Air Pollution, Rainfall Variability, and Intimate Partner Violence in India

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Violence against women

Problem: Gender-related violence negatively affects economic development outcomes:

- **Lower** female labor market performance in India [Bhalotra et al. 2021], and in Tanzania [McCarthy 2019]
- **Less autonomy** for Indian women in reproductive health [Stephenson, Jadhav, and Hindin 2013]
- **Negative** impact on capital investments in children in Turkey [Gulesci et al. 2020]

Effects of pollution on interpersonal crime:

- Exposure to air pollution is linked to an increase in **assault** and **violent crimes** in the U.S. [Burkhardt et al. 2019] and the UK [Bondy et al. 2020]
- Pollution has an adverse effect on adult **cognitive** function in China [Chen et al. 2018], and in India [Balakrishnan et al. 2022]

This Study: Research Question and Results Preview

How does air pollution impact the incidence and intensity of intimate partner violence?

- Fine Particulate Matter ($PM_{2.5}$): a 1 $\mu g/m^3$ increase in $PM_{2.5}$ is associated with a **6.1%** increase in the incidence of physical/sexual violence and a **12%** increase in the intensity of physical violence.

Why may pollution lead to intimate partner violence?

1. **Income stress** resulting from pollution-induced household level shocks
   - **Diminished labor productivity**
2. **Aggression** and reduced **cognitive ability**
   - **More time spent indoors** as a avoidance behavior leads to more contact time

Related Literature and Contributions

Weather-induced violence against women:

- **Drought** leads to increased violence against women in India (Shekari et al. 2014), and in Sub-Saharan Africa [Cools et al. 2015]
- **Rainfall shocks** lead to intimate partner violence in Tanzania [Abiona et al. 2018]
- **Extreme cold** lead to intimate partner violence in Peru [Bollman et al. 2023]

Women's employment status and spousal violence:

- Women's **access to resources** reduces intimate partner violence in Sub-Saharan Africa [Coors et al. 2017]
- Female **employment status** lead to **decrease** in intimate partner violence in India [Yoo-Mi Chin 2011], while Sujargard et al. [2020] shows a **positive** relationship between MGNREGA and spousal violence
- **Hypergamy** increases intimate partner violence in India [Roychowdhury et al. 2022]

Research Design: Epidemiological Approach

The probability of a woman i living in a air pollution grid-cell c experiencing a intimate partner violence is given by

$$y_i = f_i(PM_c, M_{i(h)}(PM_c), \mathbf{W}_c, \mathbf{X}_i, \mathbf{X}_{i(h)}; \varepsilon_i), \text{ where} \quad (1)$$

- PM_c is the average level of $PM_{2.5}$ in the grid-cell in the past 12 months
- $M_{i(h)}(PM_c)$ represents income stress that lead to aggressive behavior
- $\mathbf{W}_c$ represents a host of weather variables
- $\mathbf{X}_i$ and $\mathbf{X}_{i(h)}$ represent individual- and household-level characteristics
- ε_i are unobserved factors that influence the probability of a woman being exposed to violence
- Identifying assumption, $\mathbb{E}(Z_c, \varepsilon_i) = 0$ while $\mathbb{E}(PM_c, \varepsilon_i) \neq 0$, where Z_c is an instrument for PM_c

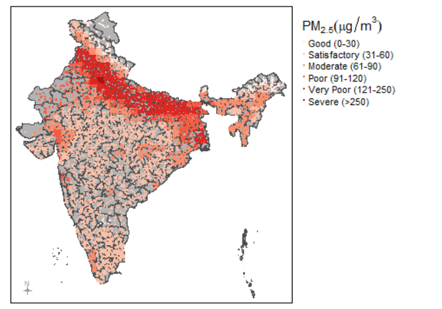
The effect of pollution on IPV, y, conditional on ε_i, is

$$\frac{dy_i}{dPM_c} = \underbrace{\frac{\partial f_i}{\partial PM_c}}_{\text{direct effect}} + \underbrace{\frac{\partial f_i}{\partial M_{i(h)}} \frac{\partial M_{i(h)}}{\partial PM_c}}_{\text{indirect effect}} \quad (2)$$

Data

- Domestic violence module from the 2015-2016 round of Indian DHS Sample
- CAMS-EAC4 satellite reanalysis air pollution data: $PM_{2.5}$, Ozone, NO_2, CO, SO_2, wind speed and direction
- CHIRPS: Daily precipitation and number of dry and wet months (in 36 months prior to the interview) Rainfall Variability
- IMDAA: Daily relative humidity and maximum temperature
- NCEP/NCAR reanalysis temperature data at two pressure levels: 1000 hPa and 925 hPa

Map of the Study Area



Note: The dots represent the average $PM_{2.5}$ levels (in $\mu g/m^3$) for the past 12 months from the survey period for DHS clusters. The district boundaries are shown in gray.

- There are 513 $PM_{2.5}$ grid-cells with an approximate horizontal resolution of 80 Km ($0.75° \times 0.75°$).
- High concentration of pollution in the Indo-Gangetic plains

Variables and Descriptive Statistics

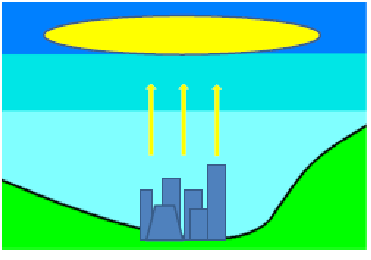
Variables:

- **Outcome variable:** Intimate partner violence (IPV) IPV Stat IPV Dist
- **Main explanatory variable:** Fine Particulate Matter ($PM_{2.5}$) $PM_{2.5}$ Dist

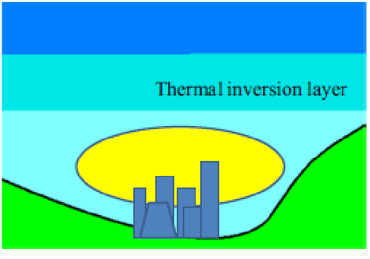
Covariates:

- **Individual-level characteristics:** Woman's age, education, working status, husband education, spousal age gap, husband drinking alcohol, husband working status, years of living together, and whether the woman's parents were exposed to IPV
- **Household-level characteristics:** Rural areas, religion, caste, age of household heads, household wealth index, and cooking fuel
- Nonlinear function of **weather** variables
- **Other pollutants:** Ozone, NO_2, CO, and SO_2
- **DHS cluster-level characteristics:** Purchasing power parity, population density and slope

Thermal Inversions



(a) Without Inversions, pollutants rise and disburse



(b) Inversion Event, pollutants are trapped beneath the inversion layer

Source: Arceo et al. 2015

- Distribution of thermal inversions — Inversion Dist
- Relationship between $PM_{2.5}$ and thermal inversions — $PM_{2.5}$ and Inversion
- Distribution of wind directions — Winds Dist
- Relationship between $PM_{2.5}$ and monsoon winds — $PM_{2.5}$ and Wind Dir

Econometric Specification: Two-Stage Least Squares (2SLS)

$$y_i = \beta_0 + \beta_1 \hat{PM}_{i(c,y)} + \mathbf{W}_{i(c,y)}\psi + \mathbf{X}_i\xi + \mathbf{X}_{i(h)}\lambda + \eta_{i(cm)} + \phi_{i(cs)} + \pi_{i(y)} + v_i, \text{ where} \quad (3)$$

First stage:

$$\begin{aligned} PM_{i(c,y)} = {} & \gamma_0 + \gamma_1 TI_{i(c,y)} + \gamma_2 NE_{i(c,y)} + \gamma_3 SW_{i(c,y)} + \gamma_4 NW_{i(c,y)} \\ & + \mathbf{W}_{i(c,y)}\psi + \mathbf{X}_i\xi + \mathbf{X}_{i(h)}\lambda + \eta_{i(cm)} + \phi_{i(cs)} + \pi_{i(y)} + u_i \end{aligned} \quad (4)$$

- $y_i = 1$ if woman i living in grid-cell c experienced IPV in past 12 months of survey year y, 0 otherwise
- $PM_{i(c,y)}$ 12 months average level of $PM_{2.5}$ in the grid-cell before the survey year y
- $TI_{i(c,y)}$ represent the average strength of inversion at midnight in the past 12 months
- $NE_{i(c,y)}, SW_{i(c,y)}$, and $NW_{i(c,y)}$ represent the number of days in the past 12 months when the wind was blowing at midnight in that direction
- $W_{i(c,y)}$ is a host of weather controls in the past 12 months
- X_i and $X_{i(h)}$ represent vector of individual- and household-level controls
- $\eta_{i(cm)}$, $\phi_{i(cs)}$, and $\pi_{i(y)}$ are grid-cell-by-month, grid-cell-by-state, and survey year fixed effects
- Standard errors are clustered at the grid-cell level

Threats to Identification

Identification Concern 1: Pollutant correlation

Correlation Matrix

- Include all pollutants in regression to isolate effects

Identification Concern 2: Covariation between pollution and weather

$PM_{2.5}$

- Include a quadratic function for precipitation, wind speed, and relative humidity
- Number of days in the previous 12 months for each temperature bin

Identification Concern 3: Measurement errors on observables

- Not fully accounting for husband's pollution exposure, as men migrate outside the village in search of work
  - Analysis at a larger spatial scale may possibly capture them

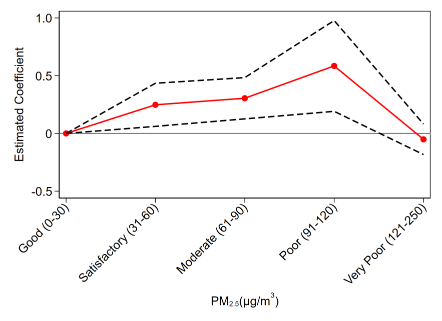
Impact of $PM_{2.5}$ on Incidence of Intimate Partner Violence

First stage

Dependent variable: Binary (0/1)	Physical/sexual violence [1]	Physical violence [2]	Severe physical violence [3]	Sexual violence [4]
Panel A: OLS estimates				
$PM_{2.5}(\mu g/m^3)$	0.038***	0.049***	0.009*	0.004
	(0.012)	(0.010)	(0.006)	(0.008)
Panel B: IV estimates using air temperature inversion and wind directions				
$PM_{2.5}(\mu g/m^3)$	0.061***	0.065***	-0.001	0.012
	(0.019)	(0.013)	(0.009)	(0.014)
Grid-cell x month FEs	Yes	Yes	Yes	Yes
Grid-cell x state FEs	Yes	Yes	Yes	Yes
Survey year FEs	Yes	Yes	Yes	Yes
First-stage (F-test)	17.91	17.91	17.91	17.91
Observations	56,806	56,806	56,806	56,806
R-square	0.115	0.110	0.054	0.036

Note: Levels of significance: $p< 0.01^{***}$, $p< 0.05^{**}$, $p< 0.10^{*}$. Robust standard errors in parentheses are clustered at the grid-cell level. All regressions include individual- and household-level, and cluster-level controls, as well as weather controls. Number of grid-cells is 512.

Nonlinear Effects of $PM_{2.5}$ on Incidence of Physical/Sexual Violence



Nonlinear OLS Model:

$$y_i = \beta_0 + \sum_{n=1}^{6} \beta_n \times 1[Bin_n(PM_{2.5})] + \mathbf{W}_{i(c,y)}\psi + \mathbf{X}_i\xi + \mathbf{X}_{i(h)}\lambda + \eta_{i(cm)} + \Phi_{i(s)} + \pi_{i(y)} + \mu_i \tag{5}$$

- **Satisfactory** (31-60, $\mu g/m^3$), **moderate** (61-90), and **poor** (91-120) levels of $PM_{2.5}$ are associated with the incidence of physical/sexual violence

Impact of $PM_{2.5}$ on Intensity of Intimate Partner Violence

First stage

Dependent variable: Count of violence	Physical/sexual violence [1]	Physical violence [2]	Severe physical violence [3]	Sexual violence [4]
Panel A: Maximum Likelihood Poisson estimates				
$PM_{2.5}(\mu g/m^3)$	1.637**	0.126***	0.010	-0.067
	(0.046)	(0.041)	(0.112)	(0.050)
Panel B: Maximum Likelihood Control Function Poisson estimates				
$PM_{2.5}(\mu g/m^3)$	0.090	0.120**	11.988**	-0.131
	(0.063)	(0.056)	(1.198)	(0.154)
First-stage residuals	0.039	0.022	−0.970**	0.093
	(0.162)	(0.179)	(1.738)	(0.156)
Grid-cell x month FEs	Yes	Yes	Yes	Yes
Grid-cell x state FEs	Yes	Yes	Yes	Yes
Survey year FEs	Yes	Yes	Yes	Yes
Observations	54,934	54,593	46,653	46,773
Pseudo R-square	0.212	0.185	0.184	0.185

Note: Levels of significance: $p< 0.01^{***}$, $p< 0.05^{**}$. Marginal coefficients are reported. Robust standard errors in parentheses are clustered at the grid-cell level. All regressions include individual- and household-level, and cluster-level controls, as well as weather controls.

Heterogeneous Marginal Effects: Air Pollution Effects on IPV

Data	Incidence of IPV [1]	Intensity of IPV [2]
Overall sample	0.061***	0.090
	[56,806]	[54,934]
Poor household sample	0.036	−0.607***
	[23,311]	[22,316]
Non-poor household sample	0.094***	0.742***
	[33,318]	[31,048]
Cooking with emitting fuels sample	0.103	−0.426***
	[34,324]	[32,816]
Wife beating justified sample	0.049**	-0.162
	[28,343]	[27,120]
Estimates	IV	Control Function Poisson

Note: Observations are presented in the square brackets. Column 1 and 2 report the marginal effects. The dependent variable in column 1 is whether the woman experienced intimate partner violence (IPV), while in column 2, the count of incidents of spousal violence. Levels of significance: $p < 0.01^{***}$ and $p < 0.05^{**}$.

Possible Mechanisms

1. Pollution has a **negative** impacts on output through labor supply and productivity
    - **Labor supply** responses to pollution in Peru [Aragón et al. 2017], in Mexico [Hanna & Olivia 2015], and an increase in **sick days** in Spain [Holub et al. 2021]
    - Effects of pollution on **worker productivity** in U.S. [Graff Zivin & Neidell 2012; Chang et al. 2016], in China [Chang et al. 2019], and in India [Adhvaryu et al. 2019; Batheja et al. 2023; Merfeld 2023]

2. Effects of pollution on **aggressive behavior** through neuroinflammation and reduced serotonin production
    - **Less time spent outside** on days with higher pollution levels in India [Jafarov et al. 2023]

Concluding Remarks

- **Key findings:** A **causal** link between $PM_{2.5}$ and IPV in India
  - **Satisfactory**, **moderate**, and **poor** pollution days have a correlation with the incidence of physical/sexual violence
  - Analysis of heterogeneous impacts suggests that the main results are driven by non-poor households and women who justify wife beating.

- **Policy implications:** Aim to formulate context-relevant **targeted** programs and policy responses to reduce violence against women.
  - Adds to the **social cost** of pollution, which was previously absent from the true cost of pollution.
  - Spark a greater interest in **environmental regulations**

Please reach out with comments/questions

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Round four of the Demographic and Health Survey (2015-2016)

Year (1)	Observations (2)	Villages (3)	Districts (4)
2015	27,713	4,406	328
2016	29,265	4,819	310
Total	**56,978**	**9,218**	**633**

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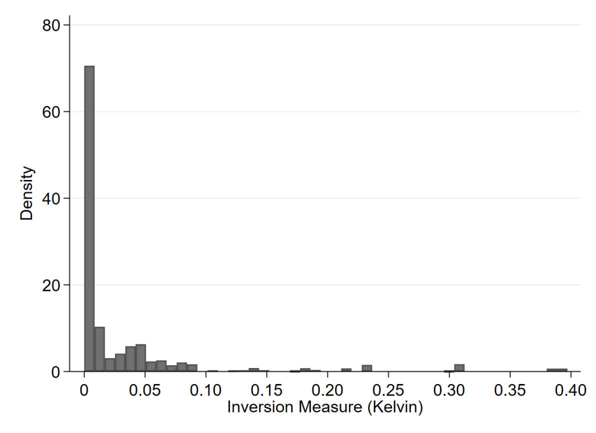
Distribution of Thermal Inversions



$$\text{Daily Inversion}_{i(c)} = \begin{cases} |\theta_{i(c)}|, & \text{if } \theta_{i(c)} < 0 \\ 0, & \text{if } \theta_{i(c)} > 0 \end{cases}$$

$$\text{where } \theta_{i(c)} = T_{i(c)}^{1000hpa} - T_{i(c)}^{925hpa}$$

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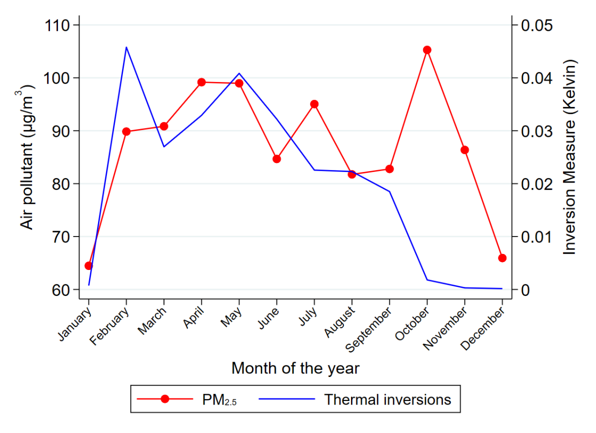
Time Trend of $PM_{2.5}$ and Thermal Inversions



- In the interview month, the figure shows the average $PM_{2.5}$ and the continuous difference in air temperature in absolute terms over the past 12 months

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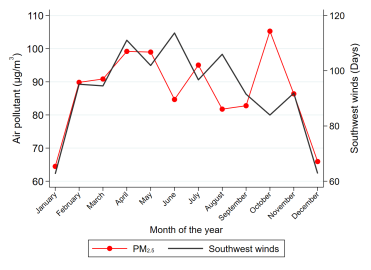
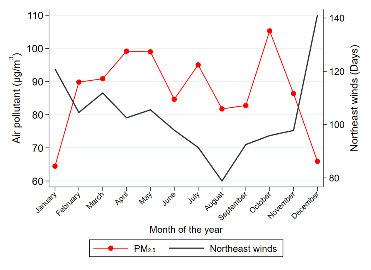
Time Trend of $PM_{2.5}$ and Monsoon Winds



(a) Southwest winds



(b) Northeast winds

- In the interview month, the figure displays the average $PM_{2.5}$ and monsoon winds days in the past 12 months
- India receives southwest monsoon winds in summer and northeast monsoon winds in winter

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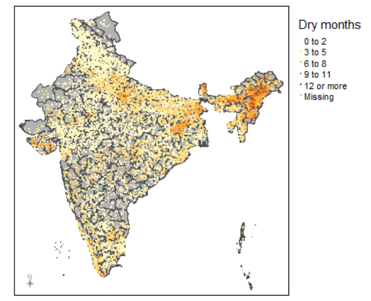
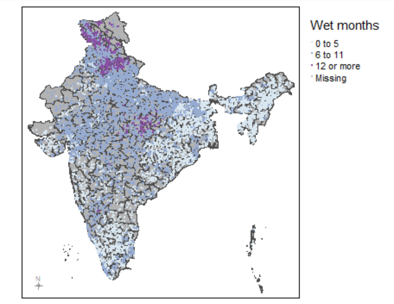
Rainfall Variablility



(a) Number of dry months



(b) Number of wet months

$$\text{Dry months}_i = \begin{cases} 1, & \text{if } r_i^m < \bar{r_i} - \sigma_i \\ 0, & \text{if otherwise} \end{cases}$$

$$\text{Wet months}_i = \begin{cases} 1, & \text{if } r_i^m > \bar{r_i} + \sigma_i \\ 0, & \text{if otherwise} \end{cases}$$

Summary statistics of rainfall variability

	Observations	Mean	SD	Min	Max
Number of dry months	56,825	2.95	2.19	0	14
Number of wet months	56,825	6.59	3.00	0	18

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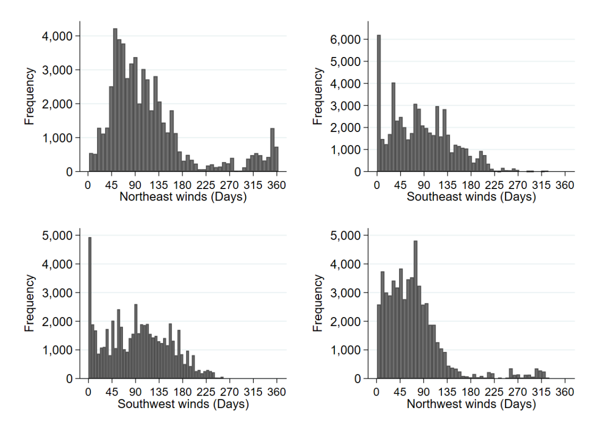
Distribution of Wind Directions



- Number of days during the past 12 months when the wind was blowing at midnight in the direction of the NE($0° - 90°$), SE($90° - 180°$), SW($180° - 270°$), and NW($270° - 360°$)

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Correlation Matrix of Coefficients of OLS Model

Pollutants	$PM_{2.5}$	Ozone	NO_2	CO	SO_2
$PM_{2.5}$	1				
Ozone	0.16	1			
NO_2	-0.63	-0.42	1		
CO	0.11	-0.26	-0.27	1	
SO_2	-0.56	-0.43	0.19	-0.45	1

- The correlation matrix is obtained by regressing the IPV on pollutants, controlling for grid-cell-by-month and survey year fixed effects.

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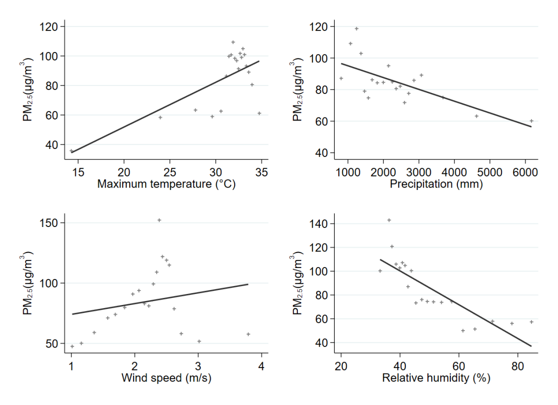
$PM_{2.5}$ and Weather Bin Scatterplot



- Maximum temperature and wind speed have a **positive** correlation with $PM_{2.5}$
- $PM_{2.5}$ is **negatively** correlated with precipitation and relative humidity

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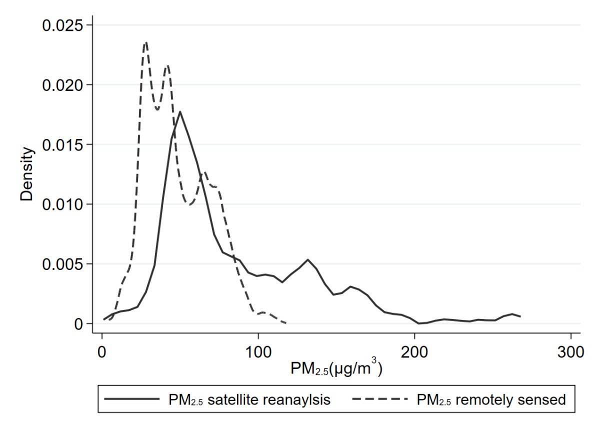
Kernel Density Estimate



- $PM_{2.5}$ distribution from satellite reanalysis is **positively** skewed

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First stage regression

	$PM_{2.5}$
Air temperature inversion	0.013
	(0.012)
NE winds	0.319***
	(0.121)
SW winds	0.264***
	(0.099)
NW winds	0.230
	(0.190)
Controls	Yes
Grid-cell x month FEs	Yes
Grid-cell x state FEs	Yes
Survey year FEs	Yes
Observations	56,806
F stat (K-P)	17.91

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First stage regression

	$PM_{2.5}$
Air temperature inversion	0.013
	(0.011)
NE winds	0.348**
	(0.136)
SW winds	0.263***
	(0.097)
NW winds	0.267
	(0.193)
Controls	Yes
Grid-cell x month FEs	Yes
Grid-cell x state FEs	Yes
Survey year FEs	Yes
Observations	56,806
F stat	104.56

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Descriptive Statistics on Intimate Partner Violence (N = 56,978)

	Mean	SD	Min	Max
Physical/sexual violence	0.24	0.43	0	1
Physical violence	0.23	0.42	0	1
Severe physical violence	0.07	0.25	0	1
Sexual violence	0.06	0.23	0	1

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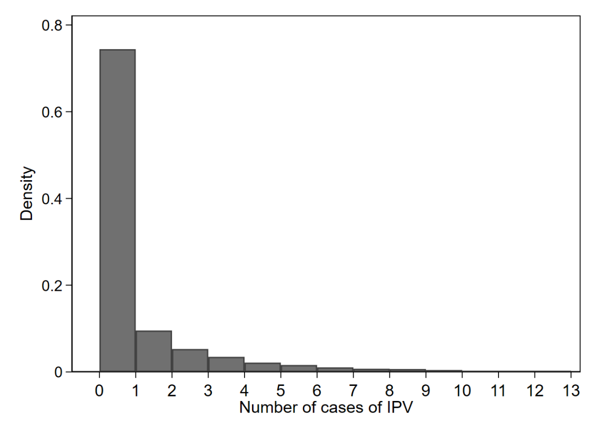
Distribution of cases of IPV



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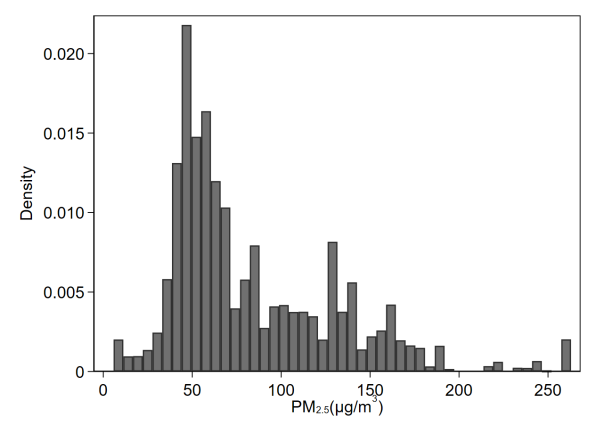
Distribution of $PM_{2.5}$



Summary statistics of $PM_{2.5}$

	Observations	Mean	SD	Min	Max
$PM_{2.5}(\mu g/m^3)$	56,978	83.99	47.77	5.80	262.93

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Sensitivity Checks

Dependent variable: Incidence of IPV (0/1)	Coef.	SE
Panel A: Alternative Instruments		
Air temperature inversion	0.003	0.085
Number of inversion	0.058	0.120
Wind directions	0.028**	0.013
Observations	56,806	
Estimates	IV	

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