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ABSTRACT

Impact of Pollution from Coal on the Anemic Status of Children and Women: Evidence from India*

Economic growth in emerging market economies has come hand-in-hand with growing demand for energy, with many of them meeting this higher demand by increased use of coal to fuel electricity generation. This paper examines the impact of pollution generated by coal fueled power units on the anemic status of children and women in India. We show that among very young children (aged 0–5 years), the number of coal units in the district in the month and year of birth significantly increases the likelihood of being anemic net of a comprehensive set of child, mother, household and district level controls. Exposure in utero matters as well for child anemia, while the number of coal plants in the district also induce greater anemia among adult women. Impacts on anemic status are driven by the growth of $PM_{2.5}$ pollution attributable to emissions from coal-powered units. We undertake a series of falsification and specification checks to underline the robustness of our results. Our research adds anemia to the list of significant health costs of relying on coal-fired power generation in meeting the increasing demand for energy that emerging market economies like India face.

JEL Classification: I15, Q32, Q53, O12

Keywords: anemia, coal units, $PM_{2.5}$, air pollution, children, women, India

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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, the more 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. Additionally, as the country has progressed economically, demand for energy has grown and India, like many other developing countries, has addressed the need for more 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 and environmental consequences of relying on this mode of energy generation.

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. An ID-anemic individual does not have enough red blood cells or hemoglobin, a protein that allows red blood cells to carry oxygen to other cells in the body. Consequences of ID anemia include weakness, reduced physical growth, and a compromised immune system which decreases the ability to fight infections and increases morbidity. Further, anemia impairs physical and cognitive

[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).

performance and delays psychomotor development. 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 in developing countries (Horton and Ross (2003)). Through its impact on health and educational outcomes, anemia could also be central to the intergenerational transmission of poverty.

Indeed, 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 41.7 percent and 32.8 percent respectively, while the comparable 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.[2] 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 collected in 2015—2016 merged with information on the location and year of commission of all power units in India (by fuel source), we find that for children aged 0—5 at the time of the survey the number of coal units in the district at the time of birth (month and year of birth) is causally associated with a significant increase in the likelihood of being anemic.[3] These results are somewhat stronger for girls, those born to less educated mothers, and those residing in rural areas. Additionally,

[2] 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.

[3] 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.

cumulative exposure to coal units is also independently associated with large 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 other factors that could potentially affect the relationship (including rainfall, temperature and nightlights) and demonstrate that the results may be attributed to coal alone. Analyzing periods that precede birth, we find that exposure *in utero* also matters. Children who suffered environmental insults due to 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 anemic.

Turning to channels, 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, especially as it can be lodged in the lungs and cause long-term health problems like asthma and chronic lung disease.[4] 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. Taken together, our findings highlight 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 including children. 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 power units has strong effects on health. In the context of developing countries, some of this 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) and Vyas (2019).[5] The medical

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[4] 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)).

[5] 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) and Ghude, et al. (2016) examine the contribution of outdoor air pollution sources to premature mortality.

literature notes that ambient air pollution increases the likelihood of anemia among children and the elderly (Nikolic, et al. (2008), Elbarbary, et al. (2019)). 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 consider the impact of pollution generated from coal on the anemic status of children and women in a less developed 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 $PM_{2.5}$ 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 these variables in detail below.

Measures of anemia and control variables from NFHS-4

We begin by discussing our main outcome variable: anemia. We use altitude adjusted hemoglobin concentration (HBA) to define our indicator for anemia.[6] 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.[7] 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 on average. For adult women, the rate is 52

[6] 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 (Center for Disease Control (CDC, 1989), updated in 1998).

[7] 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. In our analysis, therefore, we use different thresholds to categorize women as anemic depending on whether they are pregnant or not. Our key results remain unaffected both quantitatively and in terms of statistical significance when we drop the pregnant women from the estimation sample. These results are available on request.

percent. We also distinguish between mild anemia (HBA of 10.0—10.9 g/dl for children; 10.0—11.9 g/dl for non-pregnant women; 10.0—10.9 g/dl for 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 do with the severity of anemia weakening with age. This justifies our focus on child anemia in the empirical analysis though we also provide evidence on the anemic status of adult women.

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, we hypothesize that it also reflects locational factors such as 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)). 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 commissioning of all units generating power (from 1922—2016), the main source of fuel for these units (coal, non-coal (diesel and oil), hydro and nuclear), the capacity of each unit, and the district of location of each unit. Figure 3 shows that while total capacity from hydro and non-coal 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.[8] 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 non-coal, hydro and nuclear power units. Another spatial feature revealed by a comparison of Panels A and B is that in 2016, the Indo-Gangetic Plain recorded the bulk of the coal unit spread during 2000—2016 (also see Taneja, et al. (2014)). The bulk of non-coal units are located in the affluent western states.

Coal-fired power units burn coal to heat water that produces steam, which in turn drives the turbines that produce electricity. These units therefor require water and hence are typically situated near sources of water, coal or both. 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.[9] 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 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).

[8] 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.

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

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 is male. The vast majority (79 percent) of the 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. Almost 74 percent of the women in these data are uneducated and only 24 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 number of coal units in the district in the month and year of birth of the child ranges between 2 and 3. While the number of hydro units are comparable to the number of coal units, non-coal units are relatively fewer and the number of nuclear units is significantly smaller still. The estimates for mean $PM_{2.5}$, the most widely used measure of air quality, ranges from 30—37 micrograms per cubic meter of air, which is almost three times the recommended level.[10]

The statistics for power plant unit and pollution variables for the women's sample in the bottom panel of Table 2 are different to those in the top panel for the children's sample. Besides the difference in the samples themselves, the variables for women also differ in that they relate to the values at the time of the survey rather than at the time of birth as in case of children. Note however that while the magnitudes differ, the patterns are similar. For instance, similar to the children's sample, the largest mean numbers for power plant units are those for coal units, followed by hydro, non-coal and nuclear units, in that order. The summary statistics on pollutant measures in the women sample are comparable to those in the child samples.

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

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 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 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 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 (aged 18—49 years), we consider the number of coal units in the district at the time of the survey.

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:

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

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_{ch} includes a set of child, mother, household and district characteristics. The child characteristics that we focus on 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 that we condition on 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, measures of low caste 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, access to electricity, type of toilet facility, and the household's primary source of drinking water. Z_{myd} 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.[11] In additional specifications, we control for temperature and rainfall in month of birth m, in year of birth y and district of birth d.[12] 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.[13] 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.

[11] Nighttime lights (or night-lights) is increasingly used as a measure of local economic development in the absence of data on income at lower administrative levels. For example, 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.

[12] Zivin and Neidell (2013) argues that weather (rainfall and temperature) can significantly affect 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.

[13] 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.

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

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

Here H_{ihmyd} is either HBA levels or anemic status of woman *i* in household *h* in month *m* in year *y* in 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_{ih} 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_{myd}, M_m, Y_y, D_d are defined analogously to equation (1) except that they refer to the month and year of the survey and the woman's district of residence. Finally, μ_{chmyd} 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 the presence of coal units in the district increases 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. In the first step, 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 $PM_{2.5}$.

In the second step, 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:

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

Equation (3) is an extended version of equation (1) which now includes $\log(PM_{2.5})_{myd}$ in month of birth *m*, year of birth y and district of birth *d*. If anemia is due to pollution measured by $\log(PM_{2.5})_{myd}$, then with the inclusion of this variable, the impact of coal units at the time of birth should fall in magnitude or become insignificant.

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. 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.[14] Third, we implicitly assume that there are no spillovers across districts. The second and third assumptions impart a conservative bias to our results and provide a lower bound to the estimated impacts of coal units at the time of birth on anemia.

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—4 of Table 3 present results of falsification tests: an increase in the number of non-coal units, 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 used gauge of air pollution.[15]

4.2. Coal units and anemia in children

Table 4 presents our key results. The effects of coal units at the time of birth on young children's anemic status are presented in the first row of Table 4. 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

[14] Although the DHS data do provide geo-codes for clusters, it is hard to determine the exact geo-coordinates of coal and other units as these are not directly noted in the Central Electricity Authority data. Consequently, we are unable to use GIS methods to estimate proximity of clusters to units.

[15] In Section 4.5 we show that NO_2 and SO_2 do not have a significant effect on anemic status once we control for $PM_{2.5}$.

HBA of child *c* (aged 0—5 at the time of the survey) in household *h* born in month *m* in year *y* in district *d*. 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. In column 2 the dependent variable is the anemic status of child *c* in household *h* born in month *m* in year *y* in district *d*. 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 1.69 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 0.2 percent 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 5 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 1 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 non-coal power units, the number of hydro units, and the number of nuclear units in the district in the month and year of birth. The results clearly show that the non-coal sources of power generation have little discernible impact on the likelihood of a child aged 0—5 being anemic. There is some indication that non-coal units have detrimental impacts on the linear measure of HBA but in all the remaining instances, the estimated coefficients are statistically zero. The impact on anemia thus seems to be primarily driven by impacts emanating from coal.

Are the impacts on anemic status of young children independent of 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 along this health dimension. Re-estimating on the sample of children who are stunted reveals a coefficient estimate for coal on anemic status of 0.018, 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.[16] 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 merely reflect nutritional challenges that this population faces.

4.3. Coal units and anemia in adult women

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 (3). The number of coal units (at the time of the survey) has no 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 has a statistically significant 0.2 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 this increase is driven by the enhanced likelihood of women being mildly anemic (column 3). Note that overall, compared with the results in Table 4 for children, the magnitude of anemia effects for women is relatively small. However, similar to the case for children, we find that the anemia effect is confined to the presence of coal-powered units and not units that use other sources of fuel.

[16] Given the smaller sample size, we lose precision in the impact of coal when column (1) is re-estimated on the sample of children who are stunted. This is the not the case when we consider the corresponding impact of coal in column (2). These results are available on request.

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.[17]

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.[18] 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) and the rest of India (non-South states) given the better health and socio-economic status of children and women in the South.[19] 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 since 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 C in Figure 5. The Southern states also have generally better health and socio-economic measures as is well known.

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

[17] These results remain essentially unaltered if we use interaction terms instead of splitting the sample along the dimensions of interest.
[18] This difference is however small and not statistically significant.
[19] We also consider variation 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 impact is small and insignificant.

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 lack of variation in the education indicator for mothers (noted in Table 2 above), we are unable to use this measure to benchmark this level of differentiation. We thus consider work status as a proxy for mother's education and bargaining power, and the results which 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 greater bargaining power and larger control over resources within the home bequeath considerable benefits to the next generation (Schultz 2001).

Finally, the last two columns of Table 6 condition on mother's height, a widely accepted 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 is systematically different to other districts (of lower socio-economic status, or more lacking in access to health infrastructure and facilities), then our results on children's anemic status could be on account of this fact rather than emissions from coal units. The inclusion of district fixed effects should largely control for this. To further allay this concern, 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 (decrease HBA levels) in this subpopulation.

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 number of coal unit years after birth (columns 2 and 3), or (ii) the number of new coal units since birth (columns 4 and 5).[20] Results in columns 3 and 5 also control for the number of coal units in the district at the time of birth as in our baseline specification (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 baseline results. However, conditional on the number of coal units present at the time of birth, cumulative exposure is no longer significant. This suggests that the adverse anemia effect of coal units is primarily realized by the number of coal units already present at the time of birth, and subsequent additional exposure does not induce further increases in the likelihood of anemia.

In-utero impacts

The results thus far have investigated anemia effects of exposure to coal units at or since birth, 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 the child's district 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 that some of the anemia effects of coal plant pollution start *in-utero*. 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.

[20] 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 of years of operation for all these units until the time of the survey. Alternatively, the number of new coal units only conditions on the number of new units established in the district since 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. Note that 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.

5. Conclusion

A distinctive feature of this study is that it assembles a unique data set drawing upon diverse sources to examine a policy relevant question, viz. the potential effects of coal power plant 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 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 iron deficiency anemia.

Our principal finding is that 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 younger children up to age 5. The number of coal units present in the district in the month and year of birth is sufficient to generate this negative effect, controlling for a comprehensive set of child, mother, household and district characteristics. This also turns out to be a sufficient measure for identifying the effects of total exposure to coal plant pollution after birth for children. We also find the some of these anemia-inducing effects may be traced to exposure *in utero*.

Our evidence points to similar effects on anemia among women as measured by the number of coal plants in the district at the time of the survey. We identify that the anemic effects of coal plants 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 plants.

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 added. Factoring in the added costs related to anemia among children and women strengthens the case for a progressive shift to renewable energy. By providing evidence on the harmful health effects of coal fired power stations 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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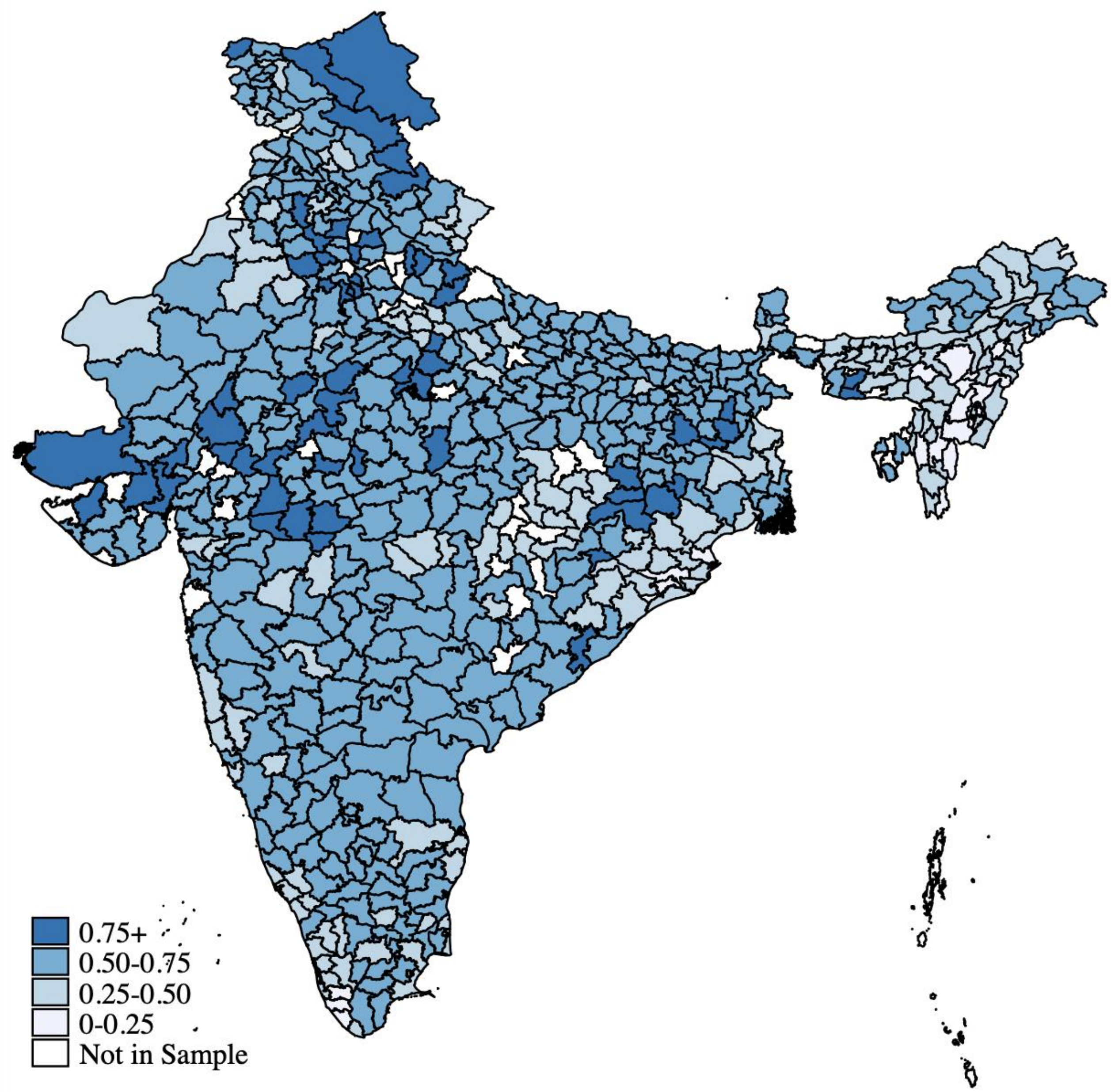
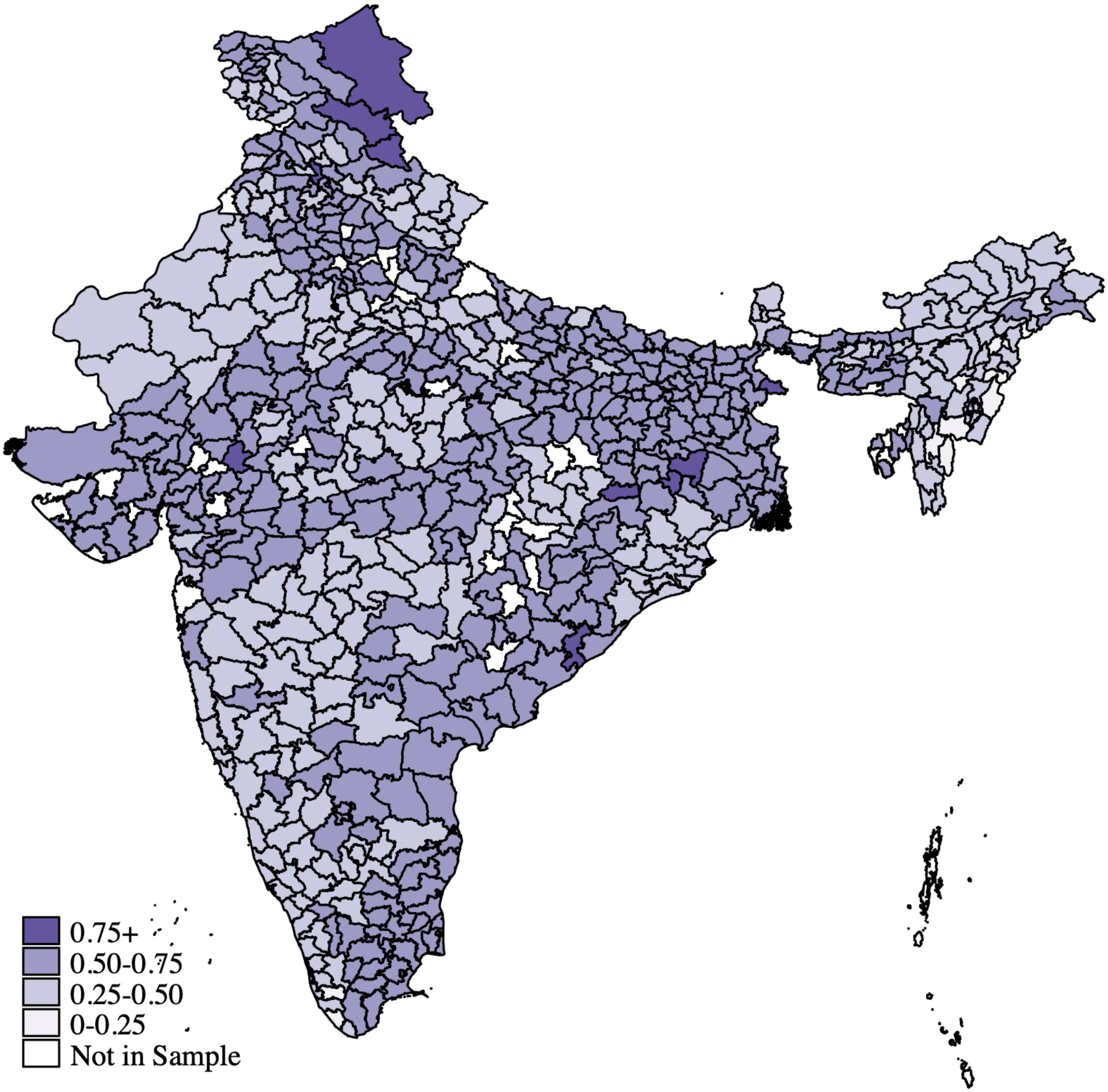
Figure 1: Proportion of Children 0—5 Years Who are Anemic, 2015—16



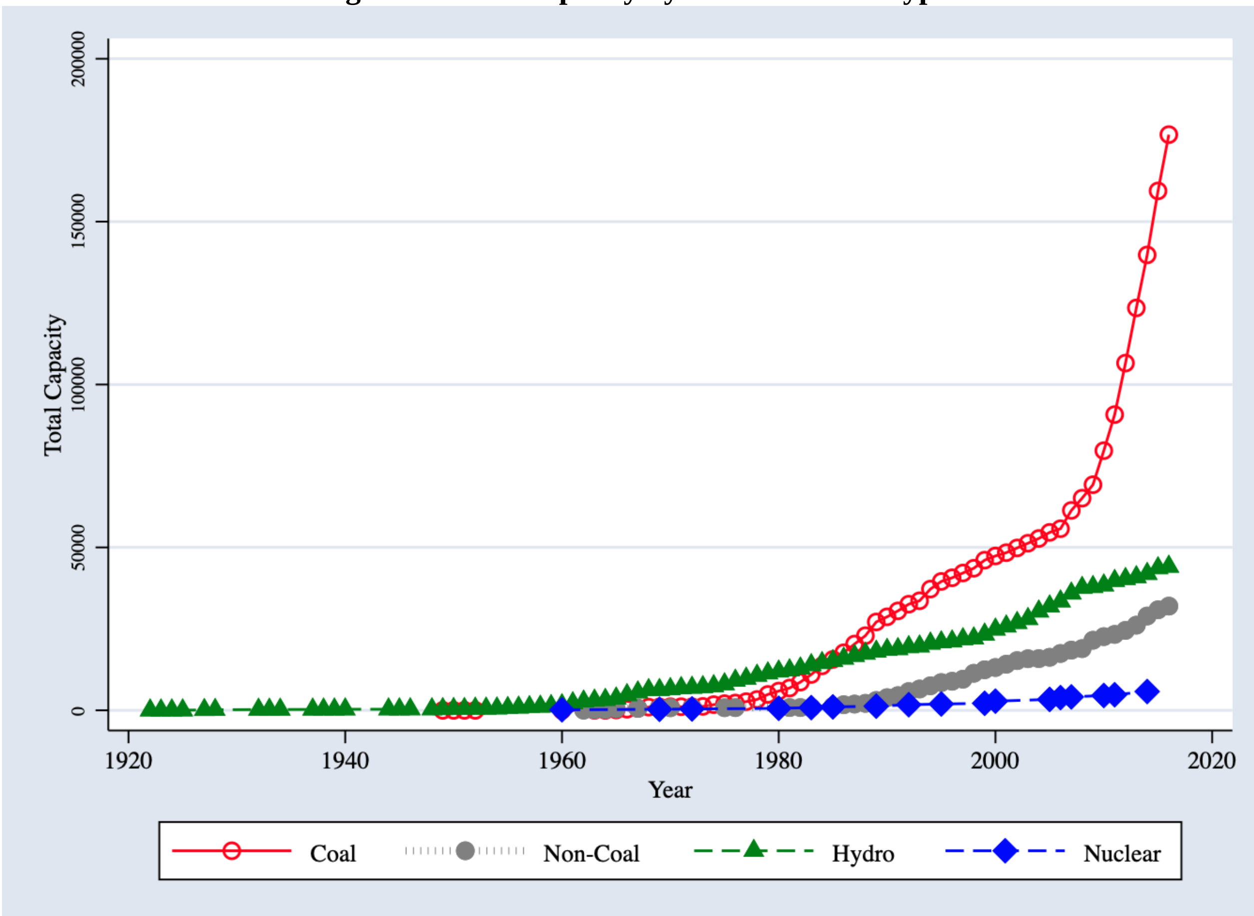
Notes: The figure presents the weighted average of the proportion of children (aged 0—5) in each district categorized as anemic i.e., altitude adjusted hemoglobin concentration (HBA) < 11.0 g/dl. Category 0—0.25 denotes up to 25 percent of the sample children in the district are characterized as anemic,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

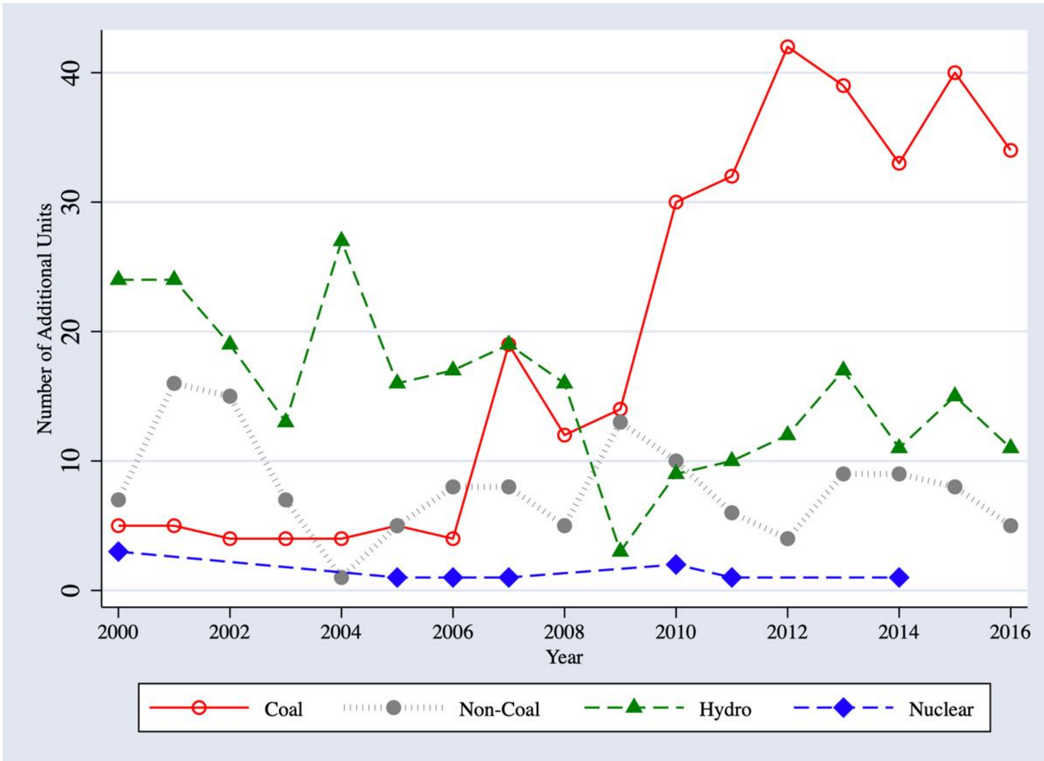
Figure 3. Total Capacity by Year and Fuel Type



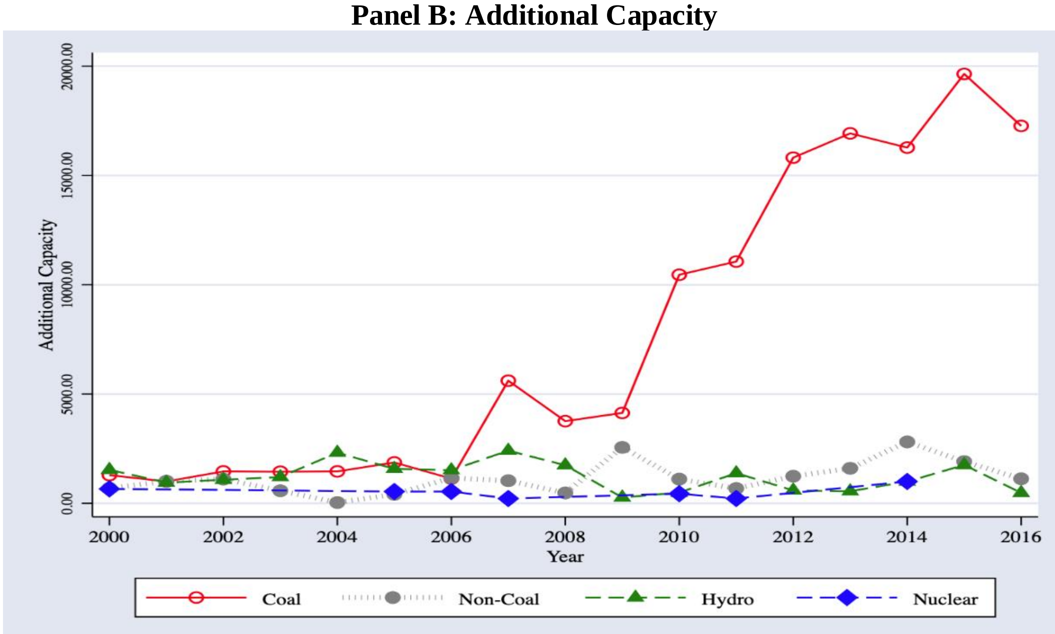
Notes: Total capacity (GW) in each year by fuel type.

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

Panel A: Additional Units



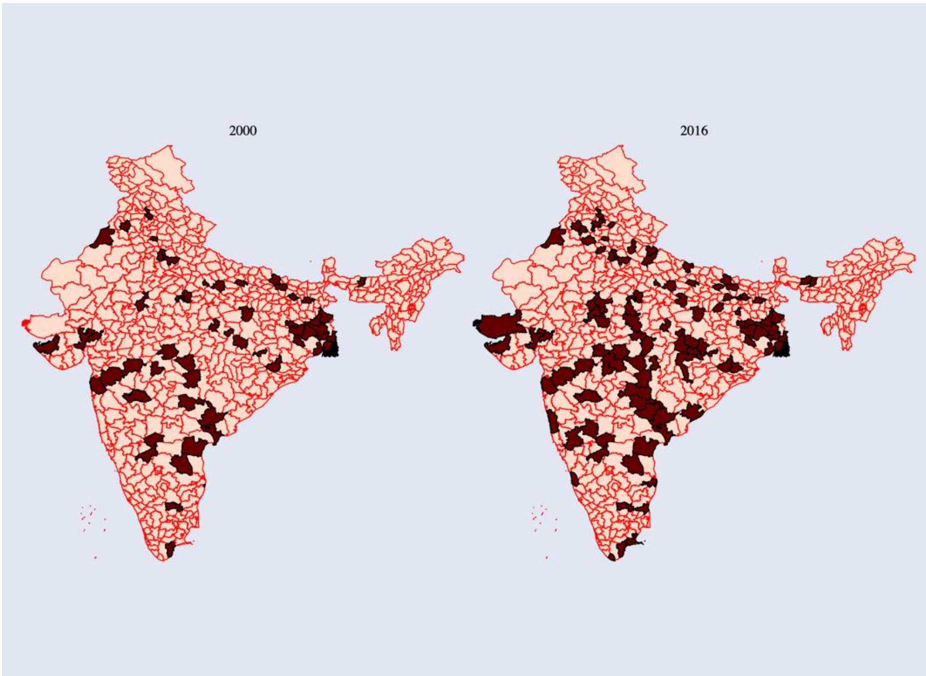
Panel B: Additional Capacity



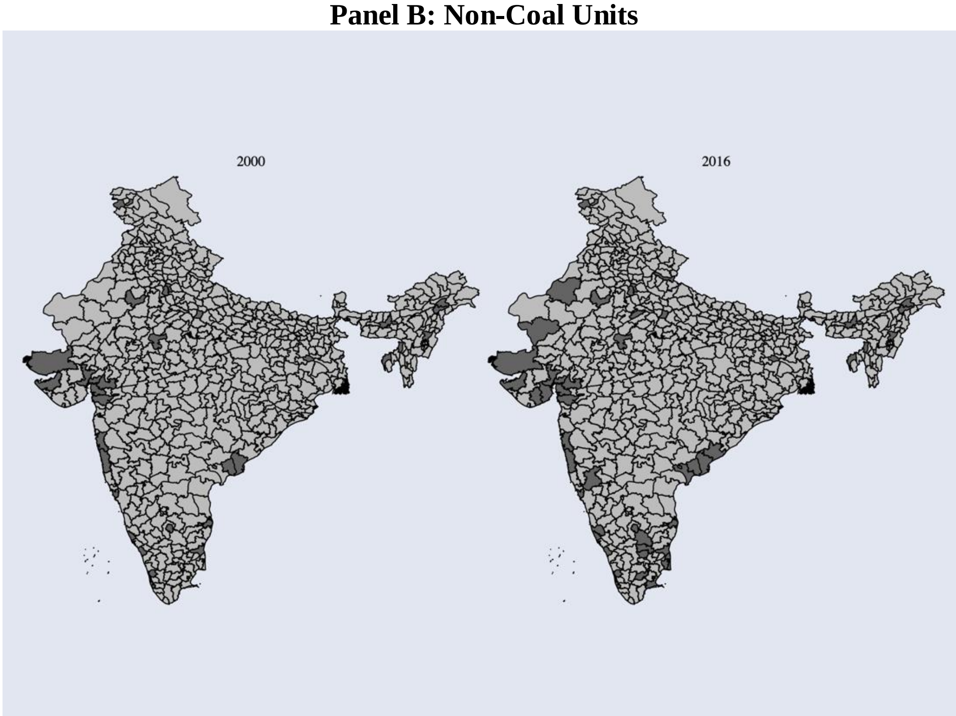
Notes: Sample restricted to units commissioned between 2000 and 2016.

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

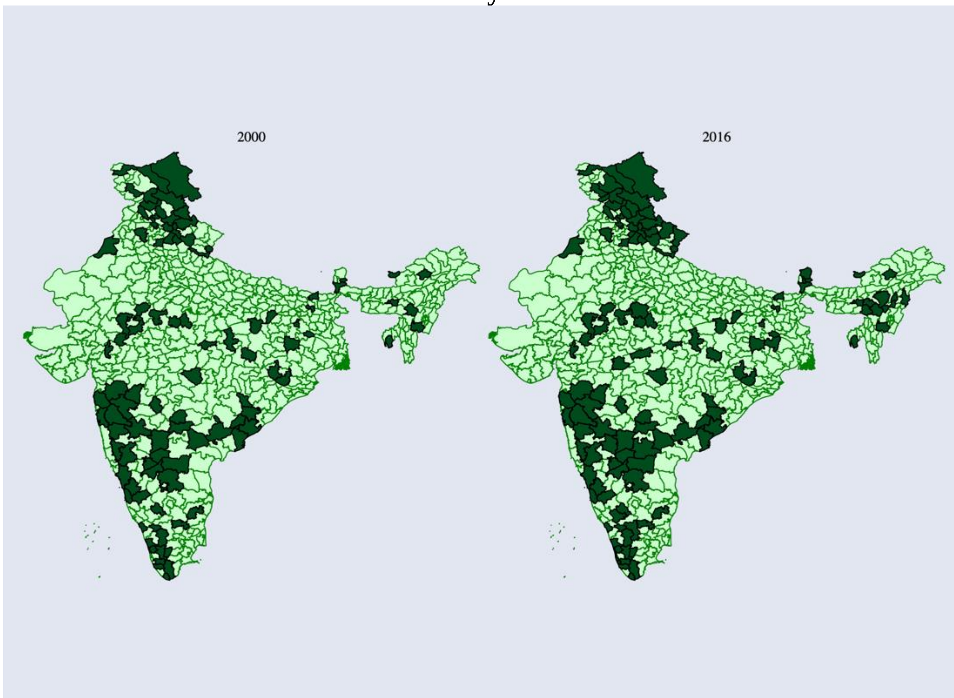
Panel A: Coal Units



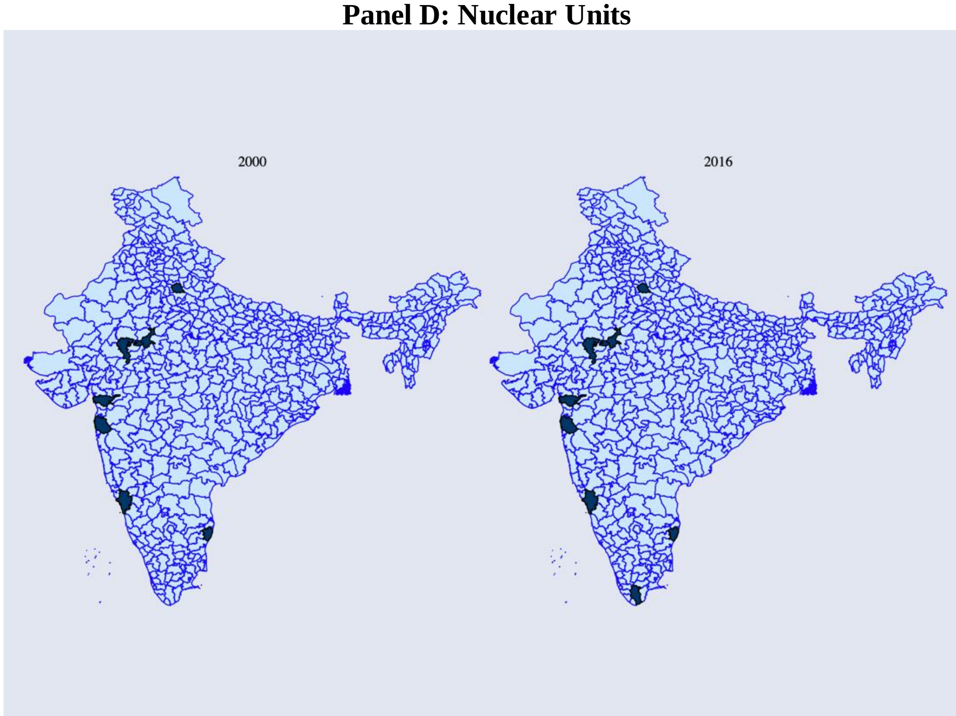
Panel B: Non-Coal Units



Panel C: Hydro Units

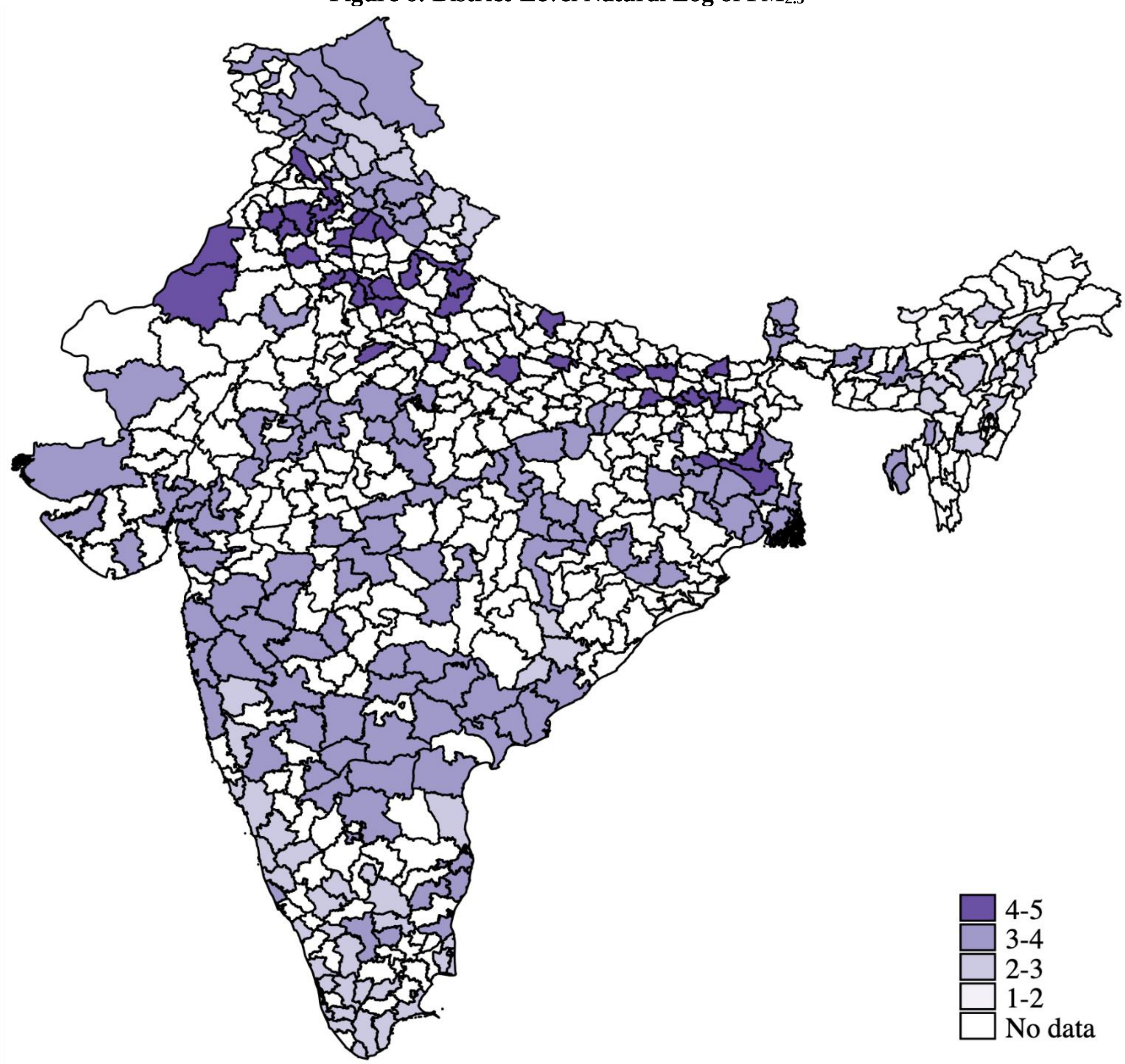


Panel D: Nuclear Units



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

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



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

Table 1. Incidence of Anemia

	Children 0—5	Women 18—49
	(1)	(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	449,816

Notes: Authors' computation using NFHS 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 of non-coal units in district in month and year of birth	1.643	4.127
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 since birth (years)	4.691	7.658
Number of new coal units established in district since 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	0.738	0.439
Has some or all primary school	0.239	0.427
Has some secondary school	0.022	0.146
Power Unit and Pollutant-Specific		
Number of coal units in district	1.608	3.785
Number of non-coal units in district	0.810	3.123
Number of hydro units in district	1.262	3.562
Number of nuclear units in district	0.075	0.488
Total capacity of coal units in district ($x10^{-3}$) in megawatts	0.338	0.993
Total capacity of non-coal units in district ($x10^{-3}$) in megawatts	0.116	0.601
Total capacity of hydro units in district ($x10^{-3}$) in megawatts	0.048	0.203
Total capacity of nuclear units in district ($x10^{-3}$) in megawatts	0.003	0.037
Change in the number of coal units in district since 2000	0.712	2.064
Change in the number of non-coal units in district since 2000	0.347	1.688
Change in the number of hydro units in districts since 2000	0.283	1.534
Change in the number of nuclear units in district since 2000	0.028	0.255
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: Table reports weighted summary statistics.

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

	Natural log($PM_{2.5}$) (1)	Natural log($PM_{2.5}$) (2)	Natural log($PM_{2.5}$) (3)	Natural log($PM_{2.5}$) (4)
Number of Coal Units in District	0.014**			
	(0.006)			
Number of Non-coal Units in District		0.002		
		(0.008)		
Number of Hydro Units in District			-0.005	
			(0.012)	
Number of Nuclear Units in District				-0.001
				(0.006)
Constant	3.559***	3.598***	3.615***	3.601***
	(0.019)	(0.013)	(0.033)	(0.001)
Sample Size	68,905	68,905	68,905	68,905

Notes: 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 Non-Coal Units in District	-0.062**	0.014			0.016	0.014
	(0.024)	(0.009)			(0.022)	(0.008)
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: 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	-0.003	0.001	0.001**	-0.000	0.002***
	(0.003)	(0.001)	(0.001)	(0.000)	(0.001)
Number Non-Coal Units in District	0.000	-0.000	-0.000	0.000	-0.000
	(0.005)	(0.001)	(0.001)	(0.001)	(0.001)
Number Hydro Units in District	0.001	-0.000	-0.001*	0.001	-0.001
	(0.003)	(0.001)	(0.001)	(0.000)	(0.001)
Number Nuclear Units in District	-0.000	-0.003	0.002	-0.005	-0.008**
	(0.017)	(0.004)	(0.003)	(0.004)	(0.004)
Includes Temperature and Rainfall	No	No	No	No	Yes
Sample Size	366,689	366,689	366,689	366,689	270,732

Notes: 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 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: 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: 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: 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: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

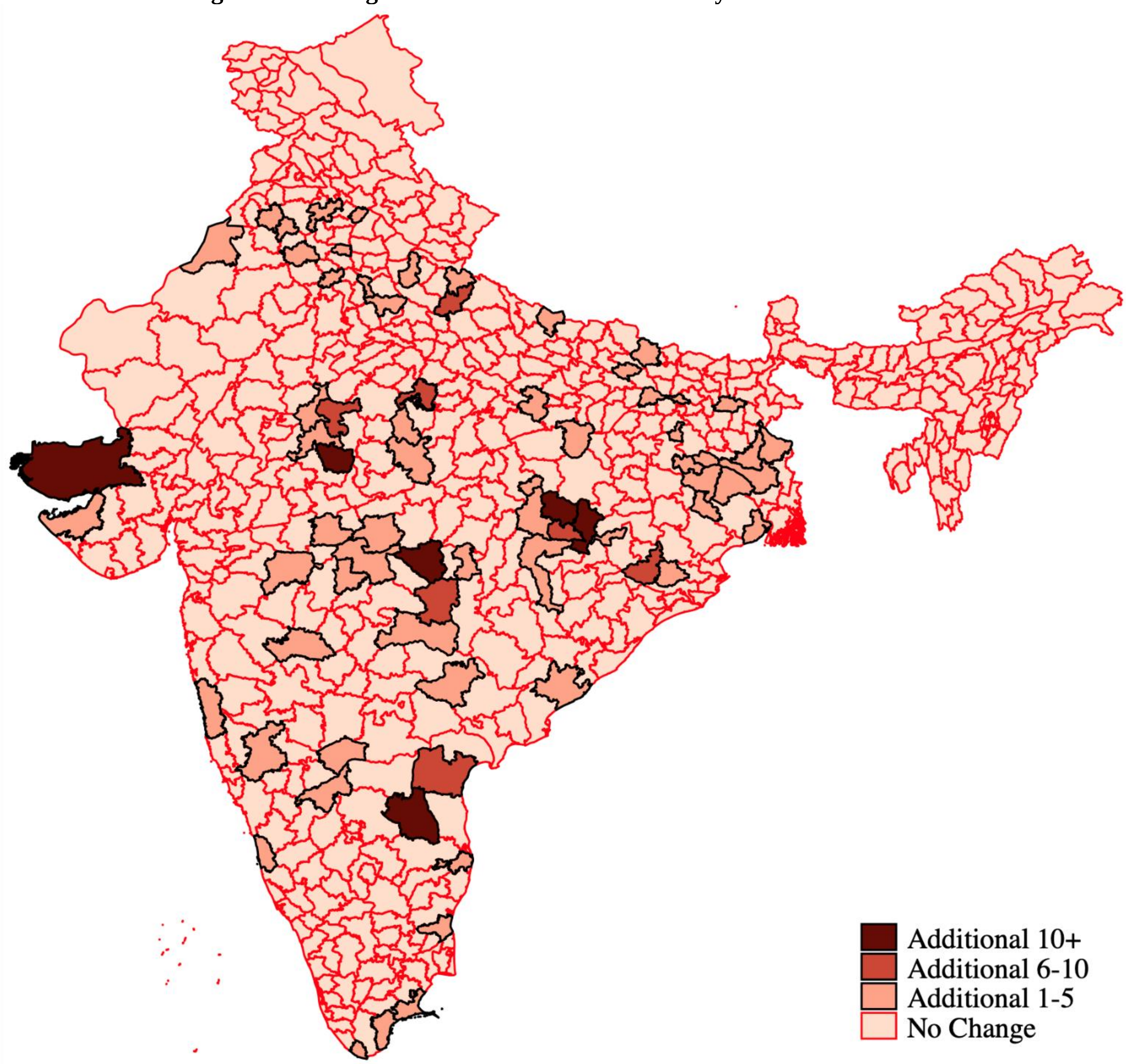
Table 9. Impact of Power Units Conditional on $PM_{2.5}$ Concentration. Children Aged 0—5

	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: 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: 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 ranges from about 3 years to 12 years in the two child samples and about 51 percent are male. Very small proportions are multiple births and those who reported illnesses in the last two weeks in the sample of very young children ranges from 19—23 percent (these questions are not asked for the older children). The proportion for whom births were at home has reduced over time and most deliveries now occur 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 in the younger children sample, 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. For children 0—5 years of age, 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—45 years) and the fact that most of these households are male-headed. The proportion that is rural is about 70 percent across both samples and about equal proportions report access to sanitary facilities and no facilities. Piped water and ground water are the major sources of drinking water in these samples. In addition, as is well known in India, rates of migration are relatively low as the average years lived in current place of residence ranges from 11—17 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	46.14	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
	(3)	(1)	(5)	(6)	(4)	(2)
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 non-coal units in	-0.045	0.008			0.031	0.004
District	(0.036)	(0.012)			(0.020)	(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: 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.