Coal Plants, Air Pollution and Anemia: Evidence from India[*]

Gaurav Datt[a], Pushkar Maitra[b], Nidhiya Menon[c] and Ranjan Ray[b]

with Sagnik Dey[d] and Sourangsu Chowdhury[d]

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Abstract

This paper examines the impact of pollution from coal-fired power units on the anemic status of children and women in India. While the number of coal units in the district at the time of birth significantly increases the incidence of anemia in young children, it has weaker effects on anemia among women. *In utero* exposure also matters for child anemia. Impacts are driven by the increase in $PM_{2.5}$ pollution from coal-fired units. Anemia is established as a significant health cost of coal-fired power generation in rapidly growing economies that use this fuel source to meet increasing energy demands.

Key Words: Anemia, Coal-power Units, $PM_{2.5}$, Air Pollution, Children, Women, India

JEL Codes: I15, Q32, Q53, O12

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[a]: Center for Development Economics and Sustainability, Monash University, Australia.
[b]: Department of Economics, Monash University Australia.
[c]: Department of Economics, Brandeis University, USA.
[d]: Center for Atmospheric Sciences, Indian Institute of Technology Delhi, India.

1. Introduction

The detrimental impacts of air pollution on various measures of health is now fairly well documented (see, for example, Zivin and Neidell (2013) and Greenstone and Jack (2015)). While the early evidence came from developed countries, recent literature using data from developing countries paints an even bleaker picture. This is particularly true of India. According to the WHO global air pollution data base, of the 20 most polluted cities in the world over the period 2008—2017, 13 are in India (16 are in the Indian sub-continent). Pollution is widespread and growing as is its health and economic burden. ICMR (2020) estimates that almost 18% of deaths in India in 2019 can be attributable to pollution, and premature deaths and morbidity attributable to pollution resulted in lost output equivalent to 1.36% of India's GDP. Additionally, as the country has grown economically, demand for energy has grown. Like many other developing countries, India has also addressed the need for energy in large measure by building additional capacity in coal-fired power generation, adding new units to existing power plants that use coal as the primary fuel (henceforth coal-power units). Indeed, the growth of coal-based power has out-run the growth of any other form of electricity generation, and coal is now the primary fuel for almost 75 percent all electricity generated in India (Ali (2018)).[1] However, coal-power units in India often do not meet emission standards or other guidelines that are commonplace in the developed world. This has exacerbated the health, economic and environmental consequences of relying on this mode of energy generation. For example, Cropper *et al*. (2020) estimates that coal-power plants that existed as of 2018 in India were responsible for approximately 78,000 premature deaths (annually) associated with $PM_{2.5}$. The true externality costs are likely to be even higher given that morbidity and damage to environmental systems and

[1] Coal generates up to 38 percent of electricity globally and is the largest source of fuel for electricity production worldwide (see https://www.worldcoal.org/coal/uses-coal/coal-electricity. Accessed on June 10, 2020). Coal-fired power plants constitute a large majority of all emissions related to energy production. For instance, 46 percent of carbon dioxide emissions worldwide result from the burning of coal, and coal-fired plants in the electricity sector are responsible for 75 percent of total greenhouse gas emissions globally (see https://endcoal.org/climate-change/. Accessed on June 10, 2020).

agriculture are not taken into account (Cropper *et al.* 2020).

Our paper investigates the impact of air pollution generated by coal-based power units on the anemic status of young children and prime-age women in a developing country context, and offers insights into the mechanisms through which exposure to coal exacerbates this important health condition. While the impact of coal on other health outcomes has been studied in the literature, the distinguishing feature of this paper is its focus on anemia.

The most common form of anemia is iron-deficiency (ID) anemia, which is our focus in this paper. An ID-anemic (henceforth anemic) individual does not have enough hemoglobin, a protein that gives blood its red color and that enables red blood cells to carry oxygen to other cells in the body. Consequences of anemia include lack of energy, impaired growth, and a weakened immune system, which decreases the body's ability to prevent infections. Further, anemia retards cognitive abilities and performance. In children, this often leads to attention problems, delays in reading ability, and poor school performance. Macroeconomic estimates suggest that the average impact of iron deficiency anemia, through both physical and cognitive channels, could be as large as 4 percent of GDP across ten developing countries including Bangladesh, India and Pakistan (Horton and Ross (2003)). Evidence establishes iron deficiency anemia to be a leading cause of premature deaths in pregnant women (Khaskheli *et al.* (2016)), and an important determinant of child mortality (Scott *et al.* (2014)).[2] Through its impact on health and educational outcomes, anemia could also play a role in the transmission of poverty across generations (Bobonis *et al.* (2006)).

Anemia among children and adults is a major health problem in India. According to the World Bank's latest figures, the global anemia rates in 2016 for children under 5 years and for women in the reproductive age, 15—49 years, were 42 percent and 33 percent respectively. The

[2] Scott *et al.* (2014) argues that approximately 1.8 million deaths in children aged 28 days to five years could be avoided each year by increasing Hb in these children by 1 g/dL.

corresponding figures for India were 59 percent and 54 percent, underlining the significantly greater severity of this problem in the Indian context. Indeed, anemia rates for India have exceeded the world average since 1900.[3] Clearly, Indian children and women have missed the progress made globally over more than a century.

Our primary interest is in understanding the detrimental effects of coal-fired power generation and the associated air pollution on anemia. Our data on power plants reveal that the increase in total capacity in recent years has primarily come from additions to the capacity of existing plants through the establishment of new *units*. Hence, we focus on units within plants and not plants *per se* in this study. We leverage the spatial variation in the presence of coal units at a point in time and the change in the spatial variation in coal units over a specific period to examine the effects of coal induced air pollution on the anemic status of children and women in India.

Using the most recent Demographic and Health Survey (DHS) data merged with information on the location and year of commission of all power units in India, we find that 50.2 percent of young children are exposed to at least one coal unit at the time of birth (month and year of birth), and approximately 56.6 percent of adult women are exposed to one or more coal units at the time of the survey. Turning to results, for children aged 0—5 the number of coal units in the district at the time of birth is causally associated with a significant increase in the likelihood of being anemic.[4] These results are mildly stronger for girls, those born to less educated mothers, and those residing in rural areas. Additionally, *cumulative* exposure to coal units is also associated with significant increases in the likelihood of a child aged 0—5 being anemic. We conduct a number of specification and falsification tests and control for a range of other factors that could potentially affect the relationship (these

[3] See https://data.worldbank.org/indicator/SH.ANM.CHLD.ZS on how the world average of anemic rate for children has evolved over the period, 1990—2015 and https://data.worldbank.org/indicator/SH.ANM.ALLW.ZS for the corresponding averages for women.
[4] An individual is characterized as anemic if the altitude adjusted hemoglobin count (HBA) is less than a critical threshold. This threshold is different for children and adults. More details are presented in Section 2.

include rainfall, temperature, district prosperity as measured by night-lights and a wide range of child, mother and household attributes) and demonstrate that the results are specifically attributable to coal. Analyzing periods that precede birth, we find that exposure *in utero* also matters. Children who suffered environmental insults due to mothers' residing in districts with coal units in the first or second trimester are more likely to be anemic. For women aged 18—49 years, our results show that the number of coal units in the district at the time of the survey significantly increases their likelihood of being mildly anemic.

Turning to mechanisms, we show that emissions from coal units are strongly and positively correlated with an increase in localized incidence of particulate matter of size 2.5 micrometers ($PM_{2.5}$), one of the most harmful of airborne pollutants as it can be lodged in the lungs and can cause long-term health problems like asthma and chronic lung disease.[5] We find that the rise in average $PM_{2.5}$ concentration associated with the increase in the number of coal units is the primary channel for the adverse consequences on anemia.[6] Taken together, our findings underline that the expedient generation of coal-fired power is occurring at the significant expense of children's and women's health in India.

Our paper adds to the growing literature on the harmful health consequences of coal on vulnerable populations. This is a relatively well researched topic in the developed world (see Honda *et al.* (2017) and Amster and Levy (2019) for an extensive review of this literature from an epidemiological point of view). This literature concludes that exposure to emissions from coal-fired

[5] In terms of population-weighted exposure to ambient $PM_{2.5}$ (defined as the average level of exposure of a nation's population to concentrations of suspended particles measuring less than 2.5 microns in aerodynamic diameter) India ranked 4th in the world in 2017 with almost 91 percent of the population exposed to $PM_{2.5}$ (Cohen *et al.* (2017)).

[6] Lancet (2018), in a special report, argues that global population weighted $PM_{2.5}$ exposure has increased by 11.2% since and that 'coal-power is responsible for more than 90% of $PM_{2.5}$ emissions, much more than its corresponding contributions to sulphur dioxide (SO_2) and nitric oxide (NO_X) emissions. See also Somanathan *et al.* (2020) who estimate the marginal contribution of an additional unit of coal to $PM_{2.5}$ emissions. They show that on average, increases in coal burnt raises pollution levels up to 900 km away from a power plant.

power units has strong effects on health. In the context of developing countries, the literature has focused on the adverse impacts of ambient air pollution on health arising from coal by specifically focusing on the effects of exposure to emissions from coal-fired power units on general health indicators, morbidity and mortality. Relevant studies include Gupta and Spears (2017), Gao *et al.* (2018), Morales-Ancajima *et al.* (2019), Barrows *et al.* (2019), Vyas (2019) and ICMR (2020).[7] The medical literature notes that ambient air pollution increases the likelihood of anemia. Among children in particular, such pollution reduces the formation of red blood cells by inhibiting enzymes. Further, air pollutants break down cell membranes and interfere with cell metabolism thus reducing cell survival (Nikolic *et al.* (2008)). Among the elderly, there is direct evidence that $PM_{2.5}$ reduces levels of hemoglobin and increases levels of c-reactive proteins that are markers of inflammation that retard the absorption of iron by the body (Elbarbary *et al.* (2019)). The literature on the effect of air pollution on health in developing countries has also examined other polluting sources or triggers like regulatory policies or agricultural and forest fires. See, for example, Jayachandran (2009), Greenstone and Hanna (2014), Rangel and Vogl (2016), and Singh *et al.* (2019). However, to the best of our knowledge, ours is the first study to use the tools of economics to evaluate the impact of pollution generated from coal on the anemic status of children and women in a developing country.

2. Data

This paper uses data from a number of different sources. Our data on anemia prevalence and individual and household variables of interest come from the 4th National Family Health Survey (NFHS-4) for India from 2015—2016. The location of power units in India as of 2016 is obtained from the Central Electricity Authority (Ministry of Power) of India (GOI (2018)). The data on

[7] Gao *et al.* (2018) investigates the impact of power generation outcomes on ambient $PM_{2.5}$ pollution and human health. Widening the sphere of the enquiry from morbidity to mortality (that we do not consider), Lelieveld *et al.* (2015), Ghude *et al.* (2016) and ICMR (2020) all examine the contribution of outdoor air pollution sources to pre-mature mortality.

$PM_{2.5}$ at the district-month-year level from 2001 to 2015 are obtained from satellite measurement estimates generated from aerosol optical depth information collected using techniques developed in Dey *et al.* (2012). We describe our data components in detail below.

Measures of anemia and control variables from NFHS-4

Our main outcome variable is anemia, which is defined as altitude adjusted hemoglobin concentration (HBA) below a certain specific threshold.[8] Anemia in children six months through 60 months of age is defined as HBA below 11.0 g/dl. While anemia has similar debilitating impacts on adult women, the anemia threshold is higher: an adult woman is anemic if HBA is below 12.0 g/dl.[9] Table 1 presents the average levels of HBA and anemia prevalence rates for the different sub-groups that we focus on: children aged 0—5 years and adult women (aged 18—49). Close to 3 out of 5 children aged 0—5 are anemic. The corresponding rate is 54% for adult women. We also distinguish between mild anemia (HBA of 10.0—10.9 g/dl for children and pregnant women; 10.0—11.9 g/dl for non-pregnant women), moderate anemia (HBA of 7.0—9.9 g/dl for both children and women), and severe anemia (HBA of <7.0 g/dl for both children and women). The majority of children are either moderately or severely anemic. Women are most likely to be mildly anemic. This suggests that while anemia prevails in both age groups, adult women fare marginally better than children, and the severity of anemia weakens with age. This argues for a special focus on child anemia as we do in the bulk of our empirical analysis though we also provide evidence on the anemic status of adult women.

[8] Hemoglobin levels are adjusted for altitude in enumeration areas that are above 1,000 meters and for smoking status, if known, using the CDC formulas (CDC (1989), updated in 1998). This is because people living at high altitudes and smokers have higher levels of hemoglobin as a result of the human body's natural adaptation mechanisms.

[9] The threshold for pregnant women to be categorized as anemic is HBA below 11.0 g/dl. Less than 3% of women in the sample are pregnant. We use different thresholds to categorize women as anemic depending on whether they are pregnant or not. Our results remain unaffected when we drop the pregnant women from the estimation sample. These results are available on request.

Figures 1 and 2 present a graphical depiction of anemia rates for children (aged 0—5) and women (aged 18—49) respectively across India's districts computed using the NFHS data. In both figures, the darker shaded districts represent those with higher anemia rates. There is a remarkable similarity between the two spatial maps of anemia: areas of high (low) female anemia are also those with high (low) rates of child anemia. While this may be due to the hereditary nature of anemia with mother-to-child transmission of iron deficiency and low hemoglobin (which we control for), we hypothesize that it mainly reflects locational factors such as the effects of pollution due to emissions from coal units.

Measures of coal and other power units

Over the last three decades, India has experienced rapid economic growth which has contributed to a substantial increase in electricity demand rising from 388 terra watt hours (TWh) in 2001 to 989 TWh in 2015, an increase of 150 percent (Ali (2018)). Given its cost-effectiveness, the country has built coal-fired power units to meet this demand. The data on power units and capacity obtained from the Central Electricity Authority provide the year of commission of all units generating power (from 1922—2016), the type of these units (thermal, hydro, or nuclear), the main source of fuel for these units (coal, diesel, oil, gas, lignite or naphtha), the capacity of each unit, and the district of location of each unit. We denote thermal units that use coal as their primary fuel source as coal-power units. Figure 3 shows that while total capacity from hydro powered units has exhibited a modest increase over the period from 2000 onwards; total capacity generated from coal-powered units has increased exponentially, especially in the last 10 years. Figure 4 presents the number of additional units (Panel A) and the additional capacity (Panel B) commissioned in each year between 2000 and 2016. It is clear that since 2006, there has been a heavy reliance on additional units and additional capacity from coal. Figure 5 depicts the geographical spread in commissioned units separated by fuel type. Darker shaded districts denote those with at least one power unit of a particular type present in 2000 and 2016. Panel

A shows that there has been a large increase in the number of districts with *at least* one coal-powered unit over the period 2000—2016.[10] A comparison of Panels A with other panels of Figure 5 provides visual confirmation that the increase in the spread of coal units has outweighed the spread of hydro and nuclear power units. Panel A also reveals that in 2016, the Indo-Gangetic Plain recorded the bulk of the coal unit spread during 2000—2016 (also see Taneja *et al.* (2014)). As we note above, approximately 50.2 percent of children 0-5 years are exposed to at least one coal unit at the time of birth, and 56.6 percent of women (18—49 years) are exposed to at least one coal unit at the time of the survey.

Coal-fired power units burn coal to heat water that produces steam, which, in turn, drives the turbines that produce electricity. These units therefore require water and hence are typically situated near sources of water (and near coal deposits). Much of the coal used in generating power in India is domestic coal that is of low quality; it has high ash and moisture content but low sulphur and calorific content. Consequently, Indian coal results in relatively low levels of emissions of sulphur dioxide (SO_2), but high levels of emissions of carbon dioxide (CO_2), nitrogen dioxide (NO_2) and fine particulate matter ($PM_{2.5}$). See Barrows *et al.* (2019).

Measure of $PM_{2.5}$

Figure 6 depicts the concentration of average $PM_{2.5}$ (specifically the natural log of $PM_{2.5}$) across the districts of India.[11] Consistent with the location of coal units (Panel A of Figure 5), the intensity of $PM_{2.5}$ pollution is highest in the northern and eastern regions of the country with some reduction as one proceeds across districts to the center and the south. Pair-wise correlation coefficients affirm a

[10] Figure A1 in the Appendix presents the change in the number of coal units by district during 2000—2016. It shows that while the large majority of districts (85.2 percent) had no change, 12.5 percent had between 1 and 5 additional units, 1.3 percent had between 6 and 10 additional units, and 1 percent had more than 10 additional units.

[11] Although we have these data for the 2001—2015 period by month and year, we have coverage only for 224 districts.

positive and significant relationship between the number of coal units and the natural log of $PM_{2.5}$ in the district at the time of birth (correlation coefficient = 0.17 with p-value < 0.05). Similarly, the pair-wise correlation coefficient between anemia in children aged 0—5 years and the natural log of $PM_{2.5}$ is significant (correlation coefficient = 0.08 with p-value < 0.05).

Summary statistics

Table 2 presents summary statistics of selected demographic variables in our sample for children and women, along with corresponding statistics for the power and pollution-specific variables. Detailed descriptive statistics of demographic variables as well as anemia-related variables in the child and women samples are presented in the Appendix (Tables A1 and A2 respectively). The means and standard deviations for the child sample (aged 0—5) are presented in Panel A of Table 2. The average age of children included in the sample is about 3 years and 52 percent are male. The vast majority (79 percent) of these children were delivered in public sector hospitals. The statistics for the women's sample (Panel B of Table 2) indicate that their average age is about 34 years and average height (a measure of their health endowment) is approximately 152 centimeters. Over 36 percent of the women in these data are uneducated, and only 15 percent report some or completed primary school.

Table 2 also reports summary statistics of the power plant unit and pollutant variables for the samples of children and women. The average number of coal units in the district in the month and year of birth of the child is about 3. While the number of hydro units are comparable to the number of coal units there are significantly fewer nuclear units . The estimates for mean $PM_{2.5}$ ranges from 30—37 micrograms per cubic meter of air, which is almost three times the recommended level.[12]

[12] The US Environmental Protection Agency's standards for a relatively safe level of $PM_{2.5}$ is about 12

The statistics for power plant units in the women's sample in the bottom panel of Table 2 indicates that the average number of coal units in the district in the month and year of survey is about 3.5. Similar to the children's sample, the number of hydro units in the district is higher than the number of nuclear units. Descriptive statistics for total capacity indicate that most capacity is generated from coal, and coal in particular has experienced a significant rise in number of units from 2000 on. The summary statistics on pollutant measures in the women sample are comparable to those in the children sample.

Table 2 also reports statistics for two variables that measure total exposure to coal units *after* birth for children aged 0—5. The first is cumulative exposure to coal units since birth (in years), which conditions on the timing of when new coal units were established in the district after the child's birth (there may be multiple), and how many total years of exposure since birth the child has had to these new coal units. Given variation in the years when units were established in a district since a child's birth, similar-aged children in different districts may have different years of total exposure since birth. Table 2 indicates that the average child has had about 5 coal unit years of exposure since birth. The second variable measuring exposure after birth is a cumulative count of new coal units established in the district after the child's birth year. The mean for this variable is about two.

3. Estimation framework

We construct samples for analysis in the following manner. We match the number of coal units in the district at the time of birth (month and year of birth) of the child to each child aged 0—5 years in the NFHS-4 data. For the *in-utero* estimations, we match the presence of coal units in the district to the three trimester windows of time for each child. Given the low rates of spatial mobility in India (see, for

micrograms per cubic meter of air. Estimates for NO_2 are also relatively large in India (SO_2 appears to be zero in Table 2 because of rounding to three decimal digits).

example, Munshi and Rosenzweig (2009)) we assume that the district of birth is the current district of residence of the child although we do run tests that control for migration. For women's sample, we match the number of coal units in the district at the time of the survey to each woman aged 18—49 years.

We begin by examining the effect of exposure to coal units at the time of birth (month and year of birth) on a child's anemic status. The estimating equation is given by:

$$H_{chmyd} = \beta_0 + \beta_1 Num\ Coal_{myd} + \gamma X_{chd} + \delta Z_{yd} + M_m + Y_y + (M_m \times Y_y) + D_d + \varepsilon_{chmyd} \quad (1)$$

Here H_{chmyd} is the health status of child *c* in household *h*, born in month *m* in year *y* in district *d*. We use either HBA levels or anemic status as the measure of health. $Num\ Coal_{myd}$ is the number of coal units in month *m* and year *y* of birth in district of birth *d*. This is thus a running count of coal units in the district in the month and year in which the child was born. X_{chd} includes a set of child, mother, household and district characteristics. The child characteristics include gender, birth order, whether twin birth, whether the child was nursed, recent illnesses (diarrhea, cough), place of delivery, whether C-section birth, and whether a bed net is used. The mother-specific controls include mother's height, hemoglobin level, whether mother works, mother's age at first birth, age at marriage, highest level of completed schooling, total number of children born, and number of children less than 5 years old in the household. Household-specific characteristics include religion and caste identifiers, type of cooking fuel used, whether the kitchen is located in a separate room of the house, ownership of assets such as radio, television, refrigerator, bicycle, motorcycle, car, telephone, and cell phone, controls for age of the head, gender of the head, household size, type of floor material of the house, wall material of the house, roof material of the house, rural/urban status, access to electricity, type of toilet facility, and the household's primary source of drinking water. Z_{yd} is a set of district specific

time-varying controls given by natural log of night-lights in year of birth *y* and district of birth *d*.[13] In additional specifications, we control for temperature and rainfall in month of birth *m*, in year of birth *y* and district of birth *d*.[14] We also condition on whether the mother used iron supplementation when she was pregnant; this variable is not used in all models as the information was collected only for the last birth. Further, the regressions control for month of birth (M_m) and year of birth (Y_y) fixed-effects, their interactions $(M_m \times Y_y)$, and district fixed-effects (D_d). The district fixed-effects absorb a range of unobserved district level characteristics that might render the placement of power units across districts endogenous.[15] Finally, ε_{chmyd} is the idiosyncratic error term. In additional specifications, we use categories of anemia (mild, moderate or severe) as dependent variables. We present various heterogeneity and robustness tests below for the child regressions as well as checks to rule out selection arising from factors including sorting.

To analyze the impact of coal units on the anemic status of women we employ a variant of equation (1):

$$H_{ihmyd} = \alpha_0 + \alpha_1 Num\ Coal_{myd} + \varphi X_{ihd} + \pi Z_{yd} + M_m + Y_y + (M_m \times Y_y) + D_d + \mu_{ihmyd} \quad (2)$$

Here H_{ihmyd} is either HBA levels or anemic status of woman *i* in household *h* in month *m* in year *y* in

[13] Nighttime lights (or night-lights) are increasingly used as a measure of local economic development in the absence of data on income at lower administrative levels. Bhandari and Roychowdhury (2011) argue that night-lights data can predict quite accurately the variation in both levels and growth rates of district-level GDP in India. Singhal *et al.* (2020) use night-lights data to construct reliable measures of inequality across districts of India.

[14] Zivin and Neidell (2013) argue that weather (rainfall and temperature) can significantly influence how pollution affects health. Rainfall and temperature might vary within districts by year (for example due to serial correlation in rainfall patterns). However, including these variables reduces the sample size as there are missing values. Therefore, our baseline specification does not include the weather variables.

[15] As noted above, coal units are likely to be established in regions of the country that have easy access to water and are naturally endowed in coal deposits. Since the location of water sources and coal deposits is geographically pre-determined, it is unlikely that there exist factors that are simultaneously correlated with our key outcome variables of interest and the presence of coal plants. This is similar to the arguments made in von der Goltz and Barnwal (2019) who find that the incidence of anemia increases in women living close to metal mines. However, their sample does not include India.

district d. As noted above, anemia in adult women is defined as HBA below 12.0 g/dl (or 11.0 g/dl if the woman is pregnant at the time of the survey). $Num\ Coal_{myd}$ is the number of coal units in month of survey m in year of survey y in district of residence d; X_{ihd} includes a set of individual and household characteristics that are the same as those in the child regressions (these women are the mothers of those children). Z_{yd}, M_m, Y_y, D_d are defined analogously as in equation (1) except that they refer to the month and year of the survey, and the woman's district of residence. Finally, μ_{ihmyd} is the error term.

Why does the presence of coal units in the district at the time of birth increase the likelihood that the child is anemic? We argue that this is because coal units in the district increase the concentration of $PM_{2.5}$, which, in turn, adversely affects anemia. To examine whether this is indeed the mechanism, we proceed in two steps. First, we examine the relationship between the number of coal units in a district in a particular month and year and the corresponding district level average $PM_{2.5}$ in that month and year. Results from this regression are presented in Table 3 (and discussed in Section 4.1). They support our contention that emissions from coal units contribute to $PM_{2.5}$.

Second, we estimate the following specification to investigate whether anemia is sensitive to the number of coal units at the time of birth conditional on $PM_{2.5}$ concentration:

$$H_{chmyd} = \beta_0 + \beta_1 Num\ Coal_{myd} + \beta_2 \log(PM_{2.5})_{myd} + \gamma X_{chd} + \delta Z_{yd} + M_m + Y_y + (M_m \times Y_y) + D_d + \varepsilon_{chmyd} \quad (3)$$

Equation (3) is an extended version of equation (1) in that it also includes $\log(PM_{2.5})_{myd}$ in the month (m), year (y) and district (d) of birth. If anemia is due to pollution measured by $\log(PM_{2.5})_{myd}$, the impact of coal units at the time of birth should fall in magnitude or become insignificant when we include $\log(PM_{2.5})_{myd}$ as an additional control.

There are caveats to our approach. First, our analysis assumes that each new unit opened has

a homogeneous effect, which might not be the case. For example, units could use different coal types or have different abatement technologies. We are not privy to these data and thus cannot control for them. Second, conditional on their number, we assume that coal-power units have uniform effects in the district without accounting for the fact that individuals residing closer to the unit may be differentially affected as compared to those residing further away.[16] Third, we implicitly assume that there are no spillovers or diffusion of air pollution across districts. The second and third assumptions impart a conservative bias to our results in that our estimates are in the nature of lower bound effects.

4. Results

4.1. Coal units and $PM_{2.5}$

Table 3 reports results on the impact of coal units on $PM_{2.5}$ net of district, year and month of birth fixed-effects. As the first column of this table shows, the number of coal units in a district in any particular month and year has a significant positive effect on the concentration of $PM_{2.5}$ in that district at that time. Each additional coal unit increases $PM_{2.5}$ concentration by 1.4 percent. Columns 2 and 3 of Table 3 present results of falsification tests: an increase in the number of hydro units and nuclear units in a district is not associated with an increase in district level average $PM_{2.5}$ concentration. This supports the hypothesis that emissions from coal-powered units contribute to higher particulate matter pollution. Coal plant units also generate nitrogen and sulphur dioxide (NO_2 and SO_2, respectively) and we test sensitivity of our results to the presence of these air pollutants as well (see section 4.5). However, we rely on $PM_{2.5}$ as our main measure as it is the most widely and consistently used gauge of air pollution.[17]

[16] Although the DHS data do provide geo-codes for clusters, we do not have the exact geo-coordinates for the location of coal power units; the Central Electricity Authority data provide only the name of the district in which these are located. Hence it is not possible to use GIS methods to match clusters to the exact location of coal plants.

[17] In Section 4.5, we show that NO_2 and SO_2 do not have a significant effect on the likelihood of being anemic, once we control for $PM_{2.5}$.

4.2. Coal units and anemia in children

Table 4 presents our key results. Each cell in this table presents results from a different regression. The first set of regressions in column 1 are those corresponding to our main specification in equation (1). The dependent variable is HBA of children aged 0—5 at the time of the survey. The results in row 1 of column 1 indicate that an additional coal unit in the district at the time of birth is associated with a statistically significant reduction in HBA concentration in children by almost 0.06 g/dl. Given that the average level of HBA in this population is 10.6 g/dl, this represents a 0.6 percent decline. In column 2 the dependent variable is the anemic status of a child. The presence of an additional coal unit in the district at the time of birth is associated with a statistically significant 1 percentage point increase in the likelihood of the child being anemic. Given that on average a child in this age group is 59 percent likely to be anemic (Table 1), an additional coal unit in the district increases this likelihood by 1.7 percent.

Columns 3—6 of Table 4 presents the results corresponding to alternative specifications of equation (1). Columns 3 and 4 report results when anemia is disaggregated by its level of severity. It is clear from column 4 that the presence of coal units has a significant impact on the likelihood of the child being moderately or severely anemic. In particular, the magnitude of the effect in column 4 is almost identical to that in column 1. Controlling for whether the mother had iron supplementation when pregnant (column 5) leads to a doubling of the coal unit effect on the likelihood that the child is anemic: an additional coal unit at birth increases the likelihood of anemia by almost 2 percentage points. We note however that the sample size in this regression is lower than that in the baseline regression (column 1) as iron supplementation is asked only for the last birth. Finally, the regression specification presented in column 6 conditions on average temperature and rainfall in the district at the time of birth. The coefficient estimate associated with number of coal units is similar in magnitude

to that in column 2, but it is now estimated imprecisely.

The remaining rows of Table 4 may be interpreted as falsification tests where instead of coal units, we sequentially include the number of hydro units or the number of nuclear units in the district in the month and year of birth. The results show that these alternative sources of power generation have little discernible impact on the likelihood of a child aged 0—5 being anemic. Clearly, the impact on anemia thus seems to be primarily driven by impacts emanating from coal.[18]

Are the impacts on anemic status of young children confounded by the possible impacts of coal on nutrition in general? In order to investigate whether this is the case, we re-analyze the baseline specifications for anemia and HBA on the sample of children who are stunted, that is, have height for age z-scores that are less than 2 standard deviations from the mean. Height for age z-scores are a widely accepted measure of long run health, and stunting is the benchmark for undernourishment in the literature. Re-estimating on the sample of children who are stunted reveals a significant coefficient estimate for coal on anemic status of 0.02, which is comparable to the impact of coal in column 2 of Table 4. Similarly, re-estimating the model for HBA on the sample of stunted children reveals a coefficient estimate for coal equal to -0.06, which is equivalent to the baseline estimate in column 1 (first row) of Table 4.[19] We conclude that the parameters related to the impacts of coal in Table 4 are independent of nutritional deficiencies in the sample of children we study. The detrimental impacts of coal on child anemic status therefore do not only reflect nutritional challenges that this population faces.

4.3. Coal units and anemia in adult women

[18] We re-estimated equation (1) replacing coal plant units with thermal plant units in the district at the time of birth of the child. The primary fuel in thermal units is coal (67.78%), but may also include gas (21.32%), lignite (4.42%), diesel (2.85%), naphtha (1.87%) or oil (1.77%). As coal is the biggest component, we find that results of the detrimental impacts of thermal units are in the same ballpark as those of coal outlined in Table 4.

[19] Given the reduced sample size, we lose precision in the impact of coal when column (1) is re-estimated on the sample of children who are stunted. These results are available on request.

We now turn to the effects of coal units on the anemic status of adult women aged 18—49 years. The first row of Table 5 presents the main results following the specification in equation (2). The number of coal units (at the time of the survey) does not have a statistically significant effect on the adjusted hemoglobin level for women (column 1) or anemia status (column 2) in the baseline sample. The presence of coal units however has a statistically significant 0.3 percentage point increase in the likelihood that the woman is anemic once we control for temperature and rainfall (column 5). The results in columns 3 and 4 indicate that an increase in the number of coal plant units in the district is associated with an enhanced likelihood of women being mildly anemic. Moreover, similar to the case for children, we find that the anemia effect is confined to the presence of coal-powered units and not units of alternative types. Overall, compared with the results in Table 4 for children, the magnitude of anemia effects for women is relatively weak.

4.4. Heterogeneity and robustness checks

We focus on the 0—5-year-old sample of children in this section beginning with a range of heterogeneity checks, the results of which are presented in Table 6.[20]

Heterogeneity of impacts

First, we estimate the impacts by gender of the child. The results presented in columns 1 and 2 show that the negative effects of coal at the time of birth on anemia status is evident for girls but not for boys.[21] Second, we consider variation by region of residence: we conduct separate regressions for districts in South India (the states of Kerala, Tamil Nadu, Karnataka, Andhra Pradesh and Telangana)

[20] These results remain essentially unaltered if we use interaction terms instead of splitting the sample along the dimensions of interest.
[21] This difference is however small and not statistically significant.

and the rest of India (non-South states) given the better health and socio-economic status of children and women in the South.[22] The regression results are presented in columns 3 and 4 of Table 7. The positive and significant association between coal at the time of birth and the anemia status of children aged 0—5 is driven by residents in non-Southern districts. This is expected for the reason noted above and because coal deposits and consequently coal-powered power units in India are primarily concentrated in these regions whereas southern districts primarily depend on hydro units as is evident from Panel B in Figure 5.

Third, we run separate regressions for rural and urban children. The results presented in columns 5 and 6 of Table 7 indicate that in the urban sample, the presence of coal units at the time of birth has no impact on a child's anemia status. The observed relationship between the two keys variables is evident only for rural children who constitute 70 percent of the sample.

Columns 7 and 8 show results separately for the sample of children with mothers who do not work outside of the home and those who do. Those with mothers who do not work outside the home experience a positive impact of coal units on anemic status; there is no impact for corresponding children whose mothers do work outside the home. Given reduced variation in the education indicator for mothers (noted in Table A1), we are unable to use mother's education to benchmark this level of differentiation. We thus consider work status as a proxy for mother's education, and the results that show that children of mothers who work outside the home fare better is suggestive of a protective role of these factors. This is consistent with the large literature from developing countries that shows that mothers with outside options and thus perhaps greater control over resources within the home bequeath considerable benefits to the next generation (Schultz (2002)).

Finally, the last two columns of Table 6 condition on mother's height, a widely accepted

[22] We also consider differences between states that have coal reserves (Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, Orissa, Telangana and West Bengal) and those that do not; while the magnitude of the impact of coal on anemic status is larger in states with coal reserves, it is measured with noise. In states that lack coal reserves, the magnitude of the impact is smaller and statistically not significant.

indicator of mother's health. The results indicate that children of mothers taller than the median height are unaffected by the number of coal units in the district. Children of mothers with below median height are the ones who are at most risk in these data.

We also examine if our results on child anemia could have been influenced by selection due to population sorting. If the population that settles in districts with coal units has systematically different characteristics as compared to populations in other districts (are of lower socio-economic status, or more lacking in access to health infrastructure and facilities), then our results on children's and women's anemic status could be on account of this fact rather than emissions from coal units. Note that the inclusion of district fixed-effects should largely control for such factors. However, to allay concerns further, we restrict our sample of children to those whose parents have resided in the current district of residence for greater than the median number of years in the data (eight years). These results are reported in Table A3 which show that in general, the results remain the same: additional coal units in the district at the time of birth significantly increase the prevalence of anemia (and decrease HBA levels).

Cumulative exposure

Thus far, we have examined the effect of emissions from coal-units measured by the number of coal units in the district at the time of birth. However, in an environment where there is increased investment in coal to generate electricity, cumulative exposure after birth may also be important. Table 7 shows the results allowing for cumulative exposure measured in two ways: (i) as the total number of coal unit years a child is exposed to after birth (columns 2 and 3), or (ii) the total number of new coal units established after birth (columns 4 and 5).[23] Results in columns 3 and 5 also

[23] Coal unit years measures the total number of years up until the time of the survey that a unit that was established after the child's year of birth has been in operation. Where multiple units were established after birth, this variable measures the sum (total) of years of operation for all these units until the time of the survey.

control for the number of coal units in the district at the time of birth as in column 1. For ease of comparison, column 1 reproduces the baseline results presented in column 2 of Table 4.

The results show that cumulative exposure measured in either of the two ways has a significant positive effect on the probability of child anemia, consistent with our main results. However, conditional on the number of coal units present at the time of birth, cumulative exposure is no longer significant. This indicates that the adverse effect of coal is primarily realized by the number of units present at the time of birth, and subsequent additional exposure does not induce further measurable increases in the likelihood of anemia.

In-utero impacts

The results thus far have investigated the effects of exposure to coal units at or since birth on anemia. But could some of the adverse effects be traced to *in utero* exposure as well? The fetal origins hypothesis (see Almond and Currie (2011)) postulates that the *in-utero* period critically determines a variety of human capital outcomes (mortality, susceptibility to disease, even education and earnings) in both the short and the long term. We investigate potential *in-utero* effects by using information on the child's district, month and year of birth and gestation period, to construct measures of the number of coal units present in each of the three trimesters prior to birth. We assume that the current district of residence of the child is the same as that in which she/he was born. The results presented in Table 8 indicate the presence of *in-utero* effects. The number of coal units in the district in the first and second trimesters significantly increases the likelihood that the child is anemic. This is consistent with the particular importance of the first two trimesters from a fetal development standpoint.

Alternatively, the total number of new coal units only conditions on the sum of new coal units established in the district after the year of birth of the child.

4.5. Mechanisms: Coal units and concentration of $PM_{2.5}$

A likely mechanism for the adverse anemia effects of coal units may be the effects of coal units on ambient air pollution, in particular on $PM_{2.5}$ concentrations. We have already presented evidence on how coal-fired units significantly contribute to higher $PM_{2.5}$ concentrations in Table 3. We now explore the effects of $PM_{2.5}$ on anemia both with and without conditioning on the number of coal units at the time of birth. Table 9 presents the results. Column 1 of this table reports the expected statistically significant positive impact of $PM_{2.5}$ on anemic status. With the inclusion of the number of coal units in this specification (column 2), $PM_{2.5}$ continues to exert a significant positive effect on child anemic status while the impact of the number of coal units is no longer significant. This underlines that the adverse anemia impact of coal may be attributed to particulate matter pollution. The results remain unchanged when we control for the natural log of NO_2 and the natural log of SO_2, the other common measures of air pollution in India, as evident in columns 3 and 4 of Table 9.

In view of the large and adverse effects of $PM_{2.5}$ on the health of women and children that this study finds, it is useful to examine one's willingness to pay (WTP) to curtail $PM_{2.5}$. We follow the "dose function" framework in Moretti and Neidell (2011) to implement a simple back-of-the-envelope calculation. Using data from Horton and Ross (2003) and Menon *et al.* (2016), the slope estimate of 0.015 in column 4 of Table 9 translates into a WTP of approximately $2.19 (2016 US Dollars or Rupees 148.74) per month per child to reduce $PM_{2.5}$ by 1%.[24]

5. Conclusion

[24] Details available from the authors. This estimate of monthly WTP is in a similar ballpark to that estimated for respiratory hospitalizations that result from PM_{10} in Colombia (see Ordoñez (2020)), although the scale in that paper is different.

A distinctive feature of this study is that it assembles a unique data set drawing upon diverse sources to examine a policy relevant question: what are the potential effects of coal-power unit induced pollution on the anemic status of children and women in India. In particular, we combine data on hemoglobin assessments conducted by the National Family Health Survey (2015—16) with time- and district-referenced data on coal-fired power generation from the Central Electricity Authority of India and satellite data on particulate matter $PM_{2.5}$ pollution. The focus on anemia also distinguishes our study from existing work on the effects of coal-based pollution on the environment and on child and adult health. The Indian context of this study confers further importance to our analysis as India's reliance on coal-fired power generation has been rapidly expanding in the backdrop of increasing energy demand, and because India does poorly on the health markers of its young children and women, especially in terms of the high prevalence of ID anemia.

Our principal finding is that, controlling for a comprehensive set of child, mother, household and district characteristics, an increase in the number of coal plant units leads to a worsening of the anemic status of children and women. We find the adverse effects to be particularly pronounced for young children up to age 5. While the total exposure of a child to coal units (consisting of the number of coal units at the time of birth in the district, and length of that child's exposure since birth) has significant adverse effects on anemic status, it is the former component, the number of coal plant units at birth, which accounts for most of this impact. We further find the some of these anemia-inducing effects may be traced to exposure *in utero*.

Our evidence points to weaker effects on anemia among women as measured by the number of coal units in the district at the time of the survey. We identify that the effects of coal units on anemia are transmitted through particulate matter ambient air pollution as the primary channel. Taken together, these findings suggest that at least a partial explanation for the relatively high rates of anemia among children and women in India may be traced to pollution emanating from coal-power units.

Our study adds to the growing evidence on the health costs of a fossil fuel based energy policy to which costs due to the effects on anemia ought to be taken into account. Factoring in the added costs related to anemia among children and women, strengthens the case for a progressive shift to cleaner sources of energy. By providing evidence on the harmful health effects of coal-fired power units on the anemic status of children and women that adds to the existing evidence on mortality and morbidity, the present study underlines the urgent need to draw a road map for reduced reliance on coal and a greater role for renewable energy, not just in India but across the world.

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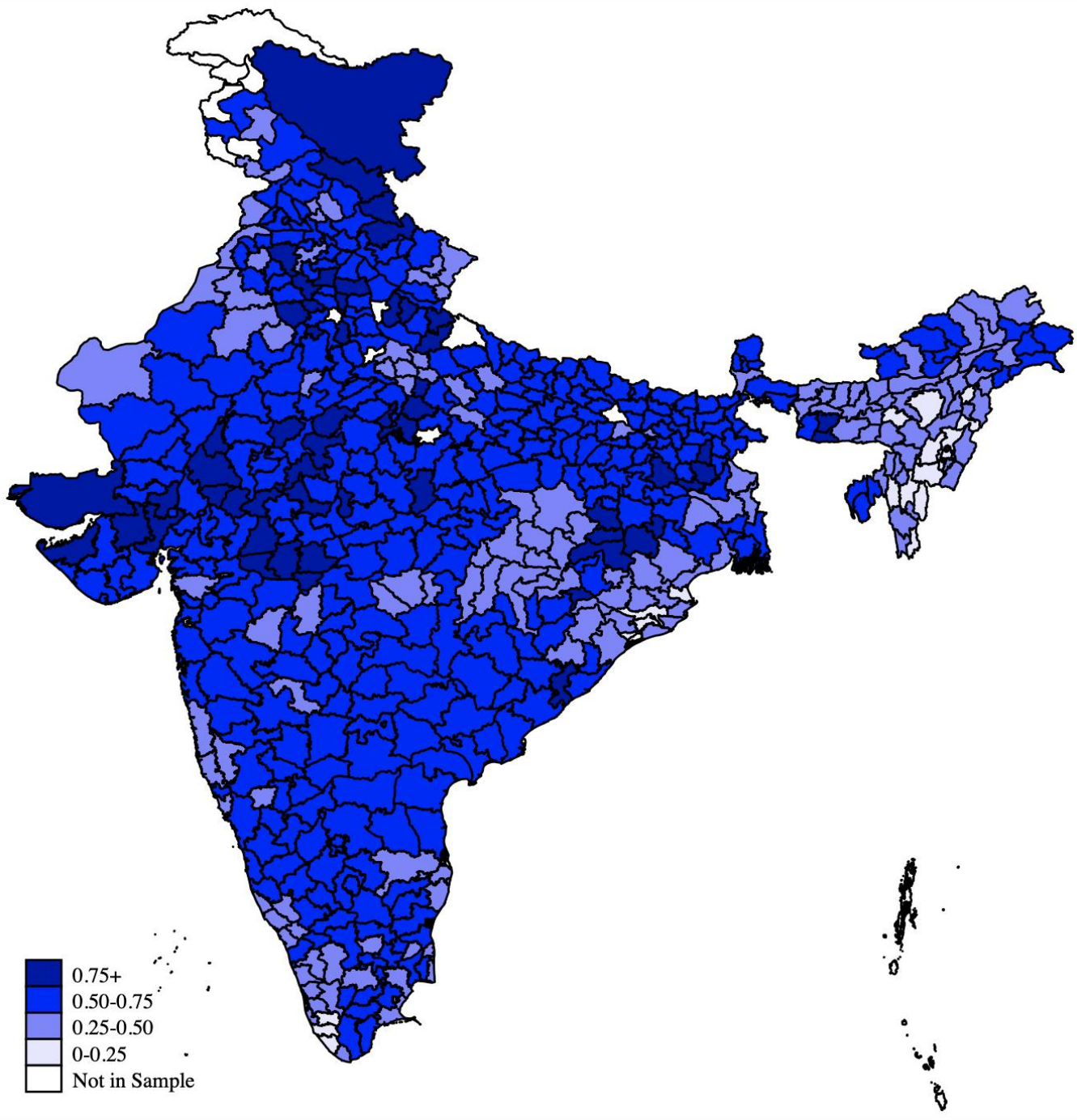
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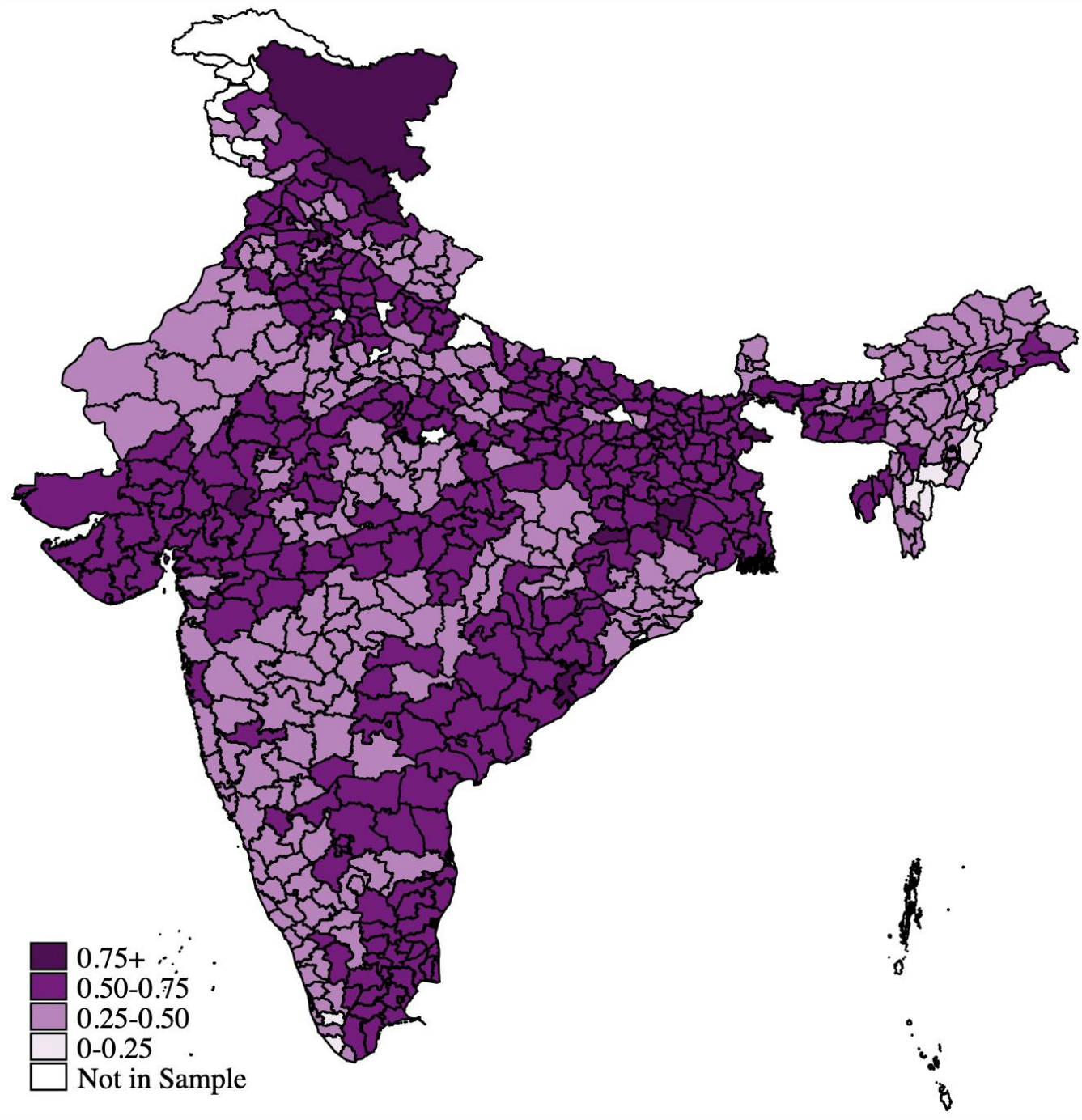
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Figure 1: Proportion of Children 0—5 Years Who are Anemic, 2015—16



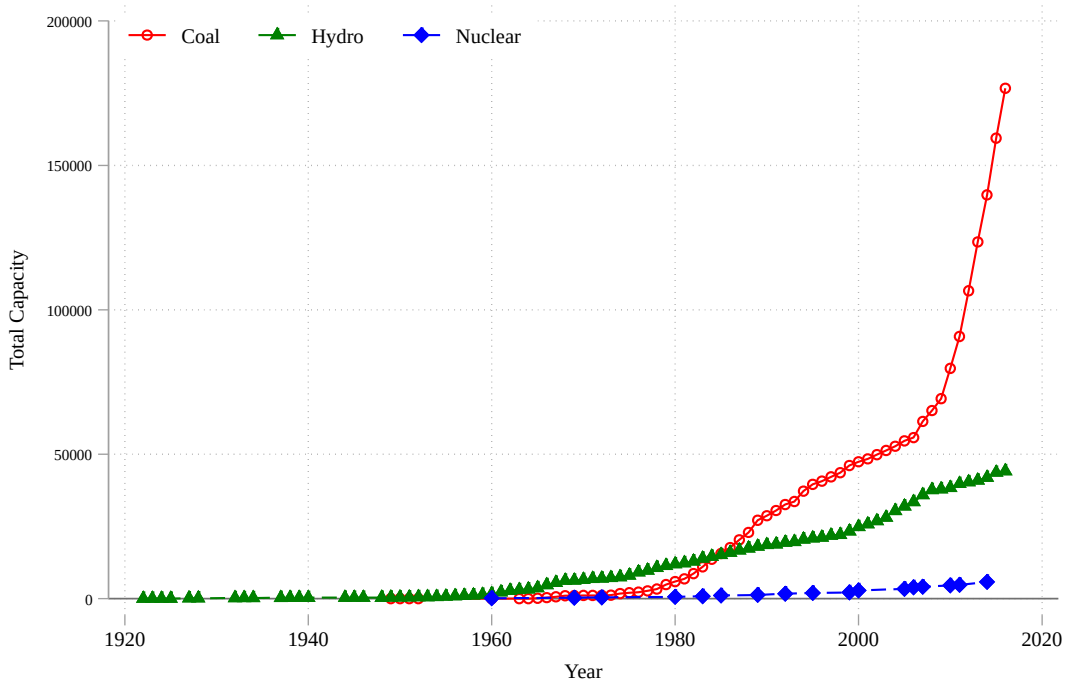
Notes: The figure presents the weighted average of the proportion of children (aged 0—5) in each district categorized as anemic i.e., altitude adjusted hemoglobin concentration (HBA) < 11.0 g/dl. Category 0—0.25 denotes up to 25 percent of the sample children in the district are characterized as anemic, and so on.

Figure 2: Proportion of Women 18—49 Years who are Anemic, 2015—16



Notes: The figure presents the weighted average of the proportion of women (aged 18—49) in each district categorized as anemic i.e., altitude adjusted hemoglobin concentration (HBA) < 12.0 g/dl for non-pregnant women, and HBA < 11.0 g/dl for pregnant women. Category 0—0.25 denotes up to 25 percent of the sample women aged 18—49 in the district are characterized as anemic, and so on.

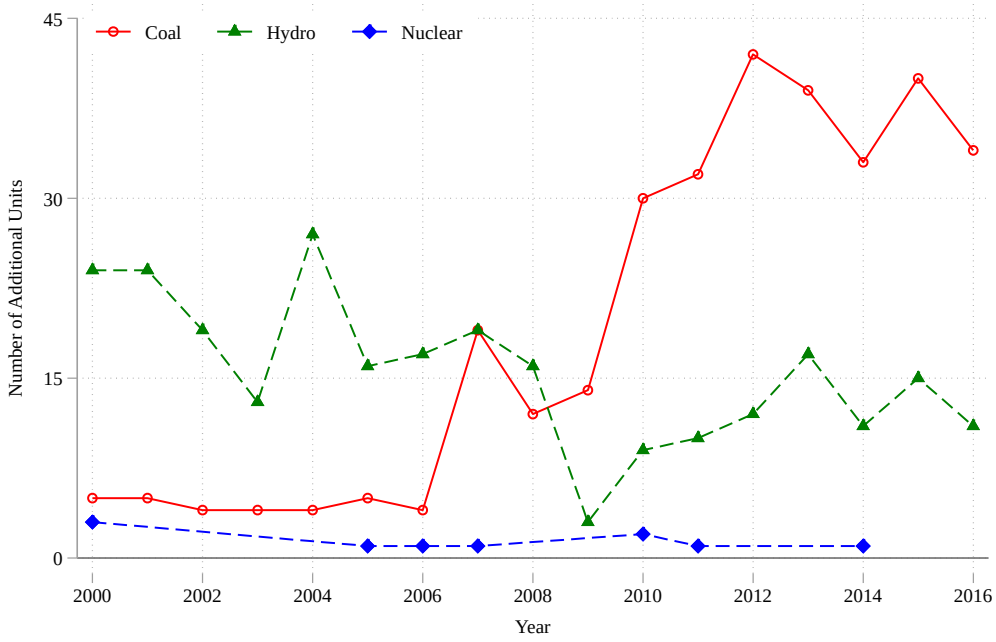
Figure 3. Total Capacity by Year and Fuel Type



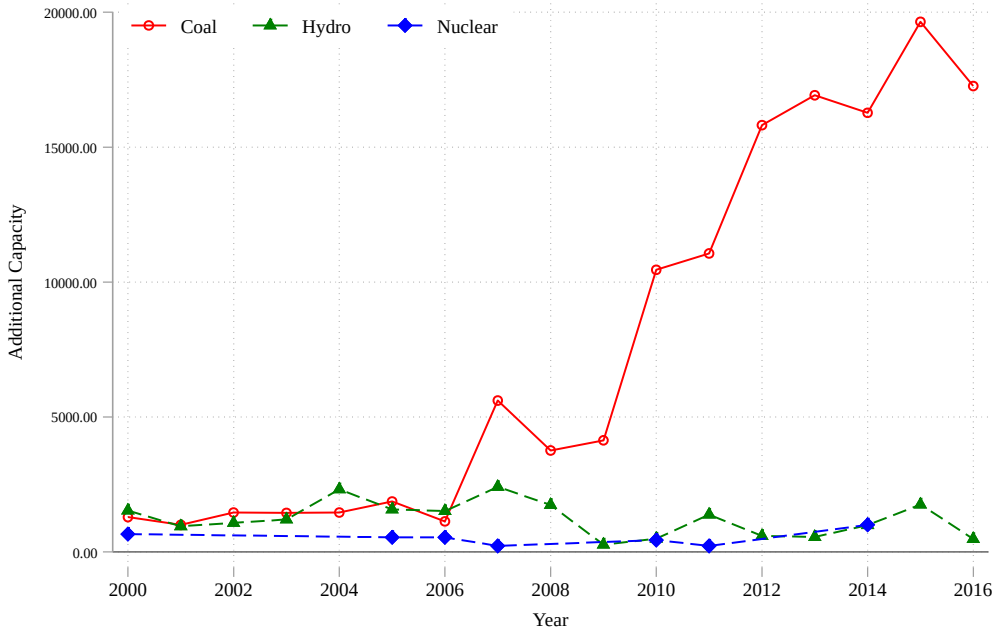
Notes: Total capacity (in gigawatts) in each year by fuel type.

Figure 4. Additional Number of Power Units and Capacity Commissioned by Year and Fuel Type, 2000—2016

Panel A: Additional Units

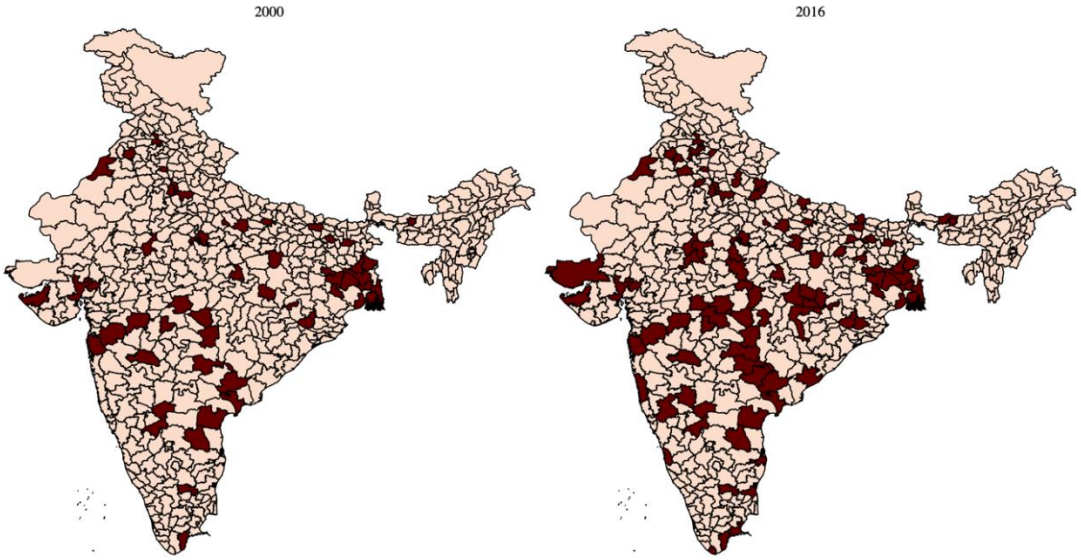


Panel B: Additional Capacity

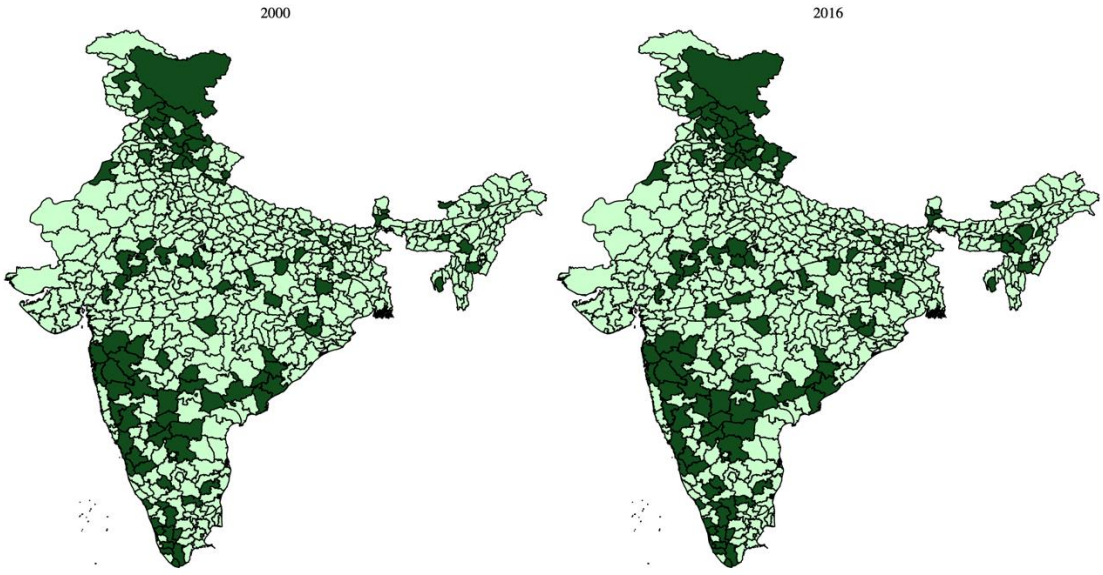


Notes: Sample restricted to units commissioned between 2000 and 2016.

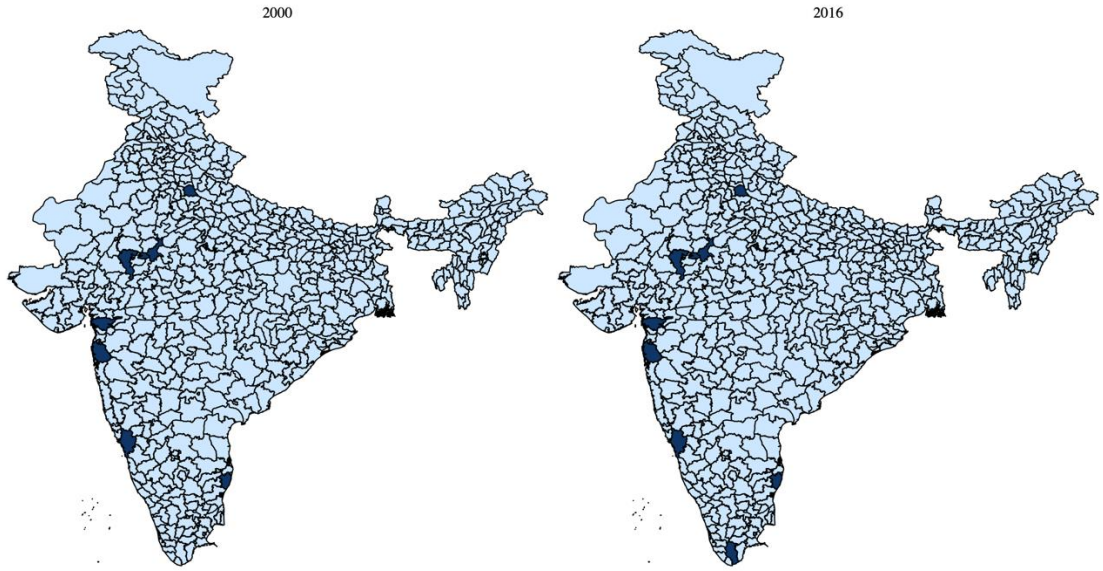
Figure 5. Districts with Coal, Non-Coal, Hydro and Nuclear Power Units 2000 and 2016.
Panel A: Coal Units



Panel B: Hydro Units

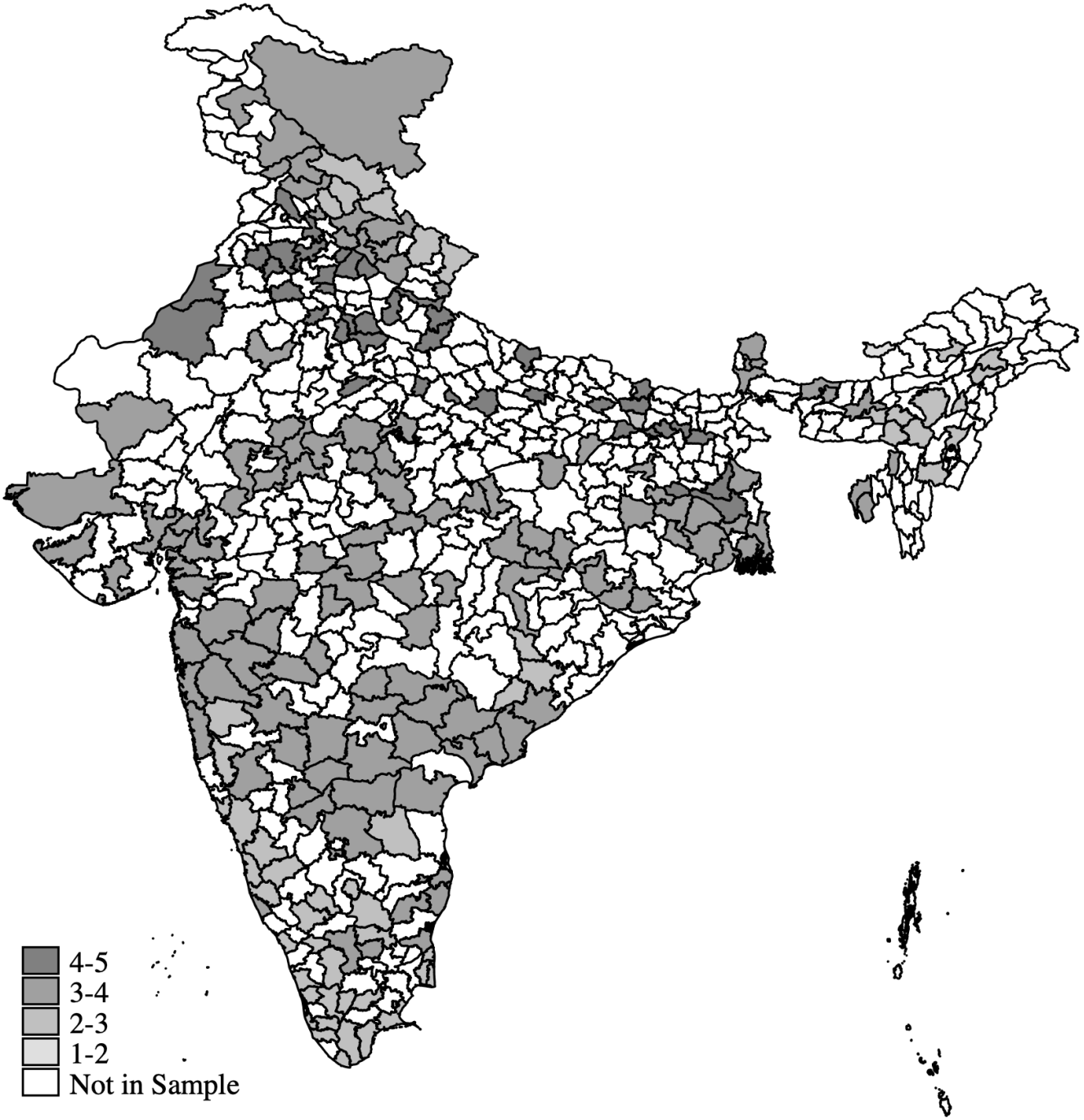


Panel C: Nuclear Units



Notes: Darker shaded districts denote units present. DHS sample does not include Andaman and Nicobar Islands.

Figure 6: District-Level Natural Log of $PM_{2.5}$



Notes: DHS sample does not include Andaman and Nicobar Islands. Figure presents average values of natural log ($PM_{2.5}$) in each district over the period 2001—2015.

Table 1. Incidence of Anemia

	Children 0—5 (1)	Women 18—49 (2)
Altitude adjusted hemoglobin level (g/dl)	10.543	11.628
Anemic	0.588	0.535
Mildly Anemic	0.279	0.399
Moderately or Severely Anemic	0.309	0.137
Sample Size	39, 356	440,056

Notes: Authors' computation using NFHS-4 data. Anemia in children six months through 60 months of age is defined as HBA below 11.0 g/dl. Anemia in women (aged 18—49) is HBA < 12.0 g/dl for non-pregnant women and HBA < 11.0 g/dl for pregnant women. Mild anemia is defined as HBA of 10.0—10.9 g/dl for children, and 10.0—11.9 g/dl for non-pregnant women and 10.0—10.9 g/dl for pregnant women. Moderate anemia uses HBA thresholds of 7.0—9.9 g/dl for both children and women whereas severe anemia is defined as HBA <7.0 g/dl in both children and women.

Table 2. Summary Statistics for Selected Demographic, Power Unit and Pollutant-specific Variables for Children and Women Samples

	Mean (1)	Std. Deviation (2)
Panel A: Children aged 0—5		
Age in years	2.566	1.666
Male	0.524	0.499
Birth order	2.060	1.269
Delivered at home	0.199	0.399
Delivered in public sector hospital	0.788	0.408
Uses mosquito bed net while sleeping	0.387	0.487
Power Unit and Pollutant-Specific		
Count of coal units in district in month and year of birth	2.968	4.314
Count if hydro units in district in month and year of birth	2.684	4.471
Count of nuclear units in district in month and year of birth	0.172	0.732
Cumulative exposure to coal units after birth (years)	4.691	7.658
Number of new coal units established in district after birth	1.519	2.088
Natural log of $PM_{2.5}$	3.601	0.751
Natural log of NO_2	0.410	0.173
Natural log of SO_2	0.000	0.000
Panel B: Adult Women aged 18—49		
Age in years	34.241	8.121
Height in centimeters	151.892	5.823
Not educated	0.362	0.481
Has some or all primary school	0.150	0.357
Has some secondary school	0.338	0.473
Completed secondary school or higher	0.151	0.358
Power Unit and Pollutant-Specific		
Number of coal units in district	3.488	4.952
Number of hydro units in district	2.739	4.846
Number of nuclear units in district	0.163	0.709
Total capacity of coal units in district ($x10^{-3}$) in megawatts	0.734	1.359
Total capacity of hydro units in district ($x10^{-3}$) in megawatts	0.104	0.289
Total capacity of nuclear units in district ($x10^{-3}$) in megawatts	0.007	0.054
Change in the number of coal units in district since 2000	1.545	2.821
Change in the number of hydro units in districts since 2000	0.613	2.215
Change in the number of nuclear units in district since 2000	0.061	0.373
Natural log of $PM_{2.5}$	3.570	0.537
Natural log of NO_2	0.413	0.173
Natural log of SO_2	0.006	0.004

Notes: Authors' computation using NFHS-4 data. Table reports weighted summary statistics.

Table 3. Power Units and $PM_{2.5}$ Concentration

	(1)	(2)	(3)
Number of Coal Units in District	0.014**		
	(0.006)		
Number of Hydro Units in District		-0.005	
		(0.012)	
Number of Nuclear Units in District			-0.001
			(0.006)
Constant	3.559***	3.615***	3.601***
	(0.019)	(0.033)	(0.001)
Sample Size	68,905	68,905	68,905

Notes: Dependent variable in regressions is log($PM_{2.5}$). Weighted OLS regression results presented. Regressions control for district fixed-effects. Standard errors clustered at the district level in parenthesis. Significance: ***p < 0.01; **p < 0.05; *p < 0.10.

Table 4. Power Units and Child Health. Children Aged 0—5

	HBA	Anemic	Mildly Anemic	Moderately or Severely Anemic	Anemic	Anemic
	(1)	(2)	(3)	(4)	(5)	(6)
Number Coal Units in District	-0.055***	0.010*	0.001	0.010**	0.019***	0.009
	(0.019)	(0.006)	(0.004)	(0.004)	(0.006)	(0.007)
Number Hydro Units in District	-0.015	-0.001			0.002	-0.004
	(0.021)	(0.005)			(0.005)	(0.005)
Number Nuclear Units in District	0.082	-0.073			-0.262	-0.081
	(0.658)	(0.204)			(0.291)	(0.205)
Specification	Baseline	Baseline	Baseline	Baseline		
Rainfall and Temperature	No	No	No	No	No	Yes
Iron Supplementation	No	No	No	No	Yes	No
Sample Size	39, 356	39, 356	39, 356	39, 356	29, 173	27, 757

Notes: Weighted OLS regression results presented. Child categorized as anemic (columns 2—6) if altitude adjusted hemoglobin count (HBA) is below 11.0 g/dl. Sample restricted to children aged 0—5 at the time of the survey. Each cell presents the results from a separate regression. Models include a constant term which is not reported. Sample size is the same across all regressions reported in each cell in a particular column. Controls include a set of child (gender, birth order, whether multiple birth, whether the child was nursed, recent illnesses (diarrhea, cough), place of delivery, whether C-section birth, and whether a bed net was used), mother (mother's height, mother's hemoglobin level, whether mother works, mother's age at first birth, age at marriage, mother's educational level, total number of children born, and number of children less than 5 years in the household) and household (religion and caste identifiers, SC/ST status, type of cooking fuel used, whether the kitchen is located in a separate room of the house, ownership of assets such as radio, television, refrigerator, bicycle, motorcycle, car, telephone, and cell phone, controls for age of the head, gender of the head, household size, type of floor material of the house, wall material of the house, roof material of the house, rural/urban status, presence of electricity, type of toilet facility and primary source of drinking water) characteristics and a set of district specific time-varying controls including natural log of night-lights in year of birth y and district of birth d. All regressions control for month and year of birth and their interactions. Standard errors clustered at the district level in parenthesis. Significance: ***p < 0.01; **p < 0.05; *p < 0.10.

Table 5. Power Units and Women's Health. Women Aged 18—49

	HBA	Anemia	Anemia Category		Anemia
			Mild	Moderate or Severe	
	(1)	(2)	(3)	(4)	(5)
Number Coal Units in District	-0.004	0.001	0.002**	-0.000	0.003***
	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)
Number Hydro Units in District	0.001	-0.000	-0.001	0.001	-0.001
	(0.004)	(0.001)	(0.001)	(0.001)	(0.001)
Number Nuclear Units in District	0.002	-0.004	0.001	-0.005	-0.006
	(0.016)	(0.004)	(0.003)	(0.004)	(0.004)
Includes Temperature and Rainfall	No	No	No	No	Yes
Sample Size	137,227	137,227	137,227	137,227	97,256

Notes: Weighted OLS regression results presented. Sample Restricted to women aged 18 and higher at the time of the survey. A woman is categorized as anemic if the altitude adjusted hemoglobin count (HBA) is below 12.0 g/dl (if the woman is not pregnant and is below 11.0 g/dl if she is pregnant at the time of the survey. Each cell presents the results from a separate regression. Models include a constant term which is not reported. Dependent variable is the number of units of a specific fuel type at the time of survey. Sample size is the same across all regressions reported in each cell in a particular column. The regressions control for a set of individual (age, height, age at marriage, age at first birth, total number of children born to the woman), household specific (religion and caste identifiers, SC/ST status, type of cooking fuel used, whether the kitchen is located in a separate room of the house, ownership of assets such as radio, television, refrigerator, bicycle, motorcycle, car, telephone, and cell phone, controls for age of the head, gender of the head, household size, type of floor material of the house, wall material of the house, roof material of the house, rural/urban status, presence of electricity, type of toilet facility and primary source of drinking water) characteristics. Regressions also include a set of district specific time-varying controls given by natural log of nightlights in year of survey y and district d. The regressions control for month and year of survey fixed-effects, their interactions and district fixed-effects. Standard errors clustered at the district level in parenthesis. Significance: ***p < 0.01; **p < 0.05; *p < 0.10.

Table 6. Heterogeneity in Impacts of Coal Units in District. Anemia Status of Children Aged 0—5

	Boys	Girls	South	Non-South	Rural	Urban	Mother Works outside home		Mother's Height	
							No	Yes	Above median	Below median
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Number of Coal Units in District	0.009	0.011*	0.008	0.012*	0.018**	0.000	0.011*	0.020	0.001	0.019***
	(0.009)	(0.006)	(0.010)	(0.007)	(0.008)	(0.010)	(0.006)	(0.029)	(0.008)	(0.007)
Constant	1.247**	1.434***	3.318***	1.121***	1.439***	0.628	1.443***	-0.225	1.267***	1.287**
	(0.508)	(0.533)	(1.179)	(0.398)	(0.448)	(0.923)	(0.424)	(1.860)	(0.565)	(0.509)
Specification	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
Rainfall and Temperature	No	No	No	No	No	No	No	No	No	No
Iron Supplementation	No	No	No	No	No	No	No	No	No	No
Sample Size	20,347	19,009	7,687	31,669	27,627	11,729	37,798	1,558	20,327	19,029

Notes: Weighted OLS regression results presented. Child categorized as anemic if altitude adjusted hemoglobin count (HBA) is below 11.0 g/dl. Sample restricted to children aged 0—5 at the time of the survey. Each cell presents the results from a separate regression. Controls include a set of child (gender, birth order, whether multiple birth, whether the child was nursed, recent illnesses (diarrhea, cough), place of delivery, whether C-section birth, and whether a bed net was used), mother (mother's height, mother's hemoglobin level, whether mother works, mother's age at first birth, age at marriage, mother's educational level, total number of children born, and number of children less than 5 years in the household) and household (religion and caste identifiers, SC/ST status, type of cooking fuel used, whether the kitchen is located in a separate room of the house, ownership of assets such as radio, television, refrigerator, bicycle, motorcycle, car, telephone, and cell phone, controls for age of the head, gender of the head, household size, type of floor material of the house, wall material of the house, roof material of the house, rural/urban status, presence of electricity, type of toilet facility and primary source of drinking water) characteristics and a set of district specific time-varying controls including natural log of night-lights in year of birth y and district of birth d. All regressions control for month and year of birth and their interactions. Work status and height of mother proxy for her education and health, respectively. Standard errors clustered at the district level in parenthesis. Significance: ***p < 0.01; **p < 0.05; *p < 0.10.

Table 7. Exposure After Birth and Child Health. Children Aged 0—5

	Anemic (1)	**Anemic (2)**	**Anemic (3)**	**Anemic (4)**	**Anemic (5)**
Number Coal Units in District	0.010*		0.014*		0.016**
	(0.006)		(0.008)		(0.008)
Cumulative Exposure After Birth		0.002**	-0.002		
		(0.001)	(0.002)		
Number Coal Units in District After Birth				0.009**	-0.007
				(0.004)	(0.008)
Constant	1.345***	2.151***	1.041*	2.152***	1.024*
	(0.406)	(0.421)	(0.544)	(0.420)	(0.545)
Specification	Baseline	Baseline	Baseline	Baseline	Baseline
Sample Size	39,356	25,178	21,390	25,178	21,390

Notes: Weighted OLS regression results presented. Child categorized as anemic if altitude adjusted hemoglobin count (HBA) is below 11.0 g/dl. Sample restricted to children aged 0—5 at the time of the survey. Each cell presents the results from a separate regression. Controls include a set of child (gender, birth order, whether multiple birth, whether the child was nursed, and whether a bed net was used), mother (mother's height, mother's hemoglobin level, whether mother works, mother's age at first birth, age at marriage, mother's educational level, total number of children born, and number of children less than 5 years in the household) and household (religion and caste identifiers, SC/ST status, type of cooking fuel used, whether the kitchen is located in a separate room of the house, ownership of assets such as radio, television, refrigerator, bicycle, motorcycle, car, and cell phone, controls for age of the head, gender of the head, household size, type of floor material of the house, wall material of the house, roof material of the house, rural/urban status, presence of electricity, type of toilet facility and primary source of drinking water) characteristics and a set of district specific time-varying controls including natural log of night-lights in year of birth y and district of birth $\boldsymbol{d}$. All regressions control for month and year of birth and their interactions. Standard errors clustered at the district level in parenthesis. Significance: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

Table 8. *In-utero* Impacts of Coal Units in District. Children Aged 0—5

	Anemic (1)	Anemic (2)	Anemic (3)
Average Number of Coal Units in District in Trimester 1	0.015*		
	(0.008)		
Average Number of Coal Units in District in Trimester 2		0.013**	
		(0.007)	
Average Number of Coal Units in District in Trimester 3			0.010
			(0.007)
Constant	1.321**	1.364***	1.385***
	(0.512)	(0.512)	(0.513)
Rainfall and Temperature	Yes	Yes	Yes
Iron Supplementation	No	No	No
Sample Size	27,298	27,474	27,635

Notes: Weighted OLS regression results presented. Child categorized as anemic if altitude adjusted hemoglobin count (HBA) is below 11.0 g/dl. Sample restricted to children aged 0—5 at the time of the survey. Each cell presents the results from a separate regression. Controls include a set of child (gender, birth order, whether multiple birth, whether the child was nursed, recent illnesses (diarrhea, cough), place of delivery, whether C-section birth, and whether a bed net was used), mother (mother's height, mother's hemoglobin level, whether mother works, mother's age at first birth, age at marriage, mother's educational level, total number of children born, and number of children less than 5 years in the household) and household (religion and caste identifiers, SC/ST status, type of cooking fuel used, whether the kitchen is located in a separate room of the house, ownership of assets such as radio, television, refrigerator, bicycle, motorcycle, car, telephone, and cell phone, controls for age of the head, gender of the head, household size, type of floor material of the house, wall material of the house, roof material of the house, rural/urban status, presence of electricity, type of toilet facility and primary source of drinking water) characteristics and a set of district specific time-varying controls including natural log of night-lights in year of birth y and district of birth d. All regressions control for month and year of birth and their interactions. Standard errors clustered at the district level in parenthesis. Significance: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

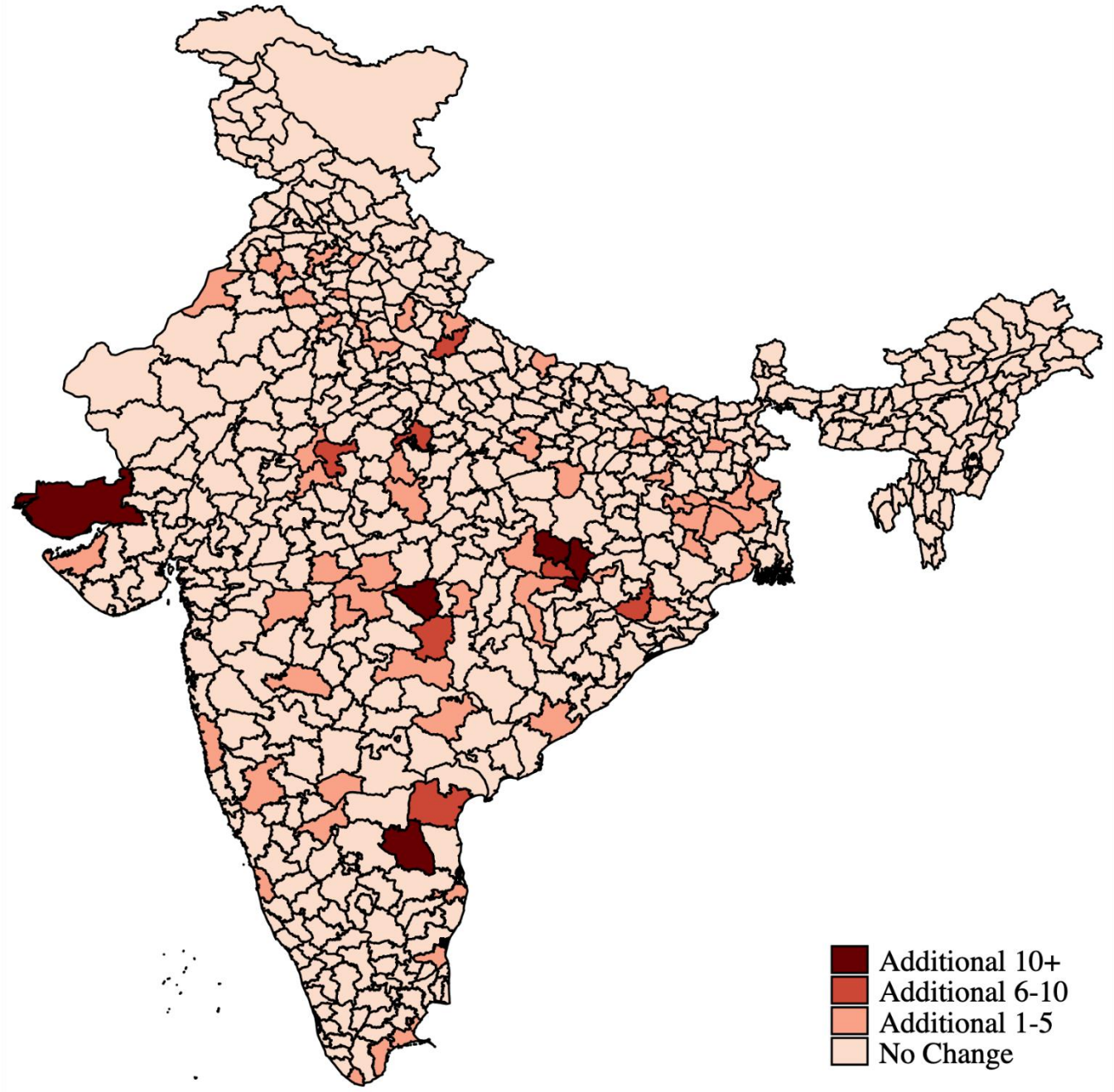
Table 9. Impact of Power Units Conditional on $PM_{2.5}$ Concentration. Children Aged 0—5

	Anemic (1)	Anemic (2)	Anemic (3)	Anemic (4)
Number of Coal Units in District		0.011		0.011
		(0.007)		(0.007)
Natural log ($PM_{2.5}$)	0.014**	0.014**	0.015**	0.015**
	(0.007)	(0.007)	(0.007)	(0.007)
Natural log (SO_2)			0.331	-0.935
			(0.712)	(1.880)
Natural log (NO_2)			-0.979	0.147
			(1.861)	(0.761)
Rainfall and Temperature	Yes	Yes	Yes	Yes
Iron Supplementation	No	No	No	No
Sample Size	24,028	24,024	24,028	24,028

Notes: Weighted OLS regression results presented. Child categorized as anemic if altitude adjusted hemoglobin count (HBA) is below 11.0 g/dl. Sample restricted to children aged 0—5 at the time of the survey. Each cell presents the results from a separate regression. Controls include a set of child (gender, birth order, whether multiple birth, whether the child was nursed, recent illnesses (diarrhea, cough), place of delivery, whether C-section birth, and whether a bed net was used), mother (mother's height, mother's hemoglobin level, whether mother works, mother's age at first birth, age at marriage, mother's educational level, total number of children born, and number of children less than 5 years in the household) and household (religion and caste identifiers, SC/ST status, type of cooking fuel used, whether the kitchen is located in a separate room of the house, ownership of assets such as radio, television, refrigerator, bicycle, motorcycle, car, telephone, and cell phone, controls for age of the head, gender of the head, household size, type of floor material of the house, wall material of the house, roof material of the house, rural/urban status, presence of electricity, type of toilet facility and primary source of drinking water) characteristics and a set of district specific time-varying controls including natural log of night-lights in year of birth y and district of birth d. All regressions control for month and year of birth and their interactions. Standard errors clustered at the district level in parenthesis. Significance: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

Appendix

Figure A1. Change in the Number of Coal Units by District 2000—2016



Notes: DHS sample does not include Andaman and Nicobar Islands.

A1. Descriptive Statistics

Summary statistics for all variables in our sample for children and women are presented in Tables A1 and A2, respectively. We begin by discussing the results in Table A1 focusing on variables beyond the anemia outcomes as these have been discussed in Table 1. Average age is about 3 years in the child 0-5 years sample and 52 percent of these children are male. Very small proportions are multiple births and those who reported illnesses in the last two weeks range from 19—23 percent. Most deliveries occurred in public sector hospitals.

Mother specific parameters reported in Table A1 indicate that average height (measure of genetic health endowment) is about 152 centimeters and 78 percent of women report taking iron supplements during pregnancy. A very small proportion of mothers' report working outside the home and age at first marriage and first birth are relatively low in these data. Almost 74 percent of mothers are uneducated and only 24 percent report some or all primary school. As expected, most households are Hindu and about 45 percent report belonging to the other backward caste category (proportions reporting membership in the scheduled caste/scheduled tribe groups are lower). The vast majority of these households use unclean sources of fuel for cooking – kerosene, coal, lignite, charcoal, wood, and agricultural crop, and only 19 percent report having a separate space for cooking. Table A1 also reports descriptive measures for assets owned, age of the household head (about 44 years) and the fact that most of these households are male-headed. The proportion that is rural is about 71 percent and equal proportions report access to sanitary facilities and no facilities. Piped water and ground water are the major sources of drinking water in the child sample. In addition, as is well known in India, rates of migration are relatively low as the average years lived in current place of residence is approximately 11 years. Table A1 reports regional specific variables including measures for nightlights density at the district level, weather conditions and an indicator for the Southern states where health outcomes for children and women are known to be better as compared to the rest of the country.

Table A2 reports the summary statistics for women aged 18—49 years and as in the case of Table A1, we focus on variables in that table beyond the anemia outcomes that we discuss above. The average age of these women is 34 years and age at first birth and first marriage are similar to those in the child samples. On average, about 36 percent are uneducated whereas 49 percent have some secondary school, or have completed secondary school or higher. About 82 percent of these women report living in households that are Hindu and 58 percent use the relatively more polluting sources of fuel for cooking. Age of the household head is slightly older than in the child samples at 46 years, and about 67 percent of these households are rural. Access to electricity is reported by almost 90 percent of households and many of the sanitation and access to drinking water measures are similar to those in the child samples. The region-specific variables and the weather indicators also offer descriptive statistics that are broadly in line with those in the children's samples.

Table A1. Descriptive statistics for children, aged 0-5 years

	Mean (1)	Std. Deviation (2)
Outcomes		
Anemic	0.588	0.492
Altitude adjusted hemoglobin level (g/dl)	10.543	1.505
Mildly anemic	0.279	0.449
Moderately or severely anemic	0.309	0.462
Child-specific		
Age in years	2.566	1.666
Male	0.524	0.499
Birth order	2.060	1.269
Twin	0.015	0.120
Nursed	0.575	0.494
Diarrhea	0.191	0.635
Cough	0.230	0.668
Delivered at home	0.199	0.399
Delivered in public sector hospital	0.788	0.408
C-section delivery	0.174	0.379
Uses mosquito bed net while sleeping	0.387	0.487
Mother-specific		
Height in centimeters	151.680	6.132
Took iron supplements in pregnancy	0.783	0.412
Altitude adjusted hemoglobin level (g/dl)	11.504	1.589
Works outside the home	0.041	0.198
Age at first birth in years	20.951	3.529
Age at first marriage in years	18.660	3.630
Total number of children ever born	2.480	1.365
Number of children below 5 years	1.816	0.899
Not educated	0.738	0.439
Has some or all primary school	0.239	0.427
Has some secondary school	0.022	0.146
Completed secondary school or higher	0.000	0.014
Household-specific		
Hindu	0.785	0.411
Muslim	0.165	0.371
Christian	0.021	0.143
Scheduled caste	0.227	0.419
Scheduled tribe	0.107	0.309
Other backward caste	0.451	0.498
Fuel for cooking: electricity or other	0.006	0.077
Fuel for cooking: liquefied petroleum gas, natural gas, biogas	0.347	0.476
Fuel for cooking: kerosene, coal, lignite, charcoal, wood, straw/shrubs/grass, ag crop, animal dung	0.647	0.478
Food is cooked in a separate building, outdoors, other	0.194	0.395

Radio	0.074	0.262
TV	0.604	0.489
Fridge	0.254	0.436
Bicycle	0.527	0.499
Motorcycle	0.389	0.488
Car	0.050	0.219
Telephone	0.023	0.151
Cell	0.929	0.257
Age of household head	43.902	15.144
Household head is male	0.881	0.323
Household size	6.430	2.883
House has raw floor	0.433	0.495
House has raw wall	0.217	0.412
House has raw roof	0.102	0.302
Rural	0.714	0.452
Electricity	0.847	0.360
Toilet facility: flush toilet	0.458	0.498
Toilet facility: pit toilet/latrine	0.071	0.256
Toilet facility: no facility/bush/field	0.462	0.499
Toilet facility: other	0.009	0.096
Source of drinking water: piped water	0.418	0.493
Source of drinking water: ground water	0.474	0.499
Source of drinking water: well water	0.075	0.263
Source of drinking water: surface water	0.015	0.123
Source of drinking water: rainwater, tanker truck, other	0.018	0.132
Years lived in place of residence	11.300	10.888
Region-specific		
Natural log of sum of annual night-lights in district	9.984	1.178
Natural log of rainfall in mms.	3.172	2.060
Natural log of temperature in centigrade	3.266	0.228
Southern states	0.188	0.391

Notes: Table reports weighted summary statistics.

Table A2. Descriptive statistics for women, aged 18—49 years

	Mean (1)	Std. Deviation (2)
Outcomes		
Anemic	0.535	0.499
Altitude adjusted hemoglobin level (g/dl)	11.628	1.630
Mildly anemic	0.399	0.490
Moderately or severely anemic	0.137	0.343
Woman-specific		
Age in years	34.241	8.121
Height in centimeters	151.892	5.823
Age at first birth in years	20.291	3.781
Age at first marriage in years	18.067	3.861
Total number of children ever born	2.683	1.495
Number of children below 5 years	0.735	0.956
Not educated	0.362	0.481
Has some or all primary school	0.150	0.357
Has some secondary school	0.338	0.473
Completed secondary school or higher	0.151	0.358
Household-specific		
Hindu	0.815	0.388
Muslim	0.129	0.335
Christian	0.023	0.151
Scheduled caste or tribe	0.312	0.463
Other backward caste	0.458	0.498
Fuel for cooking: electricity or other	0.006	0.079
Fuel for cooking: lpg, natural gas, biogas	0.415	0.493
Fuel for cooking: kerosene, coal, lignite, charcoal, wood straw/shrubs/grass, ag crop, animal dung	0.578	0.494
Food is cooked in a separate building, outdoors, other	0.191	0.393
Radio	0.081	0.273
TV	0.682	0.466
Fridge	0.302	0.459
Bicycle	0.571	0.495
Motorcycle	0.414	0.492
Car	0.059	0.236
Telephone	0.032	0.177
Age of household head	46.140	12.852
Household head is male	0.872	0.334
Household size	5.617	2.634
House has raw floor	0.357	0.479
House has raw wall	0.190	0.392
House has raw roof	0.083	0.276

Rural	0.672	0.470
Electricity	0.890	0.313
Toilet facility: flush toilet	0.522	0.500
Toilet facility: pit toilet/latrine	0.074	0.263
Toilet facility: no facility/bush/field	0.394	0.489
Toilet facility: other	0.009	0.096
Source of drinking water: piped water	0.479	0.500
Source of drinking water: ground water	0.413	0.492
Source of drinking water: well water	0.077	0.267
Source of drinking water: surface water	0.014	0.118
Source of drinking water: rainwater, tanker truck, other	0.017	0.128
Years lived in place of residence	15.304	11.923
Region-specific		
Natural log of sum of annual nightlights in district	10.202	1.070
Natural log of rainfall in mms.	2.910	1.715
Natural log of temperature in centigrade	3.367	0.166

Notes: Table reports weighted summary statistics.

Table A3. Coal Units and Child Anemia: Children Aged 0—5 in Households Resident in the District for More than 8 Years

	HBA	Anemic	Mildly Anemic	Moderately or Severely Anemic	Anemic	Anemic
	(1)	(2)	(3)	(4)	(5)	(6)
Number coal units in	-0.079***	0.015	-0.001	0.016**	0.019*	0.020*
District	(0.030)	(0.011)	(0.006)	(0.008)	(0.011)	(0.011)
Number hydro units in	0.041*	-0.021*			-0.018	-0.027**
District	(0.022)	(0.012)			(0.013)	(0.013)
Number nuclear units in	-0.181**	0.010			0.356***	0.018
District	(0.075)	(0.025)			(0.062)	(0.032)
Specification	Baseline	Baseline	Baseline	Baseline		
Rainfall and temperature	No	No	No	No	No	Yes
Iron supplementation	No	No	No	No	Yes	No
Sample Size	15, 932	15, 932	15, 932	15, 932	12, 014	11, 136

Notes: Weighted OLS regression results presented. Child categorized as anemic if altitude adjusted hemoglobin count (HBA) is below 11.0 g/dl. Sample restricted to children aged 0—5 at the time of the survey whose households have been resident in the area for eight or more years. Each cell presents the results from a separate regression. Models include a constant term which is not reported. Sample size is the same across all regressions reported in each cell in a particular column. Controls include a set of child (gender, birth order, whether multiple birth, whether the child was nursed, recent illnesses (diarrhea, cough), place of delivery, whether C-section birth, and whether a bed net was used), mother (mother's height, mother's hemoglobin level, whether mother works, mother's age at first birth, age at marriage, mother's educational level, total number of children born, and number of children less than 5 years in the household) and household (religion and caste identifiers, SC/ST status, type of cooking fuel used, whether the kitchen is located in a separate room of the house, ownership of assets such as radio, television, refrigerator, bicycle, motorcycle, car, telephone, and cell phone, controls for age of the head, gender of the head, household size, type of floor material of the house, wall material of the house, roof material of the house, rural/urban status, presence of electricity, type of toilet facility and primary source of drinking water) characteristics and a set of district specific time-varying controls including natural log of night-lights in year of birth y and district of birth d. All regressions control for month and year of birth and their interactions. Standard errors clustered at the district level in parenthesis. Significance: ***p < 0.01; **p < 0.05; *p < 0.10.