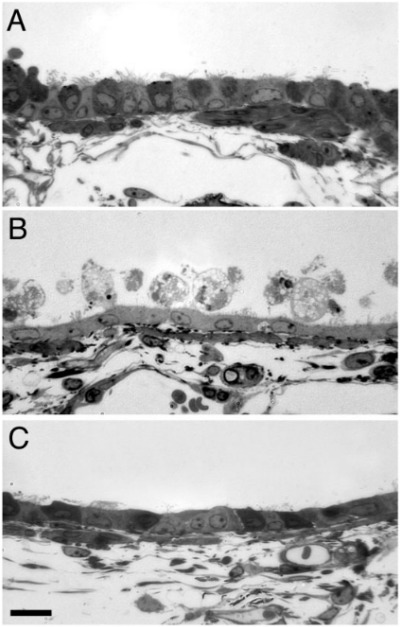
What is the physiological evidence for adaptation to PM2.5 exposure?



This figure, reproduced from West et al. (2003), displays three panels of microscopic images of cells in the lungs of mice.

- **Panel A** shows cells from mice that were in the control group and breathed clean air throughout the experiment.
- **Panel B** shows cells from mice from the treatment group that was exposed to polluted air for one day, and had their cells imaged 24 hours after.
- **Panel C** shows cells from mice that were exposed to the same level of air pollution as those in Panel B, except they were exposed for 7 days instead of 1.

3 definitions of longer-term PM

1. Mean PM2.5 over past X days:

$$PM2.5_{J(j)d} = \frac{1}{X} \sum_{d=1}^{X} \overline{PM2.5_{dj}} \tag{2}$$

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2. Number of days in past X days where PM2.5 was above threshold Z (e.g. WHO thresholds $Z \in \{25, 37.5, 50, 75\}$):

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3. Degree-day analogue (sum of exceedances above Z over past X days):

$$PM2.5_{J(j)d} = \sum_{d=1}^{X} [\mathbf{1}(PM2.5_{dj} > Z)](PM2.5_{dj} - Z) \tag{4}$$

Questions for group

- Which measure?
- What time window?
- If measure 2 or 3, what threshold Z?

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- In the following slides, I will show the three measures
  - regression table with 30 days included each measure, threshold of $Z = 50$ $\mu g/m^3$
  - figures a varying number of days included (1-90) and threshold of $Z = 50$ $\mu g/m^3$

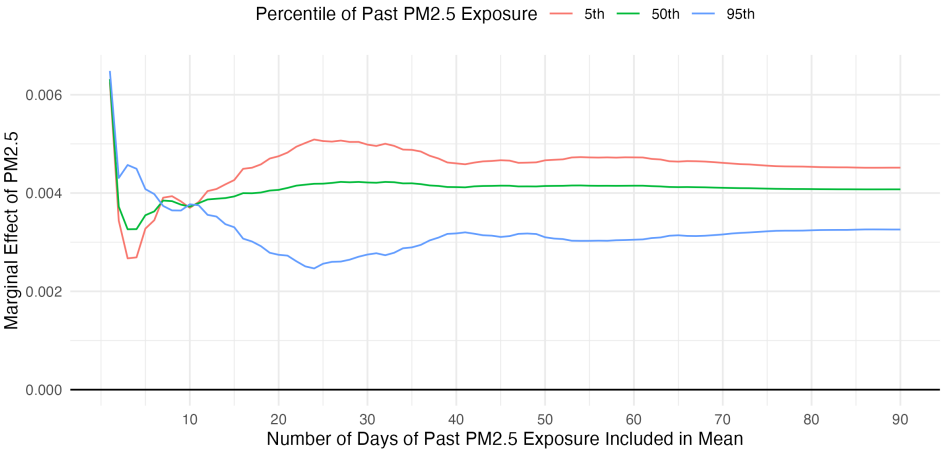
Table 1: Heterogeneous Effect of PM2.5 by Past Exposure

	(1)	(2)	(3)
	$\mathbb{1}$ (At least one run scored)		
PM2.5	0.0066*	0.0052***	0.0046***
	(0.0034)	(0.0019)	(0.0018)
Past PM2.5 (Measure 1)	0.0061*		
	(0.0034)		
PM2.5 X Past PM2.5 (Measure 1)	-0.00055		
	(0.00063)		
Past PM2.5 (Measure 2)		0.0011*	
		(0.00055)	
PM2.5 X Past PM2.5 (Measure 2)		-0.00010	
		(0.000098)	
Past PM2.5 (Measure 3)			0.00027
			(0.00018)
PM2.5 X Past PM2.5 (Measure 3)			-0.000023
			(0.000033)
All controls	✓	✓	✓
All fixed effects	✓	✓	✓
N	183,556	183,556	183,556
R^2	0.052	0.052	0.052

Notes. S.e.'s clustered two-way by match & bowler. * $p < 0.10$, ** $p < 0.05$,

Measure 1: Mean PM2.5 exposure

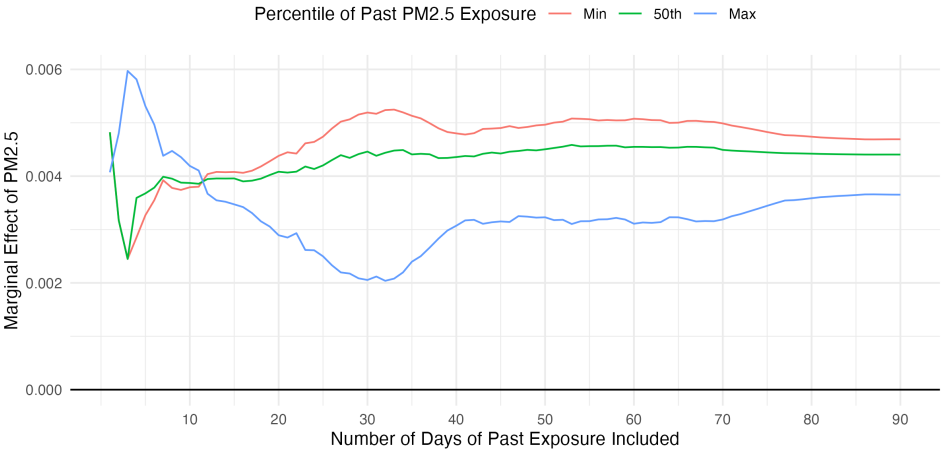
Figure 4: Effect of 10 μg/m³ Increase in PM2.5 on Run-Scoring



Notes. Estimates of β_2 from Equation 1 using $PM2.5_{j0} \equiv \frac{1}{X}\sum_{d=1}^{X}\overline{PM2.5_{dj}}$.

Measure 2: Count of days above 50 μg/m³

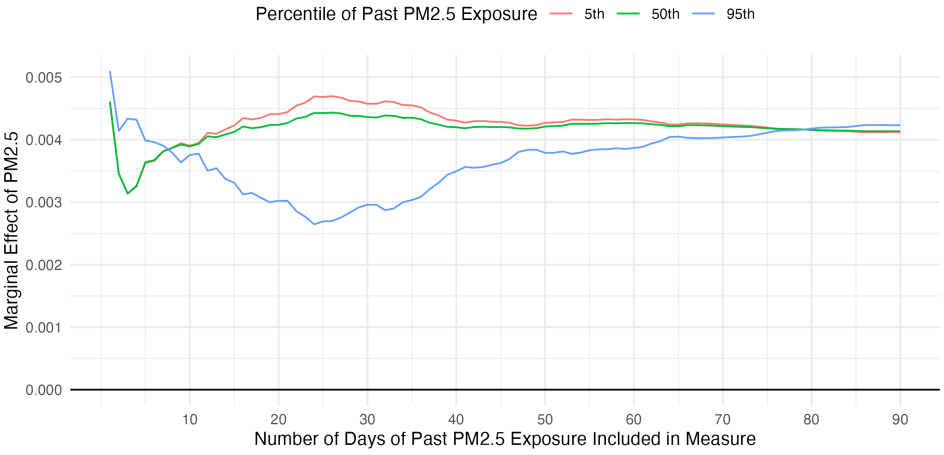
Figure 5: Effect of 10 μg/m³ Increase in PM2.5 on Run-Scoring



Notes. Estimates of β_2 from Equation 1 using $PM2.5_{j0} \equiv \sum_{d=1}^{X} \mathbf{1}(PM2.5_{dj} > Z)$.

Measure 3: Cooling degree-day analogue

Figure 6: Effect of 10 μg/m³ Increase in PM2.5 on Run-Scoring



Notes. Estimates of β_2 from Equation 1 using $PM2.5_{j0} \equiv \sum_{d=1}^{X}[\mathbf{1}(PM2.5_{dj} > Z)](PM2.5_{dj} - Z)$.

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Definition of "acclimation effect"

We define the "acclimation effect" as the difference in the marginal effect of PM2.5 for those with past exposure at the 95$^{\text{th}}$ percentile relative to those with median levels of past exposure:

$$AcclimationEffect = \frac{ME_{p50} - ME_{p95}}{ME_{p50}} \tag{5}$$

where ME_{pX} represents the marginal effect of an increase of PM2.5 by 10 $\mu g\, m^{-3}$ on run-scoring probability for bowlers at the X^{th} percentile of past exposure to PM2.5.[1]

[1]For the measure in Equation 3, we slightly modify this definition to be $\frac{ME_{p50} - ME_{max}}{ME_{p50}}$ to account for the comparatively lower variation in number of days above a particular threshold. The logic of comparing the marginal effect of contemporaneous PM2.5 for someone exposed at a "high" level relative to the typical level remains the same.

Main result: PM is less damaging for those used to it

Figure 7: Effect of 10 µg/m³ Increase in PM2.5 on Run-Scoring

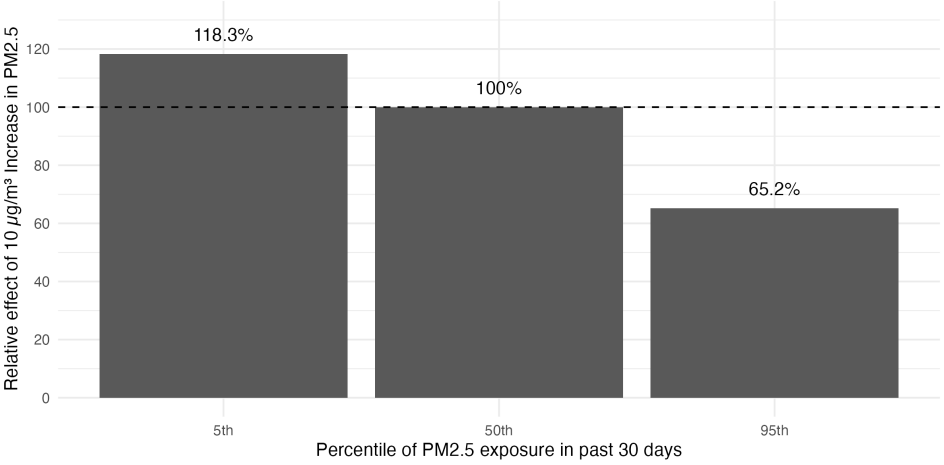

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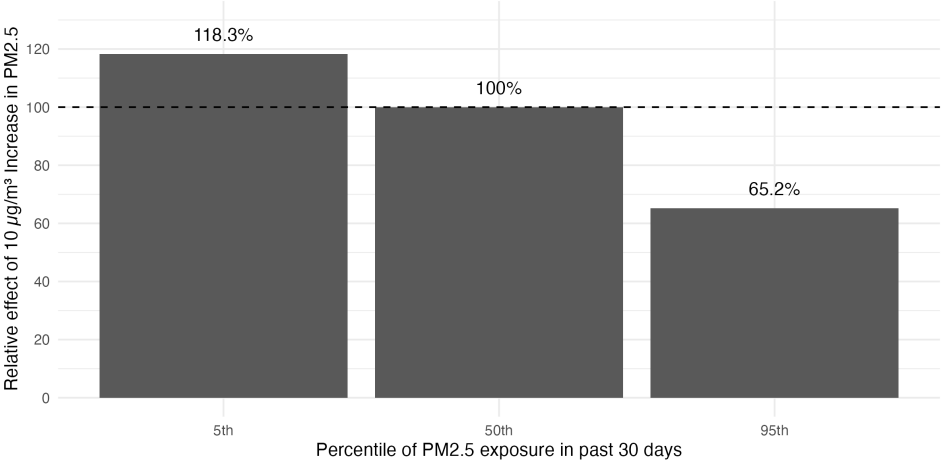
Figure 7: Effect of 10 μg/m³ Increase in PM2.5 on Run-Scoring



Thanks! msbrooks@ucdavis.edu

Rentschler, J. and N. Leonova (2023): "Global air pollution exposure and poverty," *Nature Communications*, 14, 4432, publisher: Nature Publishing Group.

West, J. A. A., L. S. Van Winkle, D. Morin, C. A. Fleschner, H. J. Forman, and C. G. Plopper (2003): "Repeated inhalation exposures to the bioactivated cytotoxicant naphthalene (NA) produce airway-specific Clara cell tolerance in mice," *Toxicological Sciences: An Official Journal of the Society of Toxicology*, 75, 161–168.

Figure 8: Dose-response of Productivity to PM2.5