Is air pollution increasing in poorer localities of Mexico? Evidence from PM 2.5 satellite data

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ONLINE APPENDIX

Table A1. Summary statistics

Variables	Obs.	Mean	Std. Dev.	Min.	Max.
LOCALIDAD DATA					
Annual PM 2.5	1,424,309	11.62	5.10	0.20	30.90
Log PM 2.5	1,424,309	2.34	0.50	-1.61	3.43
Social Lag Index	1,424,309	-0.05	0.97	-3.19	3.79
Marginalization Index	1,084,975	0.01	1.03	-3.38	8.35
Indigenous population	1,424,269	18.64	35.06	0.00	100.00
% illiterate population, over 15	1,424,309	21.06	16.69	0.00	100.00
% no schooling, 6-14 yrs.	1,424,309	11.42	17.59	0.00	100.00
% incomplete primary education, >15	1,424,309	76.31	18.04	0.00	100.00
% without health access	1,424,309	63.17	32.64	0.00	100.00
% houses with mud floors	1,424,309	33.78	32.83	0.00	100.00
% houses without toilet	1,424,309	31.11	32.37	0.00	100.00
% houses without drains	1,424,309	52.62	37.47	0.00	100.00
% houses without piped water	1,424,309	49.86	41.96	0.00	100.00
% houses without electricity	1,424,309	22.22	34.08	0.00	100.00
% houses without refrigerator	1,424,309	56.46	35.05	0.00	100.00
% houses without washer	1,424,309	72.52	29.30	0.00	100.00
MUNICIPALITY DATA					
Annual PM 2.5	32,415	12.34	5.68	1.10	30.70
Log PM 2.5	32,415	2.39	0.52	0.10	3.42
Social Lag Index	32,415	-0.10	0.95	-2.38	4.50
Marginalization Index	32,415	-0.09	0.97	-2.45	3.95
Indigenous population	32,415	21.09	32.87	0.00	100.00
Voter turnout (%)	32,415	54.62	12.14	0.00	100.00
Population density (‘000/sq km)	32,415	0.29	1.22	0.00	19.49
Manufacturing (%)	32,415	19.48	16.27	2.94	100.00
Annual average temperature ($°C$)	32,415	20.53	3.05	13.73	27.64
Annual cum. precipitation (mm)	32,415	1010.69	546.85	19.61	4305.73
% illiterate population, over 15	32,415	15.52	10.40	0.56	74.88
% no schooling, 6-14 yrs.	32,415	7.21	4.36	0.00	56.21
% incomplete primary education, >15	32,415	64.10	15.23	9.63	98.45
% without health access	32,415	59.11	24.95	1.28	99.73
% houses with mud floors	32,415	20.62	19.90	0.00	97.67
% houses without toilet	32,415	15.49	14.40	0.00	84.65
% houses without drains	32,415	32.09	26.94	0.00	100.00
% houses without piped water	32,415	21.37	20.05	0.00	99.83
% houses without electricity	32,415	7.05	8.60	0.00	87.36
% houses without refrigerator	32,415	43.58	25.70	2.13	99.80
% houses without washer	32,415	60.39	25.23	6.16	100.00

Notes: PM2.5 and weather data are from 2001 to 2015; data on socioeconomic status are from the census years 2000, 2005, and 2010.

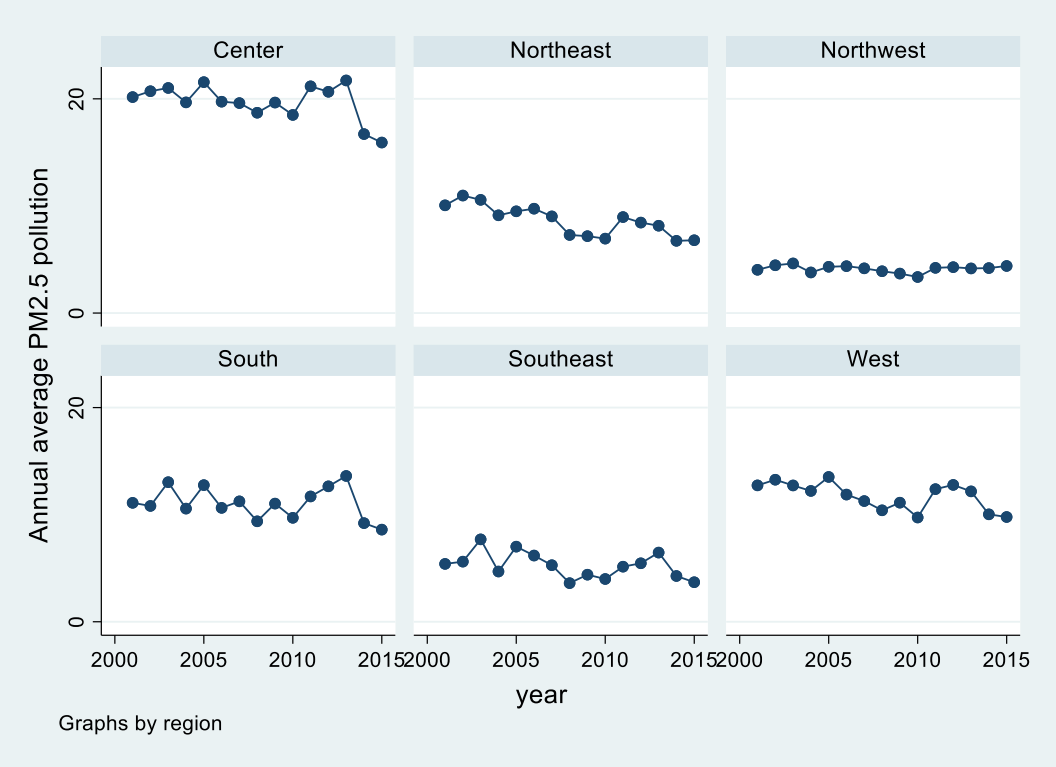

Figure A1. Annual PM2.5 pollution by region, 2001-2015.

Note: The regions are Northeast (Coahuila, Nuevo Leon, Tamaulipas, Chihuahua, Durango, Zacatecas, and San Luis Potosi); Northwest (Baja California, Baja California Sur, Sinaloa, Sonora); West (Aguascalientes, Colima, Guanajuato, Jalisco, Michoacan, Nayarit, Queretaro); Center (Distrito Federal, Mexico, Hidalgo, Morelos, Puebla, Tlaxcala); South (Guerrero, Oaxaca, Chiapas, Veracruz); and Southeast (Campeche, Quintana Roo, Tabasco, Yucatan).

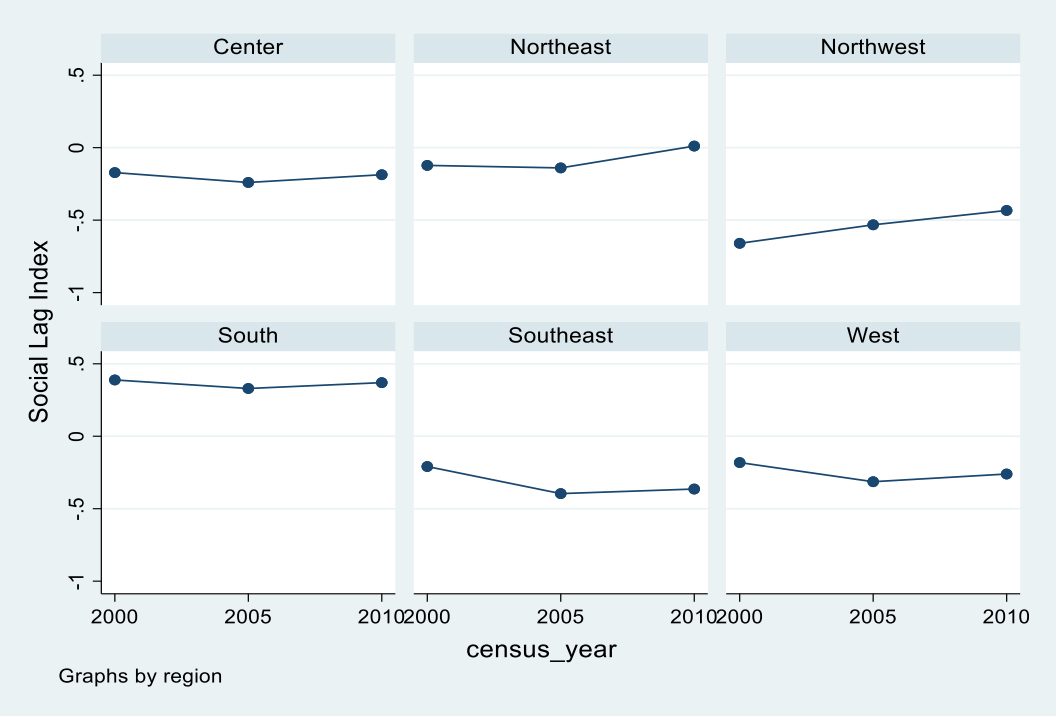

Figure A2. Average Social Lag Index, 2000, 2005, and 2010, by region.

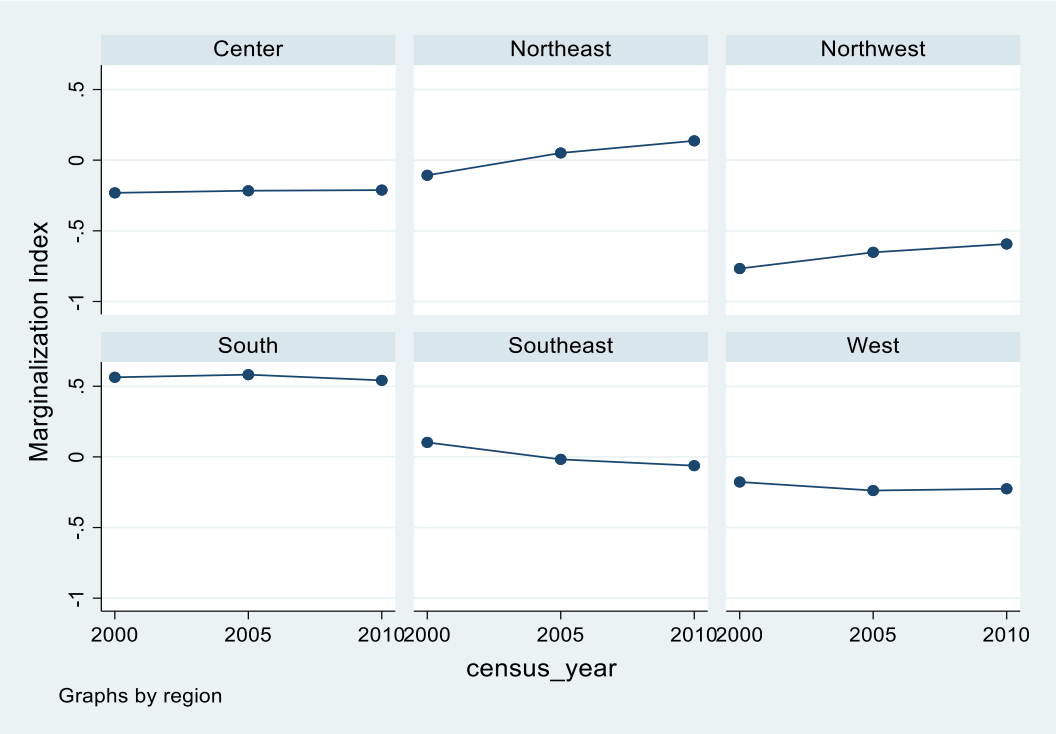

Figure A3. Average Marginalization Index, 2000, 2005, and 2010, by region.

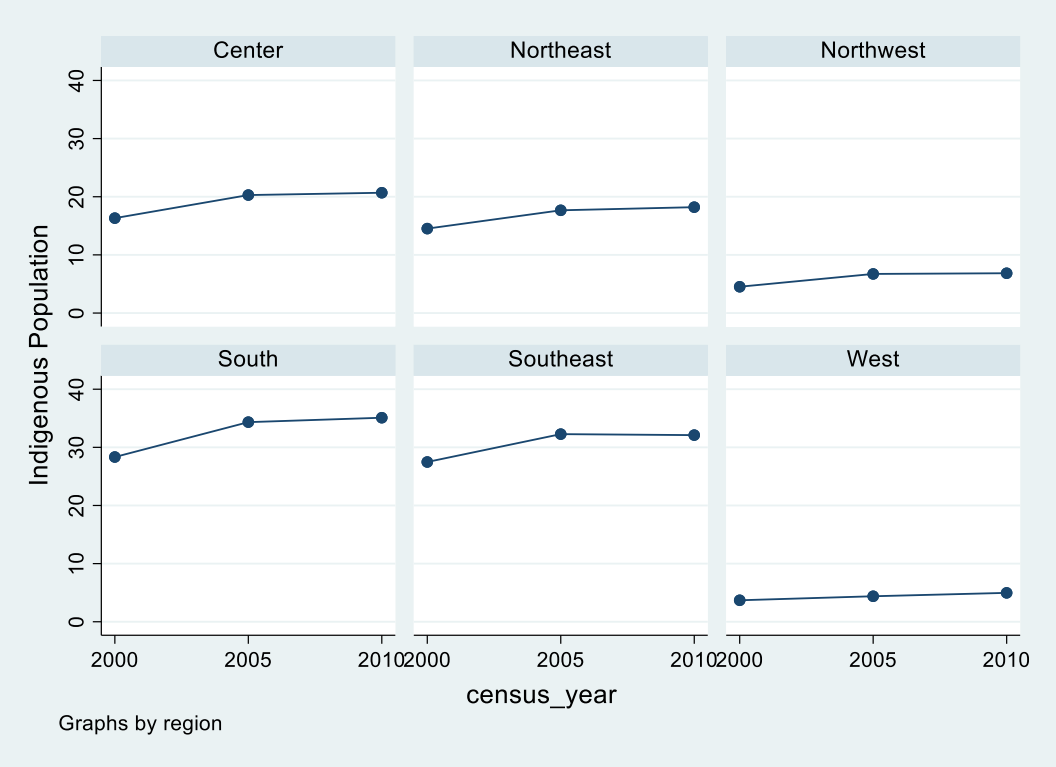

Figure A4. Average indigenous population, 2000, 2005, and 2010, by region.

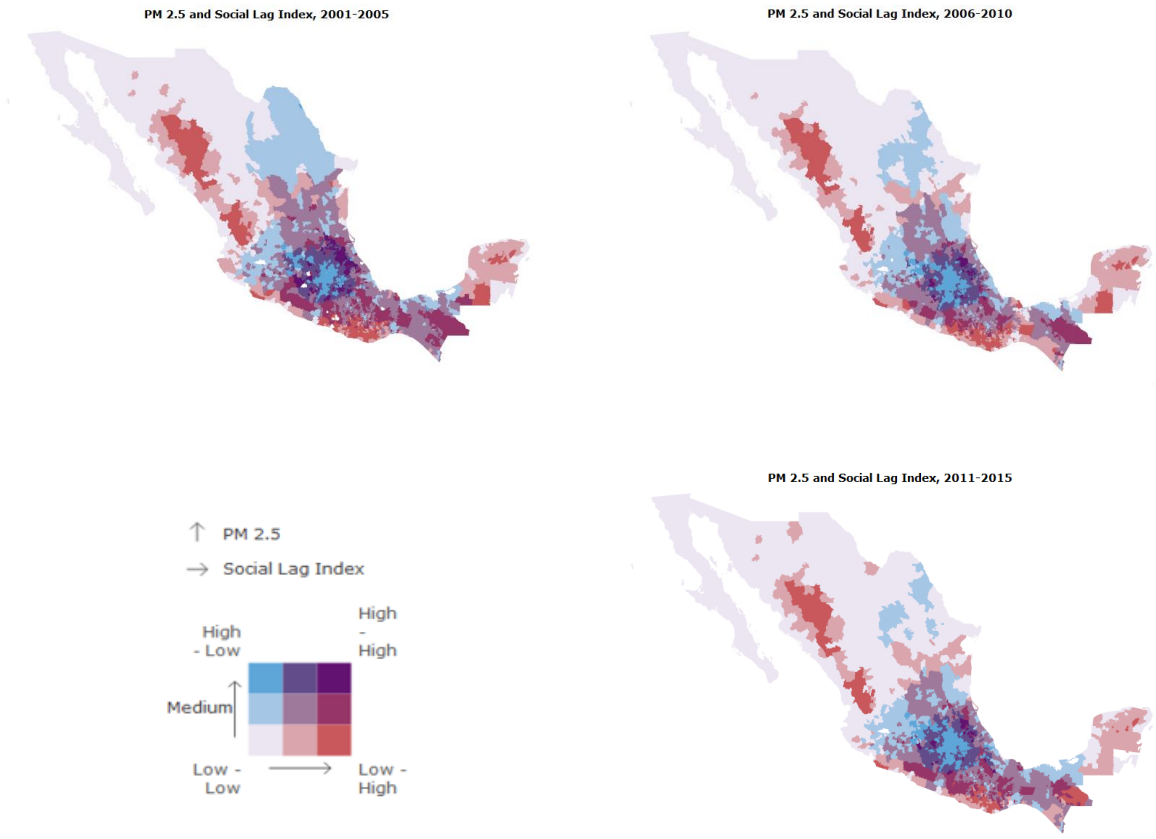

Figure A5. Spatial relationships between PM2.5 and the Social Lag Index.

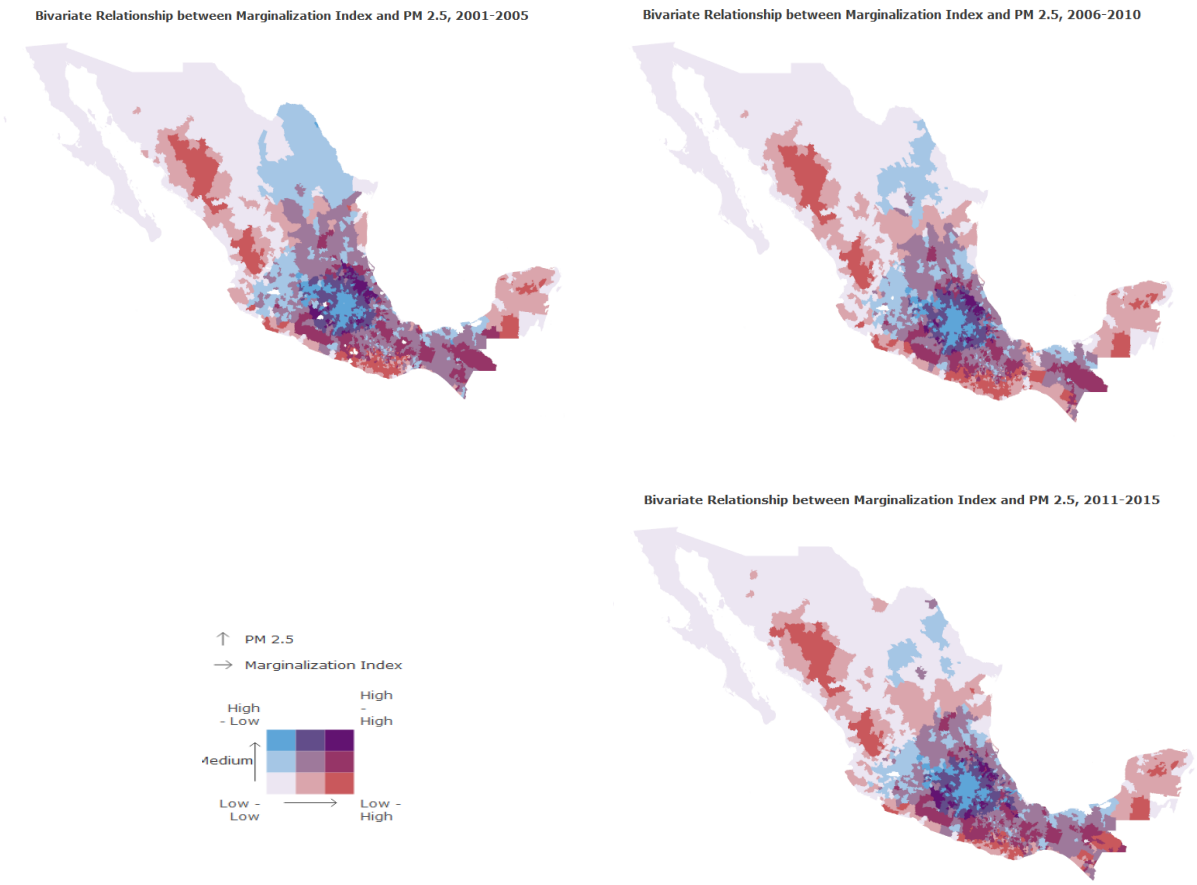

Figure A6. Spatial relationships between PM2.5 and the Marginalization Index.

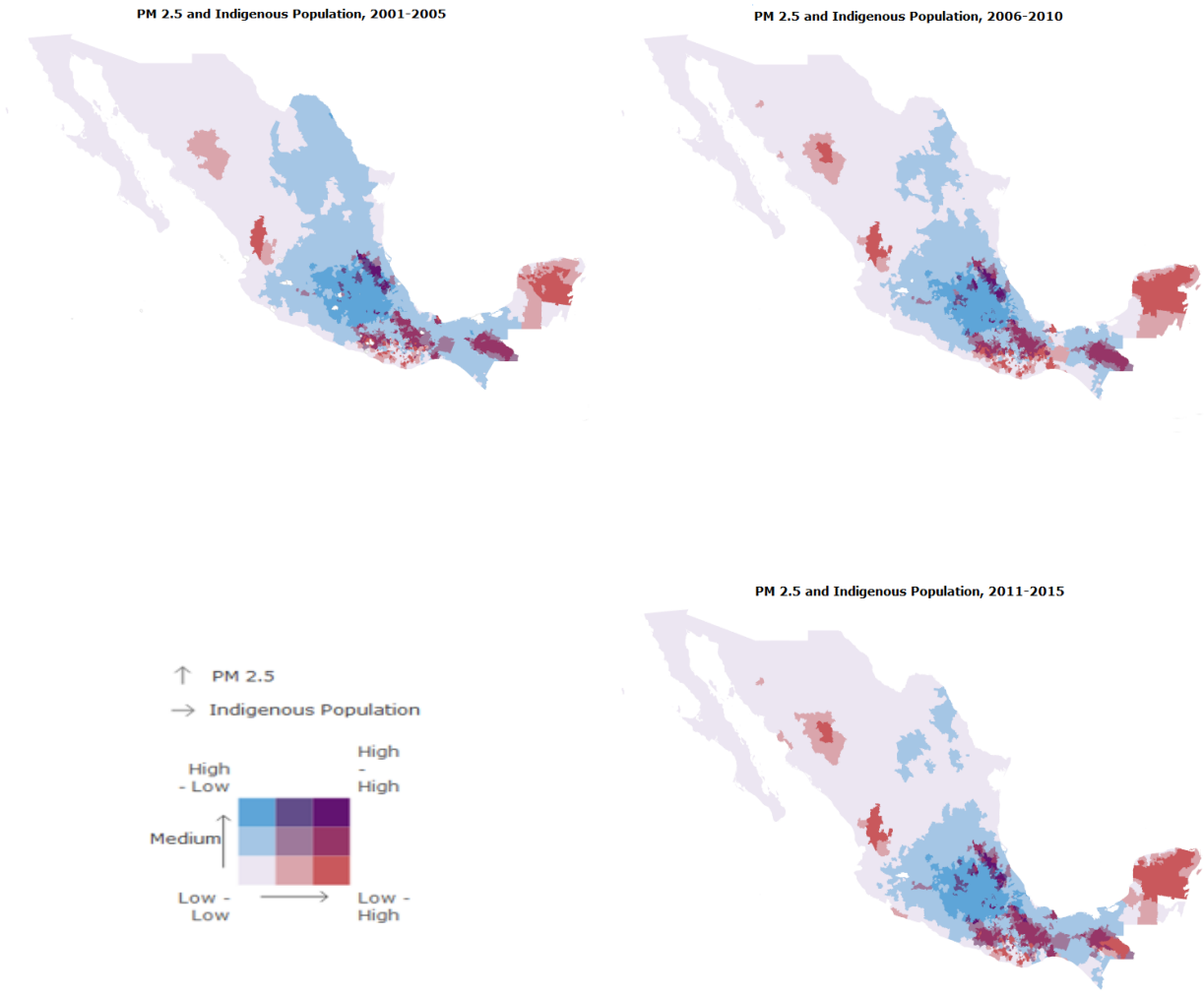

Figure A7. Spatial relationships between PM2.5 and indigenous population.

Regional results and decomposition analyses

In this section, we report robustness of the main results by estimating the model only for the central, and southern and southeast regions of the country. The central region includes Mexico City and its surrounding states that attract a lot of rapid urbanization and its associated sources of pollution from vehicles and construction activities. The surrounding states have seen increased concentration of heavily polluting industries following increased pressure on the Mexico City government to control ozone and PM levels within the metropolitan region. In general, these states are also poorer in socioeconomic status. The southern and southeastern regions support the highest concentration of indigenous populations. We report the results of the main model for only these two regions. Evidence on disproportionate burden of pollution based on socioeconomic status in the regions with highest shares of indigenous population, would make the racial discrimination channel weaker.

Table A2 shows that poor socioeconomic status is linked to higher PM pollution in the most polluted states of the country. As mentioned before these areas suffer from the highest urban pollution as well as the highest industrial concentrations in the country. Indigenous population on the other hand is associated with lower pollution levels. We infer that in these highly urban or industrial corridors, a higher proportion of indigenous populations live in mostly rural areas. Voter turnout switches sign to positive in contrast to the results from the entire country possibly linked to local labor force concentrations with civic engagement, but local employment benefits outweighing costs of exposure to higher pollution.

Table A2. Central and Southern and Southeastern region results on air pollution and socioeconomic status

Central region	Social Lag Index		Marginalization Index	
DEP VAR: log PM2.5	No controls (1)	Full model (2)	No controls (1)	Full model (2)
Socioeconomic indicator	0.00308	0.00361	0.00938	0.00996
	(0.00073)	(0.00074)	(0.00077)	(0.00078)
Indigenous population	-0.00035	-0.00034	-0.00035	-0.00035
	(0.00003)	(0.00003)	(0.00003)	(0.00003)
Voter turnout		0.00116		0.00117
		(0.00004)		(0.00004)
Population density		0.00194		0.00218
		(0.00141)		(0.00139)
Manufacturing		0.00007		0.00009
		(0.00005)		(0.00005)
R^2	0.79	0.80	0.79	0.80
N	212,290	208,915	220,140	216,610
Southern and Southeastern regions	Social Lag Index		Marginalization Index	
DEP VAR: log PM2.5	No controls (1)	Full model (2)	No controls (1)	Full model (2)
Socioeconomic indicator	0.00557	0.00253	0.01387	0.01163
	(0.00078)	(0.00079)	(0.00081)	(0.00083)
Indigenous population	-0.00031	-0.00031	-0.00007	-0.00011
	(0.00003)	(0.00003)	(0.00003)	(0.00003)
Voter turnout		-0.00316		-0.00223
		(0.00005)		(0.00006)
Population density		-0.17743		-0.31518
		(0.01733)		(0.04857)
Manufacturing		-0.00067		-0.00010
		(0.00005)		(0.00005)
R^2	0.72	0.73	0.74	0.75
N	570,140	519,295	355,275	317,145

Notes: Clustered standard errors in parentheses.

In regions with high indigenous populations, we find consistent evidence of poorer socioeconomic status linked to higher PM pollution. Evidence on racial discrimination is not found

as localities with a higher proportion of indigenous population are exposed to lower pollution levels. We infer concentration of high indigenous pockets living in rural areas in these states. Voter turnout, share of manufacturing, and population density are all linked to lower pollution exposures in these states. We infer positive evidence on political engagement, less pollution in highly dense municipalities, and less pollution due to concentration of industries in corridors.

To gain a better understanding of the magnitude of environmental inequality we undertake a slightly different analysis. Instead of focusing on the summary measure of social lag index or the marginalization index we include the underlying socioeconomic variables that are used to calculate the indices. This exercise identifies the dimensions of socioeconomic exclusion that are significant factors in determining higher exposure to PM2.5 pollution. At the same time, it helps us interpret standard deviation changes in the social lag index or marginalization index to changes in the socioeconomic indicators that are associated with various dimensions of poverty.

Four of the seven census variables that are common to both the indices, are significant drivers of the positive pollution-poverty relationship. A one standard deviation increase in the percentage of population without primary education would lead to higher PM levels by 0.005% annually. The magnitude is even lower using the sample used to construct the marginalization index (0.003%). A one standard deviation increase in the percentage of population without piped water leads to 0.003% higher PM levels. A one standard deviation increase in the percentage of houses without drainage leads to 0.001% higher PM levels. A one standard deviation increase in the percentage of houses without electricity leads to 0.002% higher PM levels. For the marginalization index sample, the coefficient is slightly higher at 0.003%. Among the variables used to construct the social lag index, the percentage of the 6 to 14 year old population not attending school and the percentage of the population without access to health services also exert

a significant influence on the high pollution-poverty relationship. A one standard deviation increase in the 6 to 14 year olds that do not attend school leads to 0.001% higher PM levels. A one standard deviation increase in the percentage without access to health services leads to 0.003% higher PM levels.

Overall, we can see that a one standard deviation change in either the social lag or the marginalization index implies substantial changes in the underlying census variables, implying that our socioeconomic indicators coefficients are economically meaningful but small in magnitude. Policies directed towards improving education, basic services, and health can improve environmental equity due to higher exposure to air pollution by the disadvantaged communities. However, we do not find consistent results for all the census variables, highlighting the usefulness of a summary indicator capturing the poverty or marginalization status of the affected community.

Table A3. Decomposing environmental inequity

	Social Lag Index		Marginalization Index	
DEP VAR:	No controls	Full model	No controls	Full model
log PM2.5	(1)	(2)	(1)	(2)
% illiterate population, over 15	-0.00026	-0.00025	-0.00030	-0.00030
	(0.00002)	(0.00002)	(0.00003)	(0.00003)
% incomplete primary education, >15	0.00028	0.00026	0.00019	0.00019
	(0.00002)	(0.00002)	(0.00002)	(0.00002)
% houses with mud floors	-0.00006	-0.00013	-0.00007	-0.00007
	(0.00001)	(0.00001)	(0.00001)	(0.00001)
% houses without piped water	0.00006	0.00006	0.00006	0.00006
	(0.00001)	(0.00001)	(0.00001)	(0.00001)
% houses without drains	0.00002	0.00003	0.00008	0.00003
	(0.00001)	(0.00001)	(0.00001)	(0.00001)
% houses without electricity	0.00006	0.00005	0.00003	0.00008
	(0.00001)	(0.00001)	(0.00001)	(0.00001)
% houses without refrigerator	0.00006	0.00005	-0.00016	-0.00016
	(0.00001)	(0.00001)	(0.00002)	(0.00002)
% houses without washer	-0.00014	-0.00009		
	(0.00002)	(0.00002)		
% no schooling, 6-14 yrs.	0.00006	0.00005		
	(0.00001)	(0.00001)		
% without health access	0.00014	0.00010		
	(0.00001)	(0.00001)		
% houses without toilet	-0.00004	-0.00005		
	(0.00001)	(0.00001)		
% houses with overcrowding			-0.01183	-0.01183
			(0.00046)	(0.00046)
Indigenous population	0.00012	0.00014	0.00028	0.00025
	(0.00002)	(0.00002)	(0.00002)	(0.00002)
Voter turnout		-0.00213		-0.00162
		(0.00003)		(0.00003)
Population density		-0.02066		0.02769
		(0.00353)		(0.00317)
Manufacturing		-0.00078		-0.00062
		(0.00003)		(0.00003)
R^2	0.59	0.59	0.62	0.63
N	1,507,229	1,424,269	1,063,552	1,003,053

Notes: Clustered standard errors in parentheses.